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An empirical assessment of the value of irrigation water: the case study of Murrumbidgee catchment*

Muhammad Ejaz Qureshi, Ram Ranjan
and Sumaira Ejaz Qureshi†

Evaluation of value of irrigation water is essential for supporting policy decision making relating to investments in the irrigation sector, efficient allocation of irrigation water and water pricing and for crafting policies to compare the variable impacts of water reform within and across sectors of the economy. This paper asks the question of how much an established irrigator would pay for water and at what price farmers planning to expand the area they have under irrigation would consider paying for the right to access water. An analytical framework is developed to estimate the net present value of both annual and perennial agricultural activities in the Murrumbidgee catchment. Using these estimates the total value of water used in Murrumbidgee catchment is estimated. An aggregate water supply curve is derived for the catchment from where water may be acquired from irrigators for environmental flows.

Key words: annual and perennial activities, asset fixity, environmental flows, water allocation, water price, water supply curve, willingness to pay.

1. Introduction

In many irrigation systems less and less water is being available for use over time. The reasons for this decline in water availability are many and include the impact of adverse climate change, increased interception of rainfall by people operating outside the formal allocation system and flaws in the allocation system (CSIRO 2008a). Increased demand from non-agricultural uses is another reason for the decline in the amount of water available to irrigators. In such an environment, irrigators of some crops are forced to consider whether or not they should sell their water entitlements and cease to irrigate part or all of their land. At the same time, as the demand for some irrigation

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* In this paper, unless specified otherwise, all dollars refer to Australian dollars, 1 Australian dollar = 0.80 US dollars as on 30th June 2009.

† M.E. Qureshi (email: ejaz.qureshi@csiro.au) is at CSIRO Sustainable Ecosystems, Gungahlin, Australian Capital Territory, Australia and the Fenner School of Environment and Society, Australian National University, Canberra, Australian Capital Territory, Australia. Ram Ranjan is at CSIRO Sustainable Ecosystems Wembley, Western Australia, Australia. Sumaira Ejaz Qureshi is at the Mathematical Sciences Institute, Australian National University, Canberra, Australian Capital Territory, Australia.

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products continues to increase, other irrigators seek opportunities to continue to irrigate.

Decision makers often lack information on irrigation water use as well as the per unit value of water to agricultural revenue in different agricultural activities and their relative economic contributions to the local and regional economies. As a result, they cannot adequately assess potential trade-offs amongst different agricultural users under different management schemes. The question that this paper seeks to explore is how much an established irrigator would pay for water and at what price farmers planning to expand the area they have under irrigation would consider paying for the right to access water. This information will be useful for irrigators, water resource managers and policy makers. Equipped with this information, an irrigator will be able to predict in advance which crops to grow, how much land, labour, and capital resources to allocate to each crop, and what technologies to employ (Young 2005). An improved understanding of different water uses and associated trade-offs will be crucial in designing and implementing effective water management strategies. The value of water in its alternative uses will be a key ingredient in the decision making process as it plays a critical role in influencing the efficiency with which water supplies are managed and how they are allocated among competing agricultural uses (Renwick 2001). At a broader policy level, understanding the economic value of irrigation water across agricultural activities and regions will help in maximising water productivity through efficient allocation for any future agricultural development and for examining effects of any future water policy changes.

Regardless of the reason for reforming water policies, knowledge of the value of water is essential for efficient allocation of water and when crafting policies to compare the variable impacts of water reform within and across sectors of the economy. However, a major difficulty policy makers and water resources managers face is over accurately determining net economic value of irrigation water due to a number of economic, political, and physical complexities. Economic gains (or net values of irrigation water) of some agricultural activities are much higher than others but these activities may require major initial investment and take years before economic gains are achieved. Also, the issue of large sunk costs in on-farm infrastructure impacts on the net economic value of irrigation water. To the authors' knowledge, such investment costs have not been incorporated in the literature pertaining to value of water in agriculture.

In this paper, we develop an analytical framework to estimate the long-run private value of irrigation water in key agricultural uses. We identify the water entitlement prices at which economically rational irrigators would contemplate abandoning an existing investment and the price levels beyond which further reinvestment in an industry is unlikely. The approach takes account of sunk costs in the form of asset fixity. In essence, our aim is to understand the nature of a water demand curve in a region that is experiencing rapid changes relating to the amount of water likely to be available to it in future. The aim is also to understand the nature of water supply curve in a region where water is acquired from irrigators for environmental flows.

A review of methods used in assessing value of irrigation water along with a justification for a new analytical framework is presented in the next section. This is followed by an overview of the Murray Basin and water quantity and quality issues. A discussion of the analytical framework including the mathematical description of the model is presented following this. Results and policy implications are presented in the subsequent sections while concluding remarks are provided in the last section.

2. Existing methods for assessing value of irrigation water

Researchers have employed many methods for assessing the value of irrigation water. These methods have been classified into two major groups, namely ‘inductive techniques’ and ‘deductive techniques’ (Young 2005). The inductive techniques (observation-based methods) for valuing irrigation water differ mainly according to the type and source of data and the form of statistical model, if any, used to estimate the productivity relationship. Most commonly used inductive techniques include: (a) direct observations on water entitlement markets, (b) land value method by imputing value of water via land and implementing valuation from land market data, (c) hedonic property (or revealed preference) value method; and (d) econometric valuation of irrigation water from primary and secondary data including stated preference techniques. Deductive techniques include residual method and its variations and are commonly used to derive shadow prices of irrigation water. A residual method for valuing irrigation water is a special case of the well-known process of performing farm budget or cost and return analysis. This method subtracts the incremental value added by all production inputs except the irrigation water from the value of total output. The method identifies the incremental contribution of each input to the value of the total output and is the most widely used methodology for valuing irrigation water (Young 2005). All costs of production except water are subtracted from the value of production and the remaining (or residual) value provides an estimate of the value of water in irrigation. The resulting value sometimes termed ‘quasi-rent’ (Brill *et al.* 1997) can be assumed to be the net value of irrigation water (Johansson 2005).

