The Australian Journal of Agricultural and Resource Economics, 51, pp. 283–303

Economic assessment of acquiring water for environmental flows in the Murray Basin*

M. Ejaz Qureshi, Jeff Connor, Mac Kirby and Mohammed Mainuddin†

This article is an economic analysis of reallocating River Murray Basin water from agriculture to the environment with and without the possibility of interregional water trade. Acquiring environmental flows as an equal percentage of water allocations from all irrigation regions in the Basin is estimated to reduce returns to irrigation. When the same volume of water is taken from selected low-value regions only, the net revenue reduction is less. In all scenarios considered, net revenue gains from freeing trade are estimated to outweigh the negative revenue effects of reallocating water for environmental flows. The model accounts for how stochastic weather affects market water demand, supply and requirements for environmental flows. Net irrigation revenue is estimated to be $75 million less than the baseline level for a scenario involving reallocating a constant volume of water for the environment in both wet and dry years. For a more realistic scenario involving more water for the environment in wet and less in dry years, estimated net revenue loss is reduced by 48 per cent to $39 million. Finally, the external salinity-related costs of water trading are estimated at around $1 million per annum, a quite modest amount compared to the direct irrigation benefits of trade.

Key words: expected value, hydrology, mathematical modelling, shadow price, stochastic.

1. Introduction

Changes to land use and river management in the Murray–Darling Basin have led to concern over water allocation security, water quality and ecosystem health (MDBC 2001). One indicator of changed river management is that the median annual flow to the sea is now only 27 per cent of the natural (predevelopment) flow (MDBMC 2002).

The Council of Australian Governments through the National Water Initiative (NWI) has committed $500 million with the intent of acquiring around

* This paper was produced as part of the CSIRO Flagship Program Water for a Healthy Country. Mike Young, Glyn Wittwer, Lindsay White and Geoff Podger made some valuable comments and provided useful suggestions. We also acknowledge suggestions, comments and recommendations provided by the editors and reviewers of the journal. Editorial assistance provided by David Kaczan is also acknowledged.

† M. Ejaz Qureshi (Ejaz.Qureshi@csiro.au) is Senior Economist and Policy Analyst in the Policy and Economic Research Unit in Land and Water of CSIRO, Canberra, Jeff Connor is a Senior Economist in the Policy and Economic Research Unit in Land and Water Division of CSIRO, Adelaide, Mac Kirby is a Research Scientist in Land and Water Division of CSIRO, Canberra, Mohammed Mainuddin is a Hydrologist in Land and Water Division of CSIRO, Canberra.

doi: 10.1111/j.1467-8489.2007.00383.x

500 GL of water for environmental flows (MDBMC 2003). Conceptually, water could be acquired through changes in the rules by which rights to consumptive and non-consumptive use are defined without compensation. Alternatively water for the environment could be sourced through a market mechanism. This would involve compensation for existing right holders to relinquish consumptive use rights.

Recovering water from existing consumptive water users may involve significant social, economic and political challenges. Young *et al.* (2002) found that the increasing environmental flows would reduce the area of irrigated agriculture. More generally, the level of impact and who is affected will depend on how acquisition is temporally and spatially targeted, and other details of the mechanism used to acquire the water (Gippel *et al.* 2002; Brennan 2006).

Any effort to acquire water for the environment will take place in an increasingly active market for water. Water has been tradeable independently from land in the Murray–Darling Basin since the 1987 water-policy reforms. A market for water in the Basin has emerged that already involves exchange of up to 20 per cent of water allocations from some supply areas (URS 2005). This has led to significant spatial reallocation of irrigation in the Basin (Bjornland 2004). Despite Commonwealth-level reforms, progress toward completely free trade has been uneven. Significant local and state-level institutional restrictions on water trade remain in some parts of the Basin (Qureshi *et al.* 2006). The recent National Water Initiative is a significant policy push at the federal level to remove remaining impediments. Consequently, the volume of trade in the market and the resulting extent of spatial reallocation of irrigation is likely to grow over time. Conceptually, further freeing of water trade should allow additional reallocation of water to higher value uses and thus increase total returns to irrigation in the Basin.

Efforts to acquire water for the environment and liberalise water trade will take place in an atmosphere of increasing concern over the rising salinity impacts of irrigation in the Murray–Darling Basin. In many parts of the Basin irrigation takes place over naturally saline groundwater (MDBMC 2000). Even in the absence of trade, salinities in the Lower Murray River in South Australia are anticipated to grow by over 200 EC to an average 800 EC by 2050 (MDBMC 2000). Water trade is likely to exacerbate river salinisation as the net flows of water from trade is generally from low to high salinity impact regions (Heaney *et al.* 2001; URS 2005). Under the Murray–Darling Basin Commission Agreement 1992, actions are needed to reduce salinity and its impact on crops and water using infrastructure.

The objective of this study is to assess how agricultural sector opportunity costs of acquiring environmental flows are likely to vary depending on the mechanism used to source water and spatial patterns of water acquisition. In this article, a model is presented on the economics of irrigation, water trade and resultant salinity externalities for the southern part of the Murray–Darling Basin.

The analysis addresses five key questions:

1. What are the costs of acquiring water for environmental flows by subregion within the Basin?
2. How do these costs vary due to variations in rainfall, water allocation and crop water demand?
3. Can the cost of acquiring environmental flows be substantially reduced through a targeted approach of sourcing water for environmental flows from regions where value of water in irrigated production is least?
4. Are the potential irrigated agricultural sector revenue gains from free water trade large enough to offset the forgone opportunity cost of reallocating 500 GL of water from irrigation to the environment?
5. How does accounting for external salinity damage costs change the conclusions regarding the net benefits of environmental water acquisition and water trade policy in the Basin?

2. This study in the context of related past research

Several studies have addressed the issues of irrigation water overallocation and salinity externalities in the Murray–Darling Basin. Quiggin (1988) developed a model of the Murray River system and illustrated how different institutional structures can affect farm land-use decisions and salinity-related problems. Quiggin (1991) examined farm responses to mitigation works and the availability of new technologies.

Hall *et al.* (1994) developed a spatial equilibrium model of the southern Murray–Darling Basin and used it to estimate the effects of water trading between regions. Several simulations were carried out using the model. They found that unrestricted trade in water between all regions increased gross margins by about $48 million in aggregate, an increase of 4.6 per cent. The Salinity and Landuse Simulation Analysis (SALSA) model (Bell and Heaney 2001) is a model of long-run response to water market incentives in the southern Murray–Darling Basin. Eigenraam *et al.* (2003) developed a model of water trade for Victorian parts of the Basin. It is a linked series of gross margin linear programming models – called the Water Policy Model (WPM). The MDBC (2004) utilised the Water Policy Model and the SALSA model to evaluate the economic and social impacts of environmental flows options.

