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Capturing benefits from the removal of impediments to water trade

A modeling framework

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That there can be substantial economic benefits from trade in water entitlements is widely recognised. However, there are numerous impediments to trade that inhibit the realisation of these potential benefits. Their identification and removal is particularly important if the introduction of environmental flows results in greater use of water markets for redistribution of irrigation water.

The model developed in this paper provides an integrated framework in which both the impact of impediments to water trade and the salinity impacts of trade can be assessed for the southern Murray Darling Basin. The initial application of the model to major irrigation areas within river valleys will provide an indication of the broad scale annualised costs to irrigators of existing restrictions on inter valley, inter state and to some extent, intra valley, water trade.

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Introduction

Trade in water entitlements has been a feature of irrigated agriculture in parts of Australia for several decades. The combination of capped river diversions, environmental flow requirements and increasing water demand from new developments has increased the interest in markets to reallocate scarce water resources. That there can be substantial economic benefits from trade in water entitlements is widely recognised. Unrestricted trade in water entitlements has been estimated to potentially increase the total gross margin to irrigators by around 5 per cent a year[1] in the southern Murray Darling Basin (Hall, Poulter and Curtotti 1994). However, there are numerous impediments to trade that inhibit the realisation of these potential benefits. Their identification and removal is critical if environmental flows are to be obtained via water markets at least cost.

In this paper, the key impediments to trade will be outlined and a framework established to enable an examination of the cost of these impediments to irrigators in the southern Murray Darling Basin. Once the costs of the impediments are estimated, it may be apparent where attention should be focussed in order to increase the benefits from water trade.

Current trading situation in the southern MDB

Water trade in Australia is concentrated in the southern region of New South Wales (Murray, Murrumbidgee and lower Darling) and north and eastern Victoria (Victorian Murray and the Goulburn), which are the main centres for irrigation (figure 1). Of the 11000 GL diverted for irrigation in the MDB in 1998-99, the southern MDB receives about 8500 GL or 80 per cent. Of this 8500 GL diverted, around 540 GL or 6 per cent was traded on a temporary and permanent basis (figure 2). Temporary trade is the transfer between parties of the annual water share associated with an entitlement to irrigation water. The transfer is usually for a defined period of between one and five irrigation seasons. Permanent trade, on the other hand, is the permanent transfer of an entitlement to irrigation water.

The bulk of trade (98 per cent) occurs within local regions or valleys. The most significant inter valley trade is temporary trade from the Murrumbidgee to the Lower Darling and NSW Murray, and from the Goulburn to the Victorian Murray. These movements in part reflect the expansion in viticulture in recent years (Shepherd 1998). Trade is likely to become more widespread in the future with increased demand for water, particularly water for the environment.

[1] That is, around $50 million a year in 1991-92 dollars.

Figure 1: The southern Murray Darling Basin water distribution network

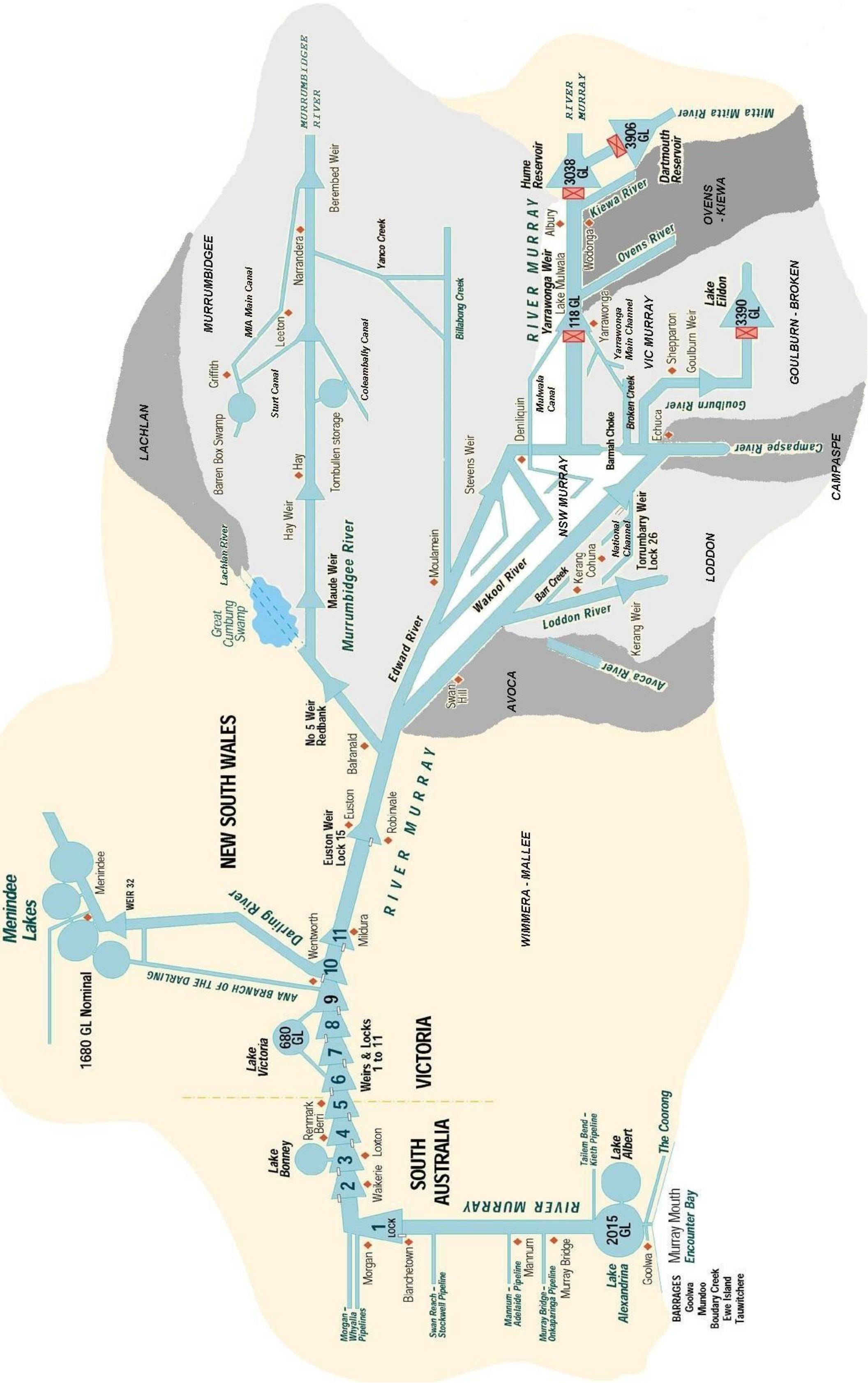