There exist several examples of this approach in the literature. Bryant *et al.* (2001) have estimated the value of water by closely noting the marginal cost of using additional unit of irrigation water along with accounting for all relevant costs of major irrigation systems used in Arkansas. They estimated the marginal cost of irrigation water varying from US\$0.8/acre inch to US\$3/acre inch. Renwick (2001) used the residual method to infer the value of irrigation water in south-eastern Sri Lanka and found values averaging Rs.0.93/m^3. Several studies have used mathematical programming techniques to evaluate irrigation water, demand for irrigation water and/or effects of alternative irrigation water charging policies (Gisser *et al.* 1979; Howitt *et al.* 1980;

Michelsen and Young 1993; Booker and Young 1994; Vaux and Howitt 1984). A study in the North West Province of South Africa (Speelman *et al.* 2008) using the residual imputation method calculated values of irrigation water for small-scale irrigation schemes and found an average water value of US\$0.188/m^3 for vegetable crops. A study in India (Kumar *et al.* 2008) assessed the value of water through estimation of the incremental value of output for a composite farming system for a unit of water. The authors analysed the response of economic surplus generated from water use in agriculture to changes in irrigation water use in two regions (a water-scarce region and a water-rich region).

Despite the extensive studies and modelling efforts mentioned above, none of these studies has estimated the value of irrigation water when there are both annual and perennial crops with varying agronomic and economic life cycles. Further, these models do not address the issue of large sunk costs in on-farm infrastructure which is one of the key factors in determining net economic value of irrigation water. Yet, these distinctions are crucial towards informing choices between annual and perennial crops when farmers are faced with long term water scarcity. Incorporating large sunk costs is also crucial for estimating the value of water correctly as failure to incorporate these costs may lead to an exaggeration of the value of water, and therefore, would distort the perceived impacts of proposed policy instruments.

The analytical framework used in this paper includes several important features critical for assessing the value of irrigation water in a number of agricultural activities. The framework includes assessment of net value of irrigation water used by agricultural activities which have varying physical and economic life cycles by determining economically optimal life cycles of these activities and by estimating net present values of irrigation water over an infinite planning horizon. Further, the framework is also used to understand the nature of irrigation water demand curve in a region that is experiencing increasing water scarcity as well as a water supply curve for environmental flows.

3. Water allocation issues in Murrumbidgee

Murrumbidgee is one of the major catchments in the Murray-Darling Basin. The Murray-Darling Basin (MDB) is Australia's most important agricultural region, accounting for around 41 per cent of the nation's gross value of agricultural production. The Basin supports almost one-third of the nation's cattle herd, half of the sheep flock, half of the cropland and almost three-quarters of the nation's irrigated land (ABS 1997).

Changes to land use and river management in the Basin have led to pressure on the Basin's resources, and concern over water quality and ecosystem health (MDBC 2001). Over the last 20 years, there has been significant expansion in the areas of agricultural activities, including crops and pasture. The expansion in agriculture has increased the use of irrigation (CSIRO 2008a).

As a result, there has been a greater need for water accompanied, at the same time, by a decline in rainfall and water allocations.

There is increasing evidence that the water resources of a number of catchments within the Murray-Darling Basin (including Murrumbidgee catchment) are over-allocated. This situation has arisen as a result of past decisions by state and territory governments to issue more entitlements than what can be delivered by water systems. It has also been caused by a failure in water sharing plans to set the pool of water available for consumption at sustainable levels (DEWHA 2009). Further, there are concerns that the river system is facing multiple threats, including changes to flow regimes. One indicator of changed river management in the Murray River of the MDB is its median annual flow to the sea. Over the last few years, the annual flow to the sea has been close to zero (CSIRO 2008a). Climate change is believed to exacerbate the water over-allocation challenges in the MDB. CSIRO (2008a) estimated that a substantial reduction in surface water availability in the south of the MDB is possible. Diversions in driest years will fall by more than 10 per cent in most NSW regions, around 20 per cent in the Murrumbidgee and Murray regions and from around 35 per cent to over 50 per cent in Victorian regions.

The understanding of the economic value of irrigation water across these activities will help in maximising water productivity through efficient allocation, for any future agricultural development and in examining effects of any future water policy changes in the MDB, including structural adjustments (if desired) within a sector or region. The study endeavours to assess the per unit value of water in agricultural revenue in different agricultural activities and total value of irrigation water in the region. Through this exercise, the study seeks to answer the following important policy questions: How much an established irrigator would pay for water and at what price a person planning to expand the area they have under irrigation would consider paying for the right to access water? Which crops an irrigator needs to grow and how much capital resources to allocate to each crop given different water uses and the associated trade-offs? At what water entitlement prices, economically rational irrigators would contemplate abandoning an existing investment and at what price levels further reinvestment in an industry is unlikely? What is the nature of a water demand curve in a region that is experiencing rapid changes relating to the amount of water likely to be available to it in future? What is the nature of water supply curve in a region where water is acquired from irrigators for environmental flows?