The model used in this analysis includes several important features of actually observed responses to water market incentives that have not been included in past analyses. Previously published Murray–Darling Basin water market models described above have assumed average conditions influencing water supply and demand. The model reported here includes market response to different water availability, effective rain and irrigation requirements in very wet, wet, average, dry and very dry years. The water availability, effective rain and irrigation requirements are treated as states of nature and weighted by probabilities derived from historical observations. This is important because one significant observed benefit of freer water trade in the Murray–Darling Basin has been significant reallocation of water with different patterns of reallocation in different years depending on annual allocation levels (Bjornland 2004).

A crop water production function is included that simulates the impacts of varying water application levels on crop yield and allows for deficit irrigation. Deficit irrigation, or providing somewhat less than full crop water requirement and accepting somewhat reduced yields, is commonly observed response to water scarcity and high water prices (Rosegrant *et al*. 2000). The past studies outlined above have not included this possibility in that they all involved an assumption of fixed crop water requirements.

The model used in this analysis also includes a representation of the way that the area of some irrigated crops is varied from year to year depending on the value of water in production in comparison to its market value. It is assumed that irrigators cannot change areas of activities requiring major capital investments in the short-run time frame modelled. However, the area allocated to certain types of annual crops is allowed to expand and contract within limits. This reflects the practice in some parts of the Basin of holding land and irrigation capital assets that allow greater areas of irrigated cropping in years of high water allocation, and idling of this capital in years of low allocation (Appels *et al*. 2004). Again this is an actually observed response to water markets that has not been included in past analyses.

3. Analytical framework and case study

Thirteen catchments (also referred to as regions) in the southern part of the Murray–Darling Basin are modelled, as shown in Figure 1. Twelve agricultural activities that occupy most of the Murray Basin are considered including: potatoes, vegetables, grapes, rice, oilseeds, deciduous fruits, citrus fruits, cereals, legumes, pasture for beef, pasture for dairy and pasture for sheep.

3.1 Water allocation optimisation model

At the core of the framework is a model of irrigation response, costs and revenue that would be expected under alternative water demand and supply scenarios. Following the currently dominant practice, the model is a mathematical programming optimisation model (e.g. McCarl *et al*. 1999; Rosegrant *et al*. 2000). While there are limitations to this approach, it is still popular for microanalysis of agricultural production and resource use because it can reliably produce characterisations of real-world constrained allocation decisions with limited data resources.

3.1.1 The objective function

The objective function of the model is to maximise the expected net revenue from water use for irrigation subject to the constraints explained below. Each region is treated as though it were a decision maker attempting to maximise economic returns from producing irrigated and dryland crops given the

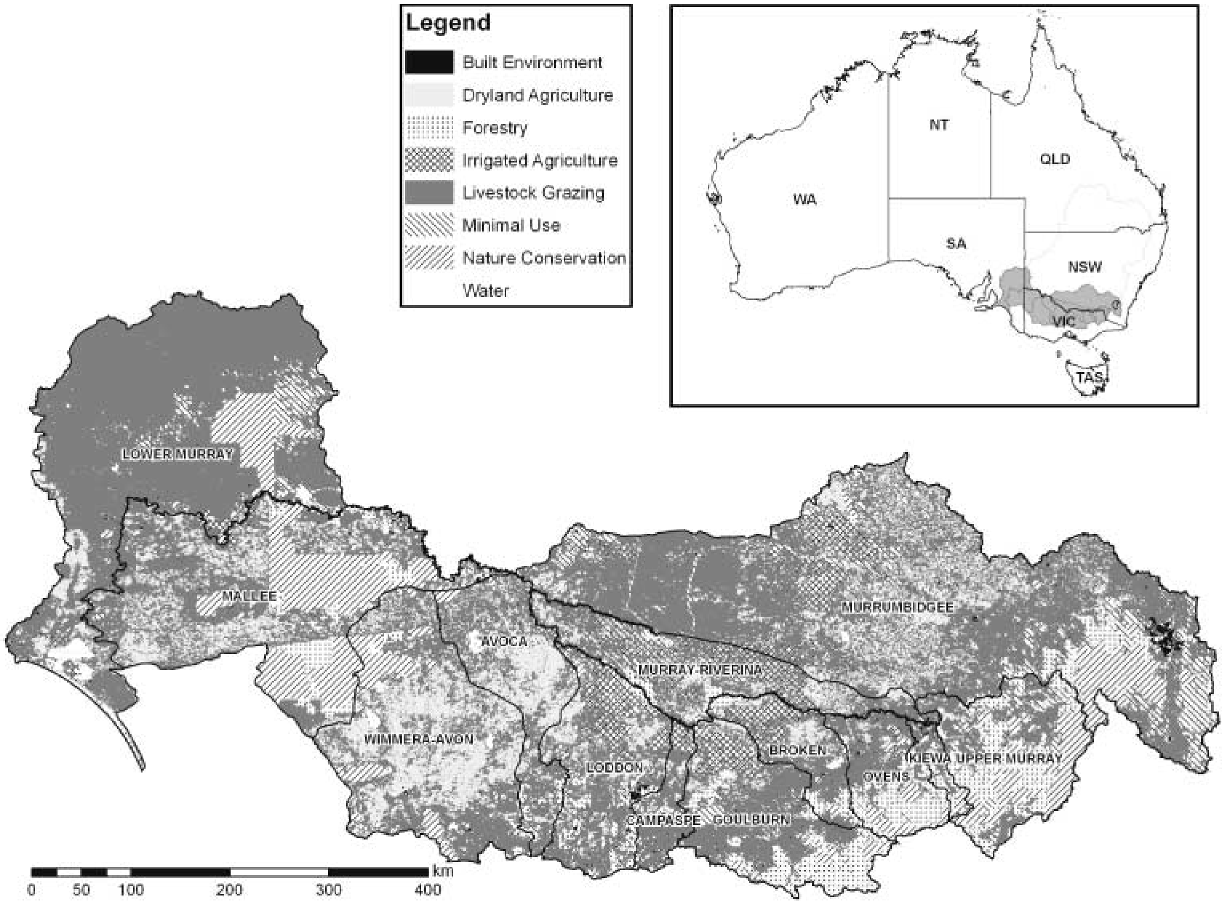

Figure 1 Catchments of the southern Murray–Darling Basin.

constrained water allocation faced by the region in a specific year. Each region chooses crops and irrigation levels, and it switches land from irrigation to dryland activity if it is more profitable to sell water than it is to irrigate. Modelled responses vary depending on rainfall, water allocation and crop water requirement. Land and capital such as irrigation equipment is assumed to be fixed. Thus, the model estimates short-run or seasonal impacts of varying water allocations.

The net revenue for each region for each state of nature is equal to the aggregate revenue for the region minus variable costs and water supply charges. The expected net revenue for the Basin (*Exp R*) is the sum across all regions of the probability weighted average net revenue across states of nature for each region:

$$\mathrm{Exp}\ R = \sum_{s} \mathrm{Prob}_{s} \times \Big(\sum_{r}\sum_{j} \mathrm{P}_{rj}\ \mathrm{Yld}_{rj}\mathrm{A}_{srj} - \sum_{r}\sum_{j}\mathrm{OC}_{rj}\mathrm{A}_{srj} - \mathrm{WCh}\sum_{r}\sum_{j}\mathrm{A}_{srj}\mathrm{w}_{srj}\Big) \quad (1)$$

where *s,* state of nature; *r*, irrigation demand sites (regions); *j*, cropping activities; *Prob*, probability of water allocations/supply; *P*, crop price ($/ha); *Yld*, actual yield (t/ha); *A*, irrigated area (ha) – the decision variables; *OC*, other cost ($/ha); *WCh*, water charge ($/mL); and *w*, water used (mL/ha).

Water charges differ from region to region, and are under review in response to water reform (COAG 2004; Heaney *et al.* 2004). For convenience, we assume that a single charging regime operates across the regions.

3.2 Hydrologic component

3.2.1 Spatial and stochastic temporal water supply

The spatial distribution of water allocations was calculated from a combination of simulation runs from the MDBC river operations model, BigMod-MSM (Andy Close, pers. comm. 2005) and information from Bryan and Marvanek (2004). The MDBC model simulates allocations at each diversion point based on simulated dam inflows for a run of 105 years of historical rainfall and evaporation (1895–2000) and assuming current levels of irrigation development. In calculating water supply across states of nature, the model accounts for administrative water allocation rules allowing for the system capacity to be stored and, hence, shifting of water towards drier years.

The analysis of Bryan and Marvanek (2004) provides the only available broad scale assessment of the distribution of irrigated land and water use in the Murray–Darling Basin though it is only for a single year. The temporal sequence of diversions from the MDBC simulation runs is combined with the spatial distribution of water use from the Bryan and Marvanek analysis to calculate the cumulative distribution of allocations for each region. The result is water allocations and crop evapotranspiration requirements for five states of nature representing the 10th, 30th, 50th, 70th and 90th percentile points of the simulated distribution of allocations and crop water requirements.

Table 1 Quantities of environmental flows allocations in each state of nature

State	10th percentile	30th percentile	50th percentile	70th percentile	90th percentile	Expected value
Environmental flows allocations (ML)	100 000	240 000	480 000	720 000	960 000	500 000

3.2.2 Stochastic environmental flows

The actual recommendation of the scientific panel investigating environmental-flow options for the Murray was a pattern of environmental flows that varies considerably across years (CRCFE 2003). This is because substantial flows in the some seasons is essential for the health of wetlands, while in other years additional flows have little value for the environment (Blackmore and Connell 1997).

Generally, additional water tends to have higher environmental value in wet years, as it can augment already significant capacity to inundate floodplains, while in dry years it would be difficult to create significant inundation even with large supplemental flows. Following the principles of 'more water in wet and less in dry years', five states of environmental-flow allocations with probabilities of 20 per cent each are presented in Table 1. This distribution is not based on an ecological assessment of when or where environmental flows would be required. However, the quantities of environmental flows vary in each state, in a way that is consistent with the 'more water in wet years and less in dry years' principle. The expected value of water for environmental flows allocations across states of nature is 500 GL/year, in line with the agreement by the government to supply 500 GL (COAG 2003).

The specification of stochastic environmental water requirements is used in the analysis to investigate efficiency gains that might result from acquiring more water for the environment when there is high rainfall and less when there are dry periods. The prior hypothesis is that in dry years irrigators will seek more water for production due to less effective rainfall and high evapotranspiration along with cuts in their actual water allocations. Therefore, the shadow price (or willingness to pay) for water is expected to be high in dry years. In the wet years, the opposite condition will prevail and the shadow price of water for irrigation is expected to be less providing greater opportunity to acquire water for environmental flows at low cost.

3.3 Agronomic component

3.3.1 Crop water yield functions and deficit irrigation

Crop water requirements depend on biophysical factors such as climate, soils and crop grown. At low water application rates, additional water results in yield increases. Beyond a certain level of water application, crop yields suffer due to lack of aeration in the root zone and the marginal product of water becomes negative (de Fraiture and Perry 2002). To model crop output as a function of water, a quadratic yield response function is used of the form:

$$\text{Yld}_{srj} = f(w_{srj}) = a_{rj} + b_{rj}w_{srj} + c_{rj}w_{srj}^2 \quad (2)$$

where *Yld*, yield (t/ha); w_{srj}, total quantity of water available for the crop including irrigation water and effective rainfall, and accounting for irrigation system efficiency (ML/ha); *a*, intercept of the yield response functions (t/ha); *b*, slope coefficient of the yield response functions (t/ML); and *c*, other (quadratic) coefficient of yield response function (t. ha/ML^2).

For each state of nature *s*, water used (w_{srj}) for region *r* and activity *j* (ML/ha) is calculated as:

$$w_{srj} = \left(\frac{(\text{ET}_{rj} - \text{EffRain}_{srj})/100}{\text{IrriEff}_{rj}} \right) \quad (2a)$$

where *ET*, actual evapotranspiration (mm); *EffRain*, effective rainfall (mm); and *IrriEff*, irrigation efficiency.

The coefficients used in crop water production functions were derived by combining field data on yield and water requirements from Bryan and Marvanek (2004) and the slope of the FAO crop yield response function (Doorenbos and Kassam 1979). The FAO approach is widely used internationally and has been used in Australia, for example by Jayasuriya and Crean (2000) and Jayasuriya (2004) who assessed the economic impacts of environmental flows.

Inclusion of a crop water production function allows modelling of deficit irrigation or applying less than the full crop water requirement and accepting less than the greatest possible yield. By reducing the water use per hectare, a greater area can be irrigated. However, the level of deficit irrigation depends on the type of crops. In general, pulses, oilseeds, cereals and grapes are tolerant to water stress to some extent. Rice is sensitive to water stress particularly at the flowering and the second half of vegetative period (Doorenbos and Kassam 1979). Thus, the current model allows deficit irrigation subject to a certain threshold of minimum water requirements for each agricultural activity, as shown in Table 2.