4. Analytical framework used for estimating value of irrigation water

In this paper, a modelling framework incorporating costs and revenues that would accrue to farmers over an infinite planning horizon has been developed. The framework includes both annual and perennial agricultural activities with varying agronomic and economic life cycles. Some of these activities are seasonal and occupy land for only a few months. Other activities may occupy land for decades and take years before any economic returns may be realized. Generally, perennial crop irrigators rely on high security water (with permanent entitlements) while annual crop irrigators depend on general/low security water or on temporary water markets.[1] Price of permanent water transfer is much higher than temporary water transfer and impacts on the producer surplus. In this analysis, all costs (except water costs) including capital costs incurred on land, fixed costs and operating costs are accounted for and the residual value of water estimated accordingly. Since land purchase results in perpetual rights (i.e. one off payment over infinite planning horizon), its annualised value is calculated using a real discount rate of 5 per cent.[2]

It is assumed that the opportunity costs of non-water inputs are given by their market prices (or their estimated shadow prices). Therefore, the shadow price of water can be calculated as the difference (the residual) between the total value of output (TVP) and the combined costs of all non-water inputs to production. The residual, obtained by subtracting the non-water input costs from total annualised crop revenue, equals the net revenue which consists of two components–water rent and the producer surplus. This is interpreted as the maximum amount the farmer would be willing to pay for water while still recovering his costs of production, and is represented as the net value of irrigation water. A detailed mathematical description of the economic component, including evaluation of annual activities and perennial activities is presented as Appendix.

4.1 Agronomic component

For an economic analysis, agronomic information (such as crop water requirements and crop yield) is also needed. Seven major agricultural activities that occupy most of the southern part of the MDB are considered in the analysis including rice, cereals, grapes, citrus fruits (oranges), deciduous fruits (almonds), vegetables, cereals and dairy. Net irrigation water requirement (ML/ha) for each of these agricultural activities were estimated using values from a recent study (Qureshi *et al.* 2007). These estimates accounted for the contribution towards evapotranspiration by effective rainfall and an allowance for irrigation system efficiency losses. Effective rainfall was subtracted from potential evapotranspiration to calculate the net irrigation requirement of each

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[1] Permanent water trade is a transfer of water access entitlement (or water right) from one legal entity to another, with or without a change in location. Temporary (or seasonal) water trade is an assignment (or trade) of water allocation from one authorised water user to another, or between water accounts held by the same water user, with or without a change in location (Commonwealth of Australia 2008).

[2] Currently, the interest rate in Australia is about 5 per cent, therefore, 5 per cent real (inflation adjusted) discount rate reflecting Australia's recent cost of private capital is used for the analysis.

activity. Irrigation scientists and horticulturalists were contacted to validate information about the net irrigation water requirements and adjustment was made where necessary to reflect basin-wide representation of irrigation water usage (ML/ha) for maximum agricultural productivity (t/ha or L/ha in case of dairy) (Neil Armstrong, pers. comm. DPI Vic 2007; Hickey *et al.* 2006). It is assumed that water usage level in crops is for their maximum production (t/ha). Rice, cereals and vegetables start their maximum production without any delay and their average yields remain the same every year. Dairy, which relies on pasture production, is a perennial activity but is considered as an annual activity with an assumption that productivity (L/ha and cows/ha) remains the same every year, for simplicity. Net irrigation water requirements of annual activities and their maximum yields are presented in Table 1.

The production of citrus, almonds and grapes starts slowly (following an initial investment), reaches to maximum productivity at a certain age and then starts declining without ever reaching zero. The years taken to develop a produce are critical in the economic evaluation. All three horticultural crops (citrus, almonds and grapes) are expected to take 3–4 years to bear fruit. Also, a certain number of years are required to reach maturity and full fruit production. Besides published sources (PIRSA 1999; Qureshi *et al.* 2006, 2007), regional horticulturalists were contacted for information on the agronomic life cycles of these three crops and their water requirements activities (David Pocock, 2007 pers. Com. PIRSA). Using the existing information, yield response functions for these three crops have been established to estimate proportion of full yield over each year of the planning horizon, as

Table 1 Volume of water used and yield for short term or seasonal activities

	Volume (ML/ha)	Yield (t or L/ha)
Rice	9	12 (t/ha)
Cereals	4	4 (t/ha)
Dairy*	9	19 250 (L/ha)†
Vegetables	5	25 (t/ha)

*Milk plus stock revenue of \$100/cow @ 3.5 cows/ha and \$350/ha; †5500 L/cow @ 33c/L and 3.5 cows/ha.

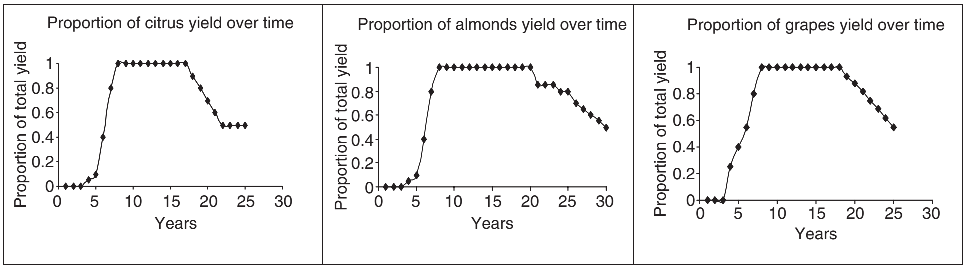

Figure 1 Proportions of citrus, almonds and grapes yields over time.