Table 2 Minimum water requirement threshold (proportion) of full irrigation

Activity	Rice	Grape, dFruit, cFruit, Potatoes, Vegetables†	pBeef, pDairy, pSheep, Oilseeds, Legumes, Cereals‡
Minimum threshold (proportion)	0.80	0.60	0.40

†'dFruit' and 'cFruit' represent deciduous and citrus fruits, respectively.
‡'pBeef', 'pDairy' and 'pSheep' represent pasture for beef, dairy and sheep, respectively.

3.4 Land and water constraints

3.4.1 Irrigation water-use accounting and basin water constraint
The water availability constraints are of the general form:

$$\sum_j w_{srj} \mathrm{A}_{srj} \leq (1 - \mathrm{CLoss}_r) \times \mathrm{TotWat}_{sr} - \mathrm{Env}_{sr} \quad \forall r, s \tag{3}$$

These constraints ensure that the sum of the amount of water required by all crops *j* for each region, *r*, and state of nature, *s*, will not exceed the total amount of water available (TotWat_{sr}) after accounting for conveyance losses (CLoss_r) and allocating water for the environmental flows (Env_{sr}) for each region.

3.4.2 Irrigated land constraints
The equations for land availability constraints are of the form:

$$\sum_j \mathrm{A}_{srj} \leq \mathrm{TotLand}_r \quad \forall s, r \tag{4}$$

where $\mathrm{TotLand}_r$ is the total available area for irrigation. The land constraint ensures that for each state, *s*, the sum of the land areas required by regions, *r*, will not exceed the total available area for irrigation for all crops, *j*.

3.4.3 Irrigated land use constraint and dryland constraint
These constraints are used to release irrigated land towards dryland activity ($Dryland_{sr}$) if it is not economic to irrigate, as shown in Equation (5).

$$\mathrm{Dryland}_{sr} = \mathrm{LandR}_r - \sum_j \mathrm{A}_{srj} \quad \forall s, r \tag{5}$$

The land constraint ensures that for each state, the sum of the land areas of the crops converted to dryland and used for irrigation will be equal to the area available for irrigation land ($LandR_r$) in that region. The equation allows conversion to dryland if this represents the most profitable land use option given water allocation and market conditions.

3.4.5 Temporary and permanent activity constraints
A fixed land constraint (6a) is imposed on perennial cropping activities (*jp*) including deciduous and citrus fruits, and grapes which involve substantial long run capital investment and thus can neither expand nor contract in the short-term. Temporary activities can release land for dryland activity if it is not economically viable to irrigate. Minimum area constraints are imposed on the temporary activities to prevent disappearance of activities with poor economic performance. Temporary activities include oilseeds, cereals, legumes, pasture for beef, dairy, sheep, potatoes and vegetables. Temporary activities (*jt*) are allowed to take land from other temporary activities if it is economically viable to expand, as shown in Equation (6b).

$$\mathrm{A}_{srj} = \mathrm{Area}_{rj} \qquad \text{if } jp \ \forall s, r, j \tag{6a}$$

$$\sum_j \mathrm{A}_{srj} \leq \sum_j \mathrm{Area}_{rj} \text{ if } jt \ \forall s, r \tag{6b}$$

Minimum irrigated land area constraints are included because survey data (ABARE 2003; Bryan and Marvanek 2004) reveal that some areas produce irrigated crops even in years when this would appear to be unprofitable. This may be because all resources, particularly water and labour, are not perfectly mobile and are not imputed by their owners to the full market value of alternative uses assumed in analyses to date.

Constraint (6a) means that the permanent activities can only decrease water use through deficit irrigation and produce less than their maximum potential yield. The idea is to ensure that permanent crops such as grapes cannot expand from year to year, given that this would require significant capital investment which is only possible in the long-run. In contrast (6b) means that areas of crops such as cereals can expand in high-water-availability years using existing excess capital capacity of assets such as irrigation equipment and land. Rice is included as a special activity which cannot expand its area because it can only be grown in specific areas and on specific soil types (Appels *et al*. 2004).

3.4.6 Allowing water trading among regions

Later in the analysis, the water constraint presented above (Equation (3)) is relaxed. Instead a total water balance account Equation (7) is added to allow trade of water among regions across the Basin along with ensuring that the sum of the amount of water required by all crops *j* for each region, *r*, and state of nature, *s*, will not exceed the total amount of water available ($TotWat_s$) after accounting for conveyance losses ($CLoss_r$) and allocating water for the environmental flows (Env_{sr}) for the whole Basin. The volume of water traded is restricted to a maximum of 40 per cent of that available. In this short-run analysis, it is assumed that several factors will prevent greater trade, including the capacity of individual farms to use more water in the short run and product-market-demand constraints. Those regions which are not part of the surface water regulated system and/or have no physical linkage with other catchments are excluded from the interregional water trading market

$$\sum_j \mathrm{w}_{srj}\mathrm{A}_{srj} \leq (1 - \mathrm{CLoss}_r) \times \mathrm{TotWat}_s - \mathrm{Env}_{sr} \ \ \forall r, s \tag{7}$$

3.6 Solution algorithm

A non-linear programming structure is used instead of the more common linear programming approach because of the non-linearities involved in the agricultural activities production functions. The model has been coded in the General Algebraic Modelling System (GAMS) (Brooke *et al*. 2004).

3.7 Modelling externality costs and benefits

Water trade has potential to create both positive and negative externality impacts. Trade into some areas where groundwater underlying irrigation areas is naturally saline drives additional salt into the river and thus increases salinity damage to irrigated crops and water infrastructure (MDBC 2001). Conversely, when water is traded out of areas where high water tables are a crop-yield-limiting factor, a positive externality can be expected as less irrigation will tend to lower water tables and reduce consequent yield losses (Heaney *et al.* 2001).

For this analysis, externality impacts of trade are analysed using a prior assessment by Heaney *et al.* (2001). These authors estimated the cost of increasing drainage by 10 000 ML/year for each subcatchment of the Basin. Costs were evaluated on a 100-year net present value (NPV) basis because salt loading is a consequence of drainage increases that in many instances is delayed by several decades. One hundred year NPV values for 10 000 ML of drainage were converted to annual values per ML. The first step is converting the 10 000 ML of drainage assumed by Heaney *et al.* (2001) to a volume applied. This involved assuming a 15 per cent average drainage fraction across the Basin, meaning the 10 000 ML of drainage would result from 66 667 ML of application. Next the 100-year NPV values estimated by Heaney *et al.* (2001) were converted to an annual payment equivalent using the standard finance formula and the 5 per cent discount rate assumed in the original analysis. The annual payment is multiplied by the drainage fraction to estimate the total externality impact of water trade.

3.8 Calibration

Ideally, calibration of a model predicted outcome should be against a number of years of observed data. The biophysical and economic data required in the analysis came from different sources. Data on annual rainfall and water allocation was available for several years while spatially explicit Basin cropping pattern and crop water use data was available only for one year: 2000–01. Therefore, predicted water use was compared to Basin water use for 2000–01. Initially, results showed poor correspondence with areas and water demands for each crop and for each region. The differences are attributable to water delivery system losses and irrigation system inefficiencies. To resolve the differences, the water supply was calibrated to predict actual 2000–01 agricultural areas and water demands by crop and region. The results, shown in Figure 2 indicate that by calibrating water allocation to actual land use and estimating per hectare water use, actual response to 2000–01 conditions could be reproduced with the model reasonably accurately.

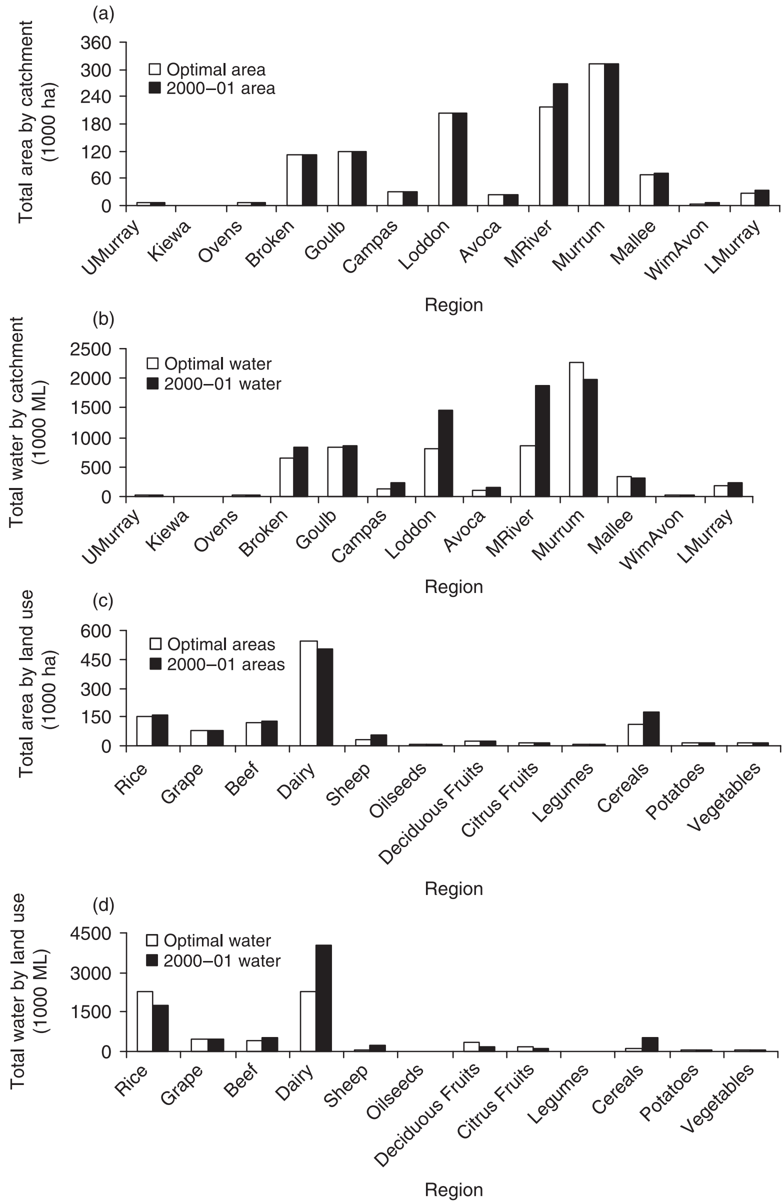

Figure 2 Comparison of modelled and actual areas of land uses and of water usage by region.

4. Policy scenario modelling

Five policy scenarios are modelled. As shown in Table 3, each is a combination of assumptions about the nature of water trade allowed and the mechanism used to source water for the environment.

In the baseline scenario and in scenarios 1 and 2, it is assumed that irrigators can only trade water within a region. This is roughly consistent with the pattern of water that would have existed in the Basin prior to the water reforms

Table 3 Policy scenarios modelled

Scenario	Assumptions	
	Water trade	Environmental flows sourcing mechanism
Baseline	No trade among regions	No water sourced for the environment
1. Proportional water sourcing without water trade	No trade among regions	Water for environment sourced as equal share of allocation from all regions
2. Targeted water sourcing without water trade	No trade among regions	Water for environment sourced from region with lowest returns to irrigation water use
3. Proportional water sourcing with water trade	Trade among regions	Same as scenario 1
4. Targeted water sourcing with water trade	Trade among regions	Same as scenario 2

(begun in 1980s and accelerated in the mid 1990s) confining water trade only within regions and along individual river valleys. In scenarios 3 and 4, it is assumed that water can be traded freely among all regions within the Basin to the extent that this is physically possible. While trade amongst regions presently occurs to some extent, institutional restrictions at State and irrigation district level still preclude completely free interregional trade (Qureshi *et al*. 2006). Volumes of water traded between valleys or regions are small and interstate trades are negligible (CIE 2004). Consequently, current conditions are somewhere between those represented with scenarios 1 and 2 (no interregional trade), and scenarios 3 and 4 (completely free interregional trade).

The opportunity cost to irrigated agriculture is estimated for two environmental water acquisition strategies. The environmental flows acquisition strategy modelled in scenarios 1 and 3 involves equal proportional reductions in irrigation allocations in all regions. Scenarios 2 and 4 assess impacts of taking water for the environment only from those regions where its value in irrigated production is least. Water sourcing from the Mallee and Lower Murray are precluded as water has the greatest productive value per ML in these regions. Upper Murray, Kiewa and Wimmera–Avon are excluded from the interregional trading market because the first two catchments are not part of the surface water regulated system while the last catchment has no physical linkage with other catchments.

5. Policy modelling results

5.1 Baseline results

Table 4 presents a summary of the assumed water available, estimated water usage, estimated expected net revenue and shadow price of water by catchment for the baseline scenario.