Table 2 Volume of irrigation water and maximum yield of perennial activities

	Volume (ML/ha)	Yield (t/ha)
Grapes	7.5	20
Citrus	8	30
Almonds	12	3

shown in Figure 1. For the first three years there is no production. Over time, production increases initially then decreases without ever reaching zero. Figure 1 also shows variation in the yields of the three activities. Citrus yield declines earlier than that of grapes and almonds.

Net irrigation water requirements of perennial activities and their maximum yields are shown in Table 2. It is assumed that crop average yields (tonnes) will remain the same despite changes in prices of agricultural activities.

4.2 Economic parameter values and assumptions

Revenue depends not only on crop yield but also on the price of each agricultural activity which may vary over time. To capture the temporal variations in price yield, historical prices of individual commodities were obtained from ABARE, ABS and other publications (ABS 2006; ABARE 2007). These data were analysed to examine whether there were any historical trends. Since these nominal data reflected inflationary factors as well, they were deflated to get real prices. These prices were used to estimate mean prices along with their standard deviations and coefficients of variation, as presented in Table 3. Average land price is about $1000/ha and, with a perpetual right, (or an annualised value of $50/ha using 5 per cent discount rate) is same for both annual and perennial activities. Average water pumping charge is $50/ML which is again the same for each activity. Other economic parameters and their values are presented in Table 3.

Table 3 Economic parameters and their values

	Rice	Cereals	Dairy	Vegetables	Citrus	Almonds	Grapes
Capital costs ($/ha)	5500*	2000	5715†	7000	19 596‡	14 000‡	25 700‡
Variable costs ($/ha/a)	990	234	4400§	5680	9605¶	9004¶	6584¶
Average price ($/ha or $/l)	341	235	0.315**	300	600	6000	711

*Capital costs of $3000/ha and laser levelling of $2500/ha; †$1429 for machinery with a life of 10 years and $4286 for milking shed with a life of 25 years; ‡Including planting and pressurised irrigation systems costs; §$400 for repair and maintenance, $250 for hay/grain, $1000 for supplementary feed cost, $700 for herd and shed, $500 for feed pasture along with $250 for overhead cost and $1300 labour cost; ¶Except some initial years when variable costs are low; **Milk 5500 l/cow, 3.5 cows/ha and $0.315/l plus stock revenue of $350/ha ($100*3.5 cows/ha) by selling of retired calves.

Determining the economically optimal life of a perennial activity depends on a number of factors including crop yield and price of output (Lien *et al.* 2007) along with the discount rate. For simplicity, economically optimal life of each activity is determined using average prices of outputs and crop yields over the planning horizon. Net revenue of each perennial activity for each year is discounted using 5 per cent real discount rate and the cumulative discounted net revenue is obtained. Annuity value for each year is obtained by multiplying the annuity factor by the cumulative discounted net revenue of each year. Finally, the optimal investment year is determined using the rule described above in the analytical framework (i.e. annuity value is less than net revenue in the same year but annuity value is greater than net revenue of the following year). Net cumulative value of the identified year (when optimal investment takes place) is multiplied by the infinite planning horizon factor and the net present value ($/ha) over an infinite planning horizon is obtained. This value is divided by irrigation water use (ML/ha) to obtain the net irrigation water value ($/ML) over the infinite planning horizon.

5. Results

5.1 Newly established irrigation investments

Estimates of the optimal life (of a perennial crop) and net economic value of irrigation water for seven major activities in the Murray Basin have been summarised in Table 4. Optimal life of almonds is the highest (26 years) followed by grapes and citrus with optimal lives of 24 and 20 years, respectively. Table 4 also shows net present values (NPVs) of irrigation water over an infinite planning horizon (i.e. willingness to pay for a perpetual water right or water entitlement in the permanent market). The NPVs over infinite planning horizon for these seven activities vary from $1107/ML for rice to $2742/ML for vegetables (i.e. potatoes). These values are further distinguished by placing the seven crops into two major groups – those with a net value of less than $2000/ML and those (mainly perennial) with a net value of greater than $2000/ML. Of the three perennial activities, grapes resulted in the highest net value followed by almonds and citrus. As far as annual activities are concerned, net value of vegetables is the highest in the ranking while net value of rice is the lowest followed by cereals and dairy.

Table 4 Optimal life, net present values and annualised values of newly established seven major activities

	Rice	Cereals	Dairy	Vegetables	Citrus	Almonds	Grapes
Optimal life (years)	N/A	N/A	N/A	N/A	20	26	24
NPV ($/ML)	1107	1281	1336	2742	2136	2395	2481
Annualised value ($/ML)	55	64	67	137	107	120	124

The annualised net values of these activities vary between \$55/ML to \$137/ML. These values are much lower than the prices received by irrigators in 2007/2008 in the Basin. The current estimates are close to the values estimated by Qureshi *et al.* (2007) across the Basin. They found that the shadow price (or net value of water) varied between \$6/ML and \$156/ML depending on the region. It is also to be noted that prices in temporary markets are much more volatile than prices in the permanent water market. For example, during the 2007/2008 irrigation season prices on the Murray connected temporary water market varied between \$180 and \$1200/ML.