Table 4 Expected water use, net revenue and shadow price of water usage in different regions

Region	Water available (ML)	Water use (ML)	Water shadow price ($/ML)	Net revenue Total ($ 000)	Net revenue $/ha	Net revenue $/ML
UMurray	20 412	20 412	10	5375	944	263
Kiewa	3543	3543	14	859	919	243
Ovens	14 768	14 768	20	11 617	1472	787
Broken	654 248	654 248	9	232 701	2064	356
Goulb	840 427	840 427	6	287 120	2388	342
Campas	132 001	132 001	12	58 529	1949	443
Loddon	799 605	799 605	12	245 081	1212	307
Avoca	104 537	104 537	22	77 036	3440	737
MRiver	853 084	853 084	33	188 563	699	221
Murrum	2 271 415	2 271 415	12	430 350	1379	189
Mallee	346 583	346 583	156	660 807	9719	1906
WimAvon	31 900	31 900	120	46 133	9308	1445
LMurray	184 335	184 335	117	256 383	9645	1388
Total	6 256 857	6 256 857		2 500 555		

Table 5 Expected water use, net revenue and opportunity cost of acquiring water for water trade and environmental policy scenarios

		No interregional trade		Interregional trade	
Scenario	Base case	Pro-rata environmental water acquisition (Scenario 1)	Targeted environmental water acquisition (Scenario 2)	Pro-rata environmental water acquisition (Scenario 3)	Targeted environmental water acquisition (Scenario 4)
Water used (ML)	6 256 857	5 756 857	5 756 857	5 756 857	5 756 857
Net revenue ($ 000)	2 500 555	2 439 999	2 466 816	2 554 447	2 556 247
Total net irrigation profit impact ($ 000)	N/A	–60 556	–33 739	+53 892	+55 692
Average net irrigation profit impact ($/ML)	N/A	121	68	+108	+111

In the baseline scenario, estimated total Basin water use is 6257 GL/year while estimated total expected net revenue is $2501 million per year. As expected, baseline results show that shadow prices of water in the Mallee and Lower Murray regions are high ($156 and $117, respectively) as high-value horticulture and viticulture are dominant crops. Results also show the expected pattern of variation in water value across water-allocation years. The estimated Basin average shadow price of water for the baseline case varies from $42 in the lowest (10th percentile) water-allocation year to $21/ML in the highest (90th percentile) water allocation year considered.

5.2 Environmental water sourcing and water trade modelling results

Table 5 presents results of scenarios 1–4, including estimated total water allocation and net revenue. Scenarios 1 and 2 results indicate that reduced irrigation revenues relative to the baseline can be expected if an expected value of 500 GL is reallocated from irrigation to environmental flows and free water trade between regions is not allowed.

Baseline estimated irrigation revenue is $2501 million per year. Scenario 1 results show that if the environmental flows were taken from across the Basin on a pro-rata basis and interregional water trade were precluded, estimated irrigation net revenue would be $61 million per year (2.4 per cent) less than under baseline conditions. Comparison of scenario 2 and baseline results indicate that revenues are estimated to decrease to be only $34 million per year (1.4 per cent) when environmental flows are taken from selected low-value regions only. A key overall conclusion is that targeted acquisition of environmental flows in relatively low opportunity cost regions results in $27 million per year less forgone irrigation profit than untargeted environmental flow acquisition through equal proportional reductions in irrigation allocations in all regions.

Comparison of scenarios 3 and 4 results with the baseline result shows that estimated irrigation revenue gains from freeing water trade exceed estimated revenue losses from reallocating 500 GL from irrigation for environmental flows. In scenario 3, interregional trade is allowed, and 500 GL is reallocated from irrigation to environmental flows through equal proportional reductions in all regions. Net revenue is estimated to increase by $54 million from the base case level of $2501 million to the scenario 3 level of $2554 million. In scenario 4, when environmental water is acquired from low-value regions only and free interregional water trade is allowed, a net revenue increase of $56 million above the baseline level is estimated to result. These gains indicate that the benefit of targeting water acquisition is minimal when free water trade is allowed.

Estimated shadow prices of water for scenarios 1 and 2 for each state of nature are presented in Table 6. The shadow price for scenario 1 varies from $44 to $29/ML, and $43 to $24/ML in scenario 2. Counter intuitively, shadow prices of 90th and 70th percentile water allocation year are higher than the shadow prices estimated in the lower water allocation 50th and 30th percentile allocation states. This is because the quantity of water acquired for environmental flows in 90th and 70th percentile states is much higher than the quantity of water acquired for environmental flows in 50th and 30th percentile states. When a uniform allocation of 500 GL of environmental flows

Table 6 Weighted average shadow prices of water under five states of nature

Acquisition regime	10th percentile	30th percentile	50th percentile	70th percentile	90th percentile
Across the basin water acquisition ($/ML)	43.66	24.85	25.31	26.74	29.12
Low-value regions water acquisition ($/ML)	43.02	24.01	23.56	24.03	25.16

per year is modelled over all five states of water allocation, the shadow price declines with increasing water allocation as expected. The estimated shadow price in the 10th percentile water state is \$49/ML which reduces to \$23/ML in the 90th percentile water allocation year.

Values of water for irrigation estimated here are close to observations from actual water market transactions and the findings from previous studies. For example, the mean price of water traded on Murray Irrigation Limited's temporary water market (for the period 1998–2002) varied between \$15/ML and \$40/ML. Similarly, the implied rental value of water estimated by Brennan (2002) was \$25/ML. MDBC (2004) also estimated the annual cost of water for environmental flows to vary between \$40 and \$53/ML.

When environmental water is acquired on a pro-rata basis, the net revenue is estimated to increase from \$2440 million (scenario 1 – no interregional trade) to \$2554 million (scenario 3 – interregional trade), an increase of 4.7 per cent. When environmental water is acquired from low-value regions only, the net revenue increases from \$2467 million (scenario 2 – no interregional trade) to \$2556 million (scenario 4 – interregional trade), an increase of 3.6 per cent. These gains are close to the net annual gains from water traded of 4.6 per cent estimated by Hall *et al*. (1994). While on average these gains are small, the benefits of water trade would be large if there is a significant reduction in water allocations either due to severe drought or due to more demand for environmental flows. For example, when demand for environmental flows is 1000 GL, the net revenue increases from \$2366 million (scenario 2 – no interregional trade) to \$2512 million (scenario 4 – interregional trade), an increase of 1.5 per cent in benefits of water trade (i.e. from 4.7 per cent to 6.2 per cent).

The results above are for environmental water acquisition varying with the year – less in dry years and more in wet years. Acquiring a constant 500 GL/year is predicted to result in greater opportunity costs. For pro-rata acquisition of water with no interregional trade, predicted net revenue is \$2426 million for constant acquisition compared to \$2440 million for varying acquisition (scenario 1). For acquisition of water from low-value regions only, predicted net revenue is \$2463 million for constant acquisition compared to \$2467 million for varying acquisition (scenario 2). Thus, the opportunity costs are greater for constant acquisition of environmental flows. Importantly, the environmental outcomes of constant acquisition would also be poorer, since options for using environmental water are less in dry years than wet.

5.3 Water trading impact on salinity

Salinity externality impacts as a result of water trade are modelled by combining the estimated spatial reallocations of water with previously published research relating irrigation drainage to salinity impact. In the analysis, both positive and negative externalities are considered. Positive externalities result from reductions in water allocation to regions such as Goulburn and Broken. Here, less irrigation will lead to lower watertables, which in turn means less

Table 7 Estimated average change in water use by region relative to the base case

	Scenario 3		Scenario 4	
Region	Change in water use (ML)	Change in water use (%)	Change in water use (ML)	Change in water use (%)
Broken	–191 163	–0.29	–185 657	–0.28
Goulb	–347 762	–0.41	–340 784	–0.41
Campas	–6 358	–0.05	–5 231	–0.04
Loddon	–89 589	–0.11	–82 650	–0.1
Avoca	26 498	0.25	27 358	0.26
MRiver	341 234	0.4	341 234	0.4
Murrum	59 079	0.03	77 445	0.03
Mallee	129 773	0.37	103 588	0.3
LMurray	72 382	0.39	58 791	0.32

yield reduction from the impact of the salinity in the groundwater. Negative externality impacts result from more water for irrigation and hence more drainage in the Mallee and Lower Murray regions. Increased drainage leads to more saline groundwater intrusion into the river and consequently increases crop and infrastructure salinity damage.

Changes in volume of regional net water use relative to the base case are shown in Table 7. Six regions increase their irrigation water use while four regions decrease. The changes to water use are multiplied by the drainage fraction and the annual externality costs per ML calculated from Heaney *et al.* (2001) as discussed in Section 3.7 above. The results are shown in Tables 8 and 9.

The largest externality impacts estimated are salinity damage costs in the Lower Murray and Mallee regions which are net demanders of water. Positive external benefits from trade could be especially significant in the Goulburn–Broken catchments. In aggregate, the negative impacts of salinity in net demand regions are estimated to outweigh the positive salinity impacts resulting from net trade out of other regions.

Overall, externality impacts of water trade are estimated to be quite modest in comparison to the value of direct revenue benefits of trade. Table 9 results indicate that estimated net salinity externality costs are in the order of \$1 million per year. In contrast, comparison of scenarios 1 and 3 results indicate that direct net revenue impacts of allowing trade are around \$114 million per annum. Gains to trade estimated through comparison of scenario 2 with scenario 4 are \$89 million.

6. Conclusions

This study used an optimisation modelling framework to estimate the cost of sourcing environmental flows from irrigation in the River Murray Basin. The optimisation model was used to evaluate alternative policy options for water trade and environmental flows acquisition.

Table 8 Estimated salinity externality costs and benefits resulting from interregional water trade ($'000/year)

Region	100 years NPV for 10 000 ML drainage†	Scenario 3		Scenario 4	
		Net trade (1000 ML)	Cost or benefit‡	Net trade (1000 ML)	Cost or benefit‡
Goulburn-broken	130	–539	53	–526	51
Campaspe	811	–63	38	–52	32
Murray	113	341	–29	341	–29
Loddon a	2 868	–45	97	–42	89
Loddon b	333	–45	11	–42	10
Murrumbidgee	13	59	–1	77	–1
Lower Murray	7 192	72	–388	59	–318
Mallee	10 102	129	–977	103	–780
Total salinity benefit of water traded out			199		183
Total salinity cost of water traded in			–1395		–1128
Net downstream salinity cost			–1196		–946

Source: the numbers in the column (†) are obtained by adding the external agricultural benefits and benefits downstream of Morgan given in table 2 of Heaney *et al*. (2001).

Notes: ‡Water trading results either in cost or benefit. Costs are indicated by negative values while benefits are indicated by positive values.

Table 9 Estimated salinity local cost or benefit within region of interregional water trade ($'000/year)

Region	100 years NPV for 10 000 ML drainage†	Scenario 3		Scenario 4	
		Net trade (1000 ML)	Cost or benefit‡	Net trade (1000 ML)	Cost or benefit‡
Goulburn-broken	1980	–539	800	–526	781
Campaspe	811	–63	38	–52	32
Murray	1437	341	–368	341	–368
Loddon a	1012	–45	34	–41.5	31
Loddon b	457	–45	15	–41.5	14
Murrumbidgee	74	59	–3	77	–4
Lower Murray	0	72	0	59	0
Mallee	0	129	0	103	0
Total salinity benefit of water traded out			888		858
Total salinity cost of water traded in			–371		372
Net within region salinity cost			518		487

Source: the numbers in the column (†) are the internal benefits given in table 2 of Heaney *et al.* (2001).

Notes: ‡Water trading results either in cost or benefit. Costs are indicated by negative values while benefits are indicated by positive values.

We conclude that irrigation net revenue would be expected to decline if water for the environmental flows were acquired through reductions in irrigation water allocations and free trade between regions were not allowed. When environmental flows are taken from across the Basin on a pro-rata basis and no interregional water trade is allowed, a net irrigation revenue decrease of $61 million per year (2.4 per cent) is estimated to result. If the water is taken only from selected low-value regions, the cost is estimated to be less (only $34 million per year). Thus, in the no-trade scenario, a further conclusion is that spatially targeted water acquisition for environmental flows from low opportunity cost regions can substantially reduce costs of acquiring environmental flows.

The model accounts for the effects of stochastic weather on market water demand, supply and requirements for environmental flows. Net irrigation revenue is estimated to be $75 million less than the baseline level for a scenario involving reallocating a constant volume of water for the environment in both wet and dry years. For a more realistic scenario involving more water for the environment in wet and less in dry years, estimated net revenue loss is reduced by $14 million.

Another key finding is that potential revenue gains to the irrigated agricultural sector as a whole resulting from free water trade are large enough to offset the revenue losses expected from reallocating 500 GL of irrigation water to the environment. For a scenario involving interregional trade and water taken from all the regions across the Basin, net revenue is estimated to be $54 million (2 per cent) greater than baseline levels. Slightly greater gains ($56 million) are estimated to result when environmental water is acquired from low-value regions only. Thus, when free trade is allowed, there is minimal gain from targeting water acquisition.

Accounting for external salinity costs does not change any of the major conclusions of the analysis regarding the net benefits of environmental water acquisition and water trade policy in the Basin. Positive external benefits are estimated as a result of water trade in net supply regions where reduced irrigation is expected to result in water table level declines and consequent improvement in yields. However, these benefits are expected to be outweighed by negative salinity externality impacts in net demand regions. The net externality impacts are estimated at around $1 million per annum which is small relative to the aggregate financial gains from moving to free-trade in water.