5.2 Existing irrigation investments

The net present values have also been estimated for existing irrigation investments to examine impact of asset age distribution level on the value of water (or willingness to pay) by both annual and perennial activities, and to compare them with newly established farms. As shown in the Table 5, values of annual activities remain the same while the values of perennial activities (including citrus, almonds and grapes) change significantly depending on the existing age of these activities and their associated assets. When the established crops were 5 and 10 years old, the NPV of citrus was highest while the NPV of almonds was the lowest. When the crops were 15 years old, NPV of grapes was highest followed by almonds. When the crops were 20 years old, NPV of grapes remained the highest but NPVs of almonds and citrus fell below their respective newly-established farms. This means the willingness to pay for water is highest for a citrus irrigator when the trees are five years old and lowest when the asset life is 20 years.

Table 5 also shows annualised values of both annual and different age groups of perennial activities. The high willingness to pay reflects the situation of some irrigators who may have been desperate either to maintain the productivity or at least minimise the losses to their assets. The willingness to pay of a citrus irrigator for one unit of water went up to \$615/ML when the age of the farm was 5 years which declined to \$245/ML when its age was 15 years. The willingness to pay of a citrus irrigator whose farm had reached

Table 5 Age distribution and willingness to pay (NPVs and annualised values) of three major perennial activities

	5 year old		10 year old		15 year old		20 year old	
	NPV (\$/ML)	Annualised value (\$/ML)	NPV (\$/ML)	Annualised value (\$/ML)	NPV (\$/ML)	Annualised value (\$/ML)	NPV (\$/ML)	Annualised value (\$/ML)
Citrus	12 302	615	10 588	529	4900	245	36	2
Almonds	9192	460	7479	374	4685	234	1374	69
Grapes	9980	499	9144	457	6526	326	3572	179

20 years was close to zero. The willingness to pay for almonds and grapes irrigators when the crops were 5 years old was $460/ML and $499/ML, respectively. When the age of these two activities reached 15 years, their willingness to pay for one unit of water was $234/ML and $326/ML, respectively. When the almonds and grapes farms reached 20 years, the irrigators were willing to pay $69/ML and $179/ML per year, respectively. These estimates are consistent with Bjornlund (2009) who found that as the allocations decreased, prices of water increased as a result of the irrigators trying to secure their investments for their long-term farm improvements.

5.3 Marginal value of water

From a policy perspective it is crucial to know, what is the amount users of water are willing to pay for a marginal unit of water? Based upon this information, the costs to society for procuring water from these users to environmental uses can be assessed. Knowing the willingness to pay for water can also form the basis for future water allocations under severe scarcity. Willingness to pay by irrigators for water usage in all the activities (and in case of perennial activities at each age distribution) has been sorted in ascending order, as shown in Figure 2. Figure 2 shows that the marginal value of water (used for irrigation) is highest when citrus farms are five years old, followed by almonds with the same age and grapes when the vineyards are 10 years old. Newly established rice, dairy and 20 year old citrus farms resulted in lowest marginal values, respectively. Average water market price in June 2008 was $1590/ML (Waterfind 2008), and recent trends indicate that the market price may reach close to $2000/ML or above. As shown in Figure 3, the values of most of these activities (except newly established dairy, cereals, rice and 20 year old citrus) are above the market price of $2000/ML.

Figure 3 presents the willingness to accept compensation for a ML of water supplied out of agriculture. This graph could be used to draw inferences for the societal costs of procuring water for environmental needs. For instance,

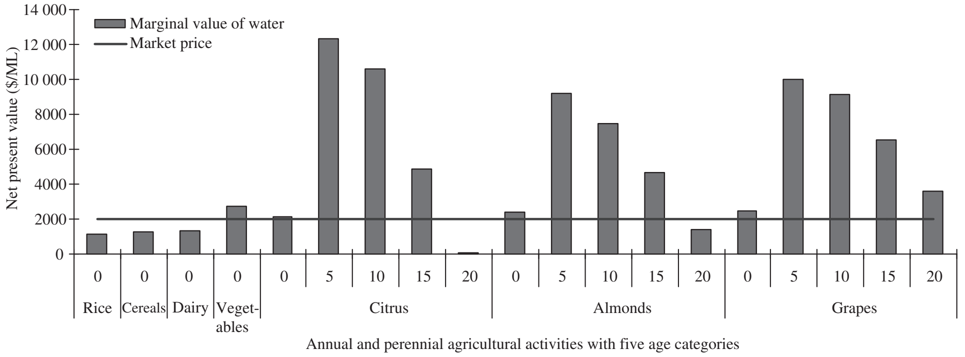

Figure 2 Marginal values of water used by major agricultural activities and their comparison with the market price of water.

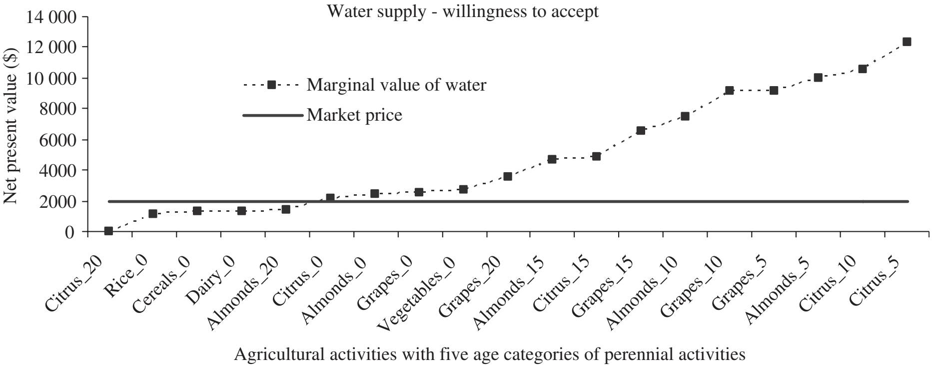

Figure 3 Willingness to accept compensation per ML of water by different growers.

citrus famers with 20 year old trees would be the cheapest source to tap into in the beginning. However, if all of agricultural water must come out for environmental provisions, it would cost over $12 000/ML to obtain water from the last agricultural users.