References

ABARE (2003). *ABARE Farm Survey Report 2002–2003*. Australian Bureau of Agricultural and Resource Economics, Canberra.

Appels, D., Douglas, R. and Dwyer, G. (2004). *Responsiveness of Demand for Irrigation Water: A Focus on the Southern Murray–Darling Basin*. Productivity Commission Staff Working Paper, Melbourne, Australia.

Bell, R. and Heaney, A. (2001). *A Basin Scale Model for Assessing Salinity Management Options: Model Documentation*. ABARE Technical working paper 2000.1, Canberra.

Bjornland, H. (2004). Formal and informal water markets: drivers of sustainable rural communities? *Water Resources Research* 40, 1–12.

Blackmore, D. and Connell, D. (1997). Are rural land practices in the Murray–Darling Basin a threat to the environment? *Australian Journal of Soil Research* 35, 995–1036.

Brennan, D. (2002). *Report on Peer Review of SALSA Model*. Reap Research, Perth.

Brennan, D. (2006). Water policy reform in Australia: lessons from the Victorian seasonal water market, *Australian Journal of Agricultural and Resource Economics* 50, 403–424.

Brooke, A., Kendrick, D., Meeraus, A. and Raman, R. (2004). *GAMS: A User's Guide*. GAMS Development Corporation, Washington, DC.

Bryan, B.A. and Marvanek, S. (2004). *Quantifying and Valuing Land-Use Change for ICM Evaluation in the Murray–Darling Basin 1996/97–2000/01*, CSIRO Land and Water Stage 2 Report. Murray–Darling Basin Commission, Canberra.

CIE (Centre for International Economics) (2004). *Implications of Water Reforms for the National Economy*. Centre for International Economics, Canberra.

Council of Australian Governments (COAG) (2003). *Intergovernmental Agreement on a National Water Initiative*. Council of Australian Governments, Canberra.

Council of Australian Governments (COAG) (2004). *Intergovernmental Agreement on a National Water Initiative*. Council of Australian Governments, Canberra.

Cooperative Research Centre for Freshwater Ecology (CRCFE) (2003). *Ecological Assessment of Environmental Flow Reference Points for the River Murray System*. Interim report prepared by the Scientific Reference panel for the Murray–Darling Basin Commission, Living Murray Initiative, Canberra University, Canberra.

Doorenbos, J. and Kassam, A.H. (1979). *Yield Response to Water*: *FAO Irrigation and Drainage Paper 33*. Food and Agriculture Organisation, Rome.

Eigenraam, M., Crean, J., Wimalasuriya, R. and Jayasuriya, R. (2003). *Economic Analysis of Environmental Flow Scenarios in the Murray River System, Stage 1. Final Report prepared for SERP 'The Living Murray'*. Economics and Policy Research Branch Publications, Department of Primary Industries, Victoria.

de Fraiture C., and Perry, C. (2002). Why is irrigation water demand irresponsive at low price ranges? *World Bank Water Conference*, Agadir, Moroco.

Gippel, C.J., Jacobs, T. and McLeod, T. (2002). Determining environmental flow needs and scenarios for the River Murray System, Australia, *Australian Journal of Water Resources* 5, 61–74.

Hall, N., Poulter, D. and Curtotti, R. (1994). *ABARE Model of Irrigation Farming in the Southern Murray–Darling Basin*. ABARE Research Report 94.4. Australian Bureau of Agriculture and Resource Economics, Canberra.

Heaney, A., Beare, S. and Bell, R. (2001). *Targeting Land and Water Use Options for Salinity Management in the Murray–Darling Basin*. ABARE report to the Murray–Darling Basin Commission, Canberra.

Heaney, A., Thorpe, S., Klijn, N., Beare, S. and Want, S. (2004). Water charges and interregional trade in the southern Murray–Darling Basin. *Establishing Australian Water Markets Symposium*. Institute of Public Affairs, Melbourne.

Jayasuriya, R.T. (2004). Modelling the regional and farm-level economic impacts of environmental flows for regulated rivers in NSW, Australia. *Agricultural Water Management* 66, 77–91.

Jayasuriya, R.T. and Crean, J. (2000). *The Agricultural Impacts of Environmental Flow Rules in the Murrumbidgee Valley*. NSW Agriculture, Orange, Australia.

McCarl, B.A., Dillon, C.R., Keplinger, K.E. and Williams, R.L. (1999). Limiting pumping from the Edwards Aquifer: an economic investigation of proposals, water markets, and spring flow guarantees, *Water Resources Research* 35, 1257–1268.

Murray–Darling Basin Commission (MDBC) (2001). *Integrated Catchment Management in the Murray–Darling Basin 2001–10: Delivering a Sustainable Future*. Murray–Darling Basin Commission, Canberra.

Murray–Darling Basin Commission (MDBC) (2004). *The Living Murray: Scoping of Economic Issues in the Living Murray, with an Emphasis on the Irrigation Sector*. Murray–Darling Basin Commission, Canberra.

Murray–Darling Basin Ministerial Commission (MDBMC) (2000). *The Salinity Audit of the Murray–Darling Basin: a 100-year Perspective, 1999*. The Murray–Darling Basin Ministerial Commission, Canberra.

Murray–Darling Basin Ministerial Commission (MDBMC) (2002). *The Living Murray: a Discussion Paper on Restoring the Health of the River Murray*. Murray–Darling Ministerial Commission, Canberra.

Murray–Darling Basin Ministerial Commission (MDBMC) (2003). *Communiqué on the First Step Decision of the Living Murray*. Murray–Darling Basin Ministerial Council, Canberra.

Quiggin, J. (1988). Murray river salinity: an illustrative model, *American Journal of Agricultural Economics* 70, 635–645.

Quiggin, J. (1991). Salinity mitigation in the Murray River system, *Review of Marketing and Agricultural Economics* 59, 53–65.

Qureshi, M.E., Proctor, W.L. and Kirby, M. (2006). *Economic assessment of water trade restrictions in the Murray–Darling Basin*. Available from URL: http://www.ecomod.org/files/papers/990.pdf [accessed Dec 2006].

Rosegrant, M.W., Ringler, C., McKinney, D.C., Cai, X., Keller, A. and Donoso, G. (2000). Integrated economic-hydrologic water modelling at the basin scale: the Maipo river basin. *Agricultural Economics* 24, 33–46.

URS (2005). *Salinity Impact of Water Trade, Review of Water Trade in the Riverine Plains*. Prepared for Murray–Darling Basin Commission, Canberra.

Young, M., Young, D., Hamilton, A. and Bright, M. (2002). *A Preliminary Assessment of the Economic and Social Implications of Environmental Flow Scenarios for the River Murray*. CSIRO Land and Water, Adelaide.