5.4 Water acquisition for environmental flows

Next, we used water allocations data of Murrumbidgee (one of the MDB catchments) to estimate total value of irrigation water in the entire catchment and to estimate volume of water available in each agricultural activity for acquisition for environmental flows. According to Qureshi *et al.* (2007), out of the total expected allocations for irrigation, 53 per cent was allocated to rice, 10 per cent to cereals (including wheat), 20 per cent to combined dairy, beef, sheep, 4 per cent to vegetables (including potatoes), 5 per cent to citrus, 2 per cent to deciduous fruits (almonds) and 6 per cent to vineyards (grapes). A recent study (CSIRO 2008b) estimated that in Scenario A which considered the historical climate data, only 1592 GL were available for diversion (excluding about 29 per cent conveyance losses) for entitlement holders (irrigators) in the catchment.[3]

Assuming the same proportion of water considered by Qureshi *et al.* (2007), total water allocated for the seven major activities is multiplied by the net value of water to get total value of water for each activity. Total value of water for rice was estimated to be $934 million, for cereals was $204 million, dairy, sheep and beef was $425 million and for vegetables was $175 million. In case of perennial activities, it is assumed that water allocated to these activities (i.e. citrus, almonds and grapes) is equally divided between their five age

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[3] There are three types of irrigation entitlement holders in Murrumbidgee which are assigned shares: 2 043 432 unit shares for general security; 298 021 unit shares for high security and 220 000 unit shares for supplementary access (CSIRO 2008b).

(i.e. years) categories (0, 5, 10, 15 and 20 plus), respectively. Based on this assumption, total water allocated to each age category of citrus, almonds and grapes in the catchment was 16 GL, 6 GL and 19 GL, respectively. Multiplying the allocated volume (GL) of water to the respective net values of water shown in the Table 5 resulted in total value of $479 million for citrus, $151 million for almonds and $602 million for grapes. By adding the total values of all the seven activities resulted in about $3 billion of water allocated to the whole catchment. Total value of both high and general security water entitlements in the Murrumbidgee catchment estimated by previous study (Waterfind 2008) was $3.138 billion. The total value estimates (about $3 billion) of the current analysis are slightly lower than the WaterFind assessment. This is due to the fact that: a) the previous study multiplied an average price of high security and general security water entitlements by total entitlements assuming full 100 per cent allocations and got total value for the whole catchment and b) the current analysis estimates total net value based on performance of individual activities along with the age (in perennial case) multiplied by their individual allocations.

Figure 4 shows weighted average willingness to accept (net present value) of each of the three perennial activities and the four annual activities along with the total volume of water that can sourced from each of these activities. Rice, cereals and dairy are the three activities from where more than 80 per cent (i.e. 1321 GL) of the total catchment allocated water can be sourced for environmental needs at the cost of $1107/ML, $1281/ML and $1336/ML, respectively. The fourth annual activity, vegetables, can release 64 GL at the cost of $2481/ML. The (weighted average) willingness to accept (value) of almonds, grapes and citrus is more than double (i.e. $4602/ML, $5359/ML and $5485/ML, respectively) the average market price of permanent trading (i.e. $2000/ML). However, total water allocated for these three

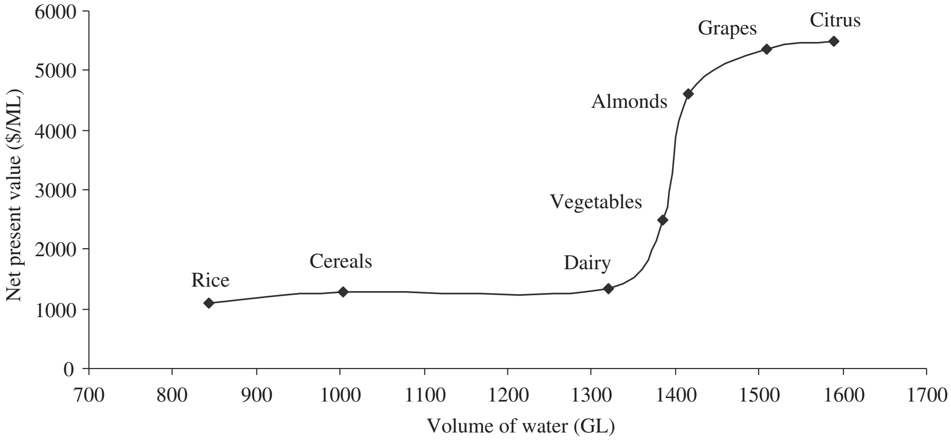

Figure 4 Marginal values of water and volume of water available for acquisition.

activities is relatively small (i.e. about 15 per cent of the total allocations). When the proportions of the volume of water allocated for the seven activities are multiplied by their respective values, weighted average value of the whole catchment is estimated to be $1765/ML. This value is slightly lower than the average market price of the permanent water trading in the catchment.

6. Research outcomes

Information over the value of irrigation water is essential for supporting policy making about the efficient allocation of water among different agricultural activities in a river basin or catchment. In this study the residual estimation approach was used to calculate irrigation water values in the Murrumbidgee catchment in southern MDB, Australia. The study assessed the per unit value of water to agricultural revenue in different agricultural activities and the total value of irrigation water in the region. The results suggest that the value of irrigation water is positive for all the activities. The observed values were in the range of those found in previous studies for irrigated activities in the MDB (Waterfind 2008). However, the study found a high level of variability in irrigation water values across activities.

The study revealed two major groups of water values – annual activities with a value of about $1000/ML and perennial activities with a value of over $2000/ML. Among the perennial activities, the study also highlighted the role of age distribution of perennial activities as a key factor in determining the value of irrigation water. Along with vegetables, the willingness to pay by a newly established grapes farmer for a permanent water entitlement is the highest, followed by almonds and citrus. When these farms were five and 10 years old, citrus resulted in the highest net values, followed by grapes and almonds. However, when these farms were 15 years old, grapes emerged with the highest net value followed by citrus and almonds. When these farms reached the age of 20 years, grapes remained on the top followed by almonds while citrus resulted in a value close to zero. This reflects the shorter agronomic life cycle of citrus compared to grapes and almonds.

Among the annual activities, the willingness to pay of dairy farmers is the highest followed by cereals and rice. The weighted average willingness to accept of all the three perennial activities is much higher than the market price. However, the estimated weighted average willingness to accept of all the seven activities is slightly lower than the average market price in the catchment.

The annualised values of these activities are close to the previous estimates. However, these annualised values are slightly lower than the prices paid by irrigators in temporary water markets in recent years. The reason could be due to the asset fixity issue and the irrigators wanting to maintain productivity of their high value crops. Others might have paid to minimise losses as a result of crop damage and to avoid major investments, such as reestablishment of vineyards. For these reasons, irrigators are willing to pay high prices in order to secure their investments in their long-term farm improvements.

7. Policy implications

In 2008, the Rudd Government announced the '*Water for the Future*' plan. The plan acknowledges both the importance of water markets and investment in efficiency improvements for acquiring water for the environment in the MDB (*Government of Australia*, 2008). The plan aims for the modernisation of irrigation infrastructure and relies on entitlements purchase in the market for environment. The plan is also aimed at addressing water over-allocation issues by providing assistance to irrigation districts to reconfigure irrigation systems and retire non-viable areas along with the assistance to help relocate non-viable or inefficient irrigators, or help them with exiting the industry. An efficient and complete water market is essential for efficient irrigation water allocation, for least cost environmental water acquisitions and for any future water related investment. Currently, there are many barriers to the smooth functioning of water markets which do not allow efficient allocation of water across activities and regions (Qureshi *et al.* 2009).

In light of the above need to allocate water to most efficient irrigators through markets and through other means of government intervention, the analysis performed in this paper has several implications for policy purposes. First, it provides a much more realistic estimation of the value of water to various irrigators by incorporating their fixed and sunk investment costs. Second, by ranking various annual and perennial crops on the basis of their values of water it provides a basis for allocating water out of less efficient users first so as to maximize societal benefits from water. Third, when faced with increasing water scarcity, farmers are likely to exit farming as water prices increase. The supply function derived for water is reflective of the pattern of exit out of agriculture and informs policy relating to intervention when continuation of particular crops/irrigators is deemed desirable by policy makers. Alternatively, the water demand function is an indicator of those crops that would still be planted in a water scarce environment if water trading were allowed. Finally, the finding that annualized value of water is slightly lower than the price paid in temporary water markets, signifies the role of uncertainty relating to water supply in influencing water demand. Therefore, the need for a consistent long term water policy is highlighted in order to minimize inefficient water uses.

7. Conclusions

The purpose of this paper has been to develop and apply an analytical framework that is useful in determining value of irrigation water use in both annual and perennial activities. Net present values over infinite planning horizon are estimated and used to compare rankings of individual activities based on the net value of irrigation water or the willingness to pay by each individual irrigator. Along with vegetables, the willingness to pay by a newly established grapes farmer for a permanent water entitlement is the highest, followed by almonds and citrus. Among the annual activities, the willingness to pay of a dairy farmer is highest followed by cereals and rice. The weighted average willingness to accept of all the three perennial activities is much higher than the market price. However, the estimated weighted average willingness to accept of all the seven activities is slightly lower than the average market price in the catchment.

The finding that the annualised values are slightly lower than the prices paid by irrigators in temporary water markets in recent years highlights the tendency towards securing water supply by the farmers. Farmers may also be substituting more water for a water-efficient technology as the former option is much cheaper.

Several challenges remain, however, to refine the approach adopted in this paper in order to improve the estimates of the value of water to its key users and the overall value of water to the economy. The uncertainty associated with future water supply, water prices and agricultural commodity prices is crucial in affecting the value of water to its users. This is because such uncertainties encourage sub-optimal uses of water by delaying adoption of water efficient technologies. Similarly, the risk preferences of individual irrigators for individual activities could influence investment decisions thereby impacting on value of irrigation water and requires further investigation. The variation in crop water requirements, effective rainfall and crop yields in different catchments will impact on net values as well and warrants further investigation across the MDB catchments.

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Appendix

1. Economic component

1.1 Evaluation of annual activities

For each annual agricultural activity (j), gross revenue (P_jY_j) per hectare is calculated by multiplying the annual produce yield (Y_j) by price (P_j). The net annualised value (NV_j) (\$/hectare) equals the gross revenue less all the annualised capital costs (CC_j), fixed costs (FC_j), variable costs (VC_j), water related costs (WC_j) and water charges (WP_j):

$$NV_j = P_jY_j - \left(CC_j + FC_j + VC_j + WC_j + WP_j\right). \tag{1}$$

The present net value of an income stream (i.e. of irrigation water) realised in a single cycle ($PV_{j,(1)}$) is equal to the net annualised value:

$$\forall j\ :\ PV_{j,(1)} = \left[NV_j\right] \tag{2}$$

The present value of an income stream realised over infinite planning horizon ($PV_{j,(\infty)}$) is obtained by multiplying the infinite planning factor $(1/1-(1+r)^{-1})$ by net annualised value:

$$\forall j : PV_{j,(\infty)} = \frac{1}{1-(1+r)^{-1}} PV_{j,(1)} \tag{3}$$

where r is an appropriate annual discount rate, consistent with the real cost of capital. Net present value of a unit of water is estimated by dividing net present value per hectare by the total irrigation water requirement for the relevant crop for a hectare.

1.2 Evaluation of perennial activities

In perennial activities, on farm investment costs including crop establishment and irrigation system costs are first accounted for in the first year of the planning horizon and then a new investment is made depending on economic (optimal) life of the crop. A model has been developed here to determine optimal age to replace assets in particular perennial activities (i). It is assumed that asset of an activity is created in year 1 and replaced perpetually every time it reaches an optimal age m_i (replacement time) years by a series of assets of the same activity. It is also assumed that the asset has no salvage value at the time of the replacement. For each perennial activity i in time t, the present value of an income stream of net value ($NVP_{i,t}$) realised in a single cycle, $PVP_{i,(\mathrm{I},m_i,1)}$, can be given as:

$$\forall i : PVP_{i,(\mathrm{I},m_i,1)} = \sum_{t=1}^{m_i} NVP_{i,t}(1+r)^{-(t-1)}. \tag{4}$$

The net value $NVP_{i,t}$ of each perennial activity and over time equals the gross revenue less all the capital costs, fixed costs, variable costs and water pumping costs:

$$NVP_{i,t} = P_i Y_{i,t} - \left(CC_{i,t} + FC_{i,t} + VC_{i,t} + WC_{i,t} + WP_i\right). \tag{5}$$

The present value of an income stream realised over the infinite planning horizon ($PVP_{i,(\mathrm{I},m_i,\infty)}$) is obtained by multiplying the infinite planning factor $(1/1-(1+r)^{-m_i})$ by net perennial value:

$$\forall i : PVP_{i,(\mathrm{I},m_i,\infty)} = \frac{1}{1-(1+r)^{-m_i}} PVP_{i,(\mathrm{I},m_i,1)}. \tag{6}$$

For an infinite number of identical cycles of an asset (i.e. Equation 6), the problem is to find the optimal age 'm_i' which maximises the value of the entire income stream for each perennial activity i. Following Etherington (1977), the optimal age m_i at which the asset should be replaced can be found by looking at m_i which maximises Equation (6). The right hand side of the Equation (6) attains a maximum at an age m_i where discounted marginal annual net returns must equal the annuity formed by the sum of the discounted annual earnings from the asset:

$$\forall i\ :\ NVP_{i,m_i}(1+r)^{-m_i} = \sum_{t=1}^{m_i} NVP_{i,t}(1+r)^{-(t-1)}\frac{r}{(1+r)^{m_i}-1}. \tag{7}$$

As, in reality, the equality condition in (7) is unlikely to hold, the decision rule can be best expressed in the form of an inequality by collecting all the discounted terms into right hand side:

$$\forall i\ :\ NVP_{i,m_i} \geq \sum_{t=1}^{m_i} NVP_{i,t}(1+r)^{-(t-1)}\frac{r(1+r)^{m_i}}{(1+r)^{m_i}-1} \geq NVP_{i,m_{i+1}}. \tag{8}$$

The middle term in the Equation (8) is the equal annual payment or annuity calculated from the discounted total earnings. The optimal value of m_i is found by sequentially comparing at each age of the asset the annual net return at that age NVP_{i,m_i} and the annuity formed (the middle term) if the asset were to be replaced at that age. If at age m_i, the annuity just exceeded NVP_{i,m_i} but fell short of $NVP_{i,m_{i+1}}$, the age m_i is the optimal time to replace. Once the optimal investment year is identified, net cumulative value is multiplied by the infinite planning horizon factor to arrive at the net value ($/ha) over the infinite planning horizon. This value is divided by irrigation water use (ML/ha) to obtain the net irrigation water value over infinite planning horizon of each perennial activity.

If the asset is n years old and replaced perpetually every time it reaches an optimal age m_i years by a series of asset of the same activity, then its net present value is obtained, following Gordon *et al.* (2005), as[4]:

$$\begin{aligned}\forall i\ :\ PVP_{i,(n,m_i,\infty)} = &\sum_{t=n}^{m_i} NVP_{i,t}(1+r)^{-(t-n)} \\ &+ (1+r)^{-(m_i-n+1)}\left[\frac{1}{1-(1+r)^{-m_i}}PVP_{i,(\mathrm{I},m_i,1)}\right].\end{aligned} \tag{9}$$

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[4] The letter ‘I’ in Equation (4) and ‘*n*’ in Equation (9) are used to show how old is the asset. ‘I’ is used specifically for asset or activities created in first year, year 1 or base year while ‘*n*’ is used in general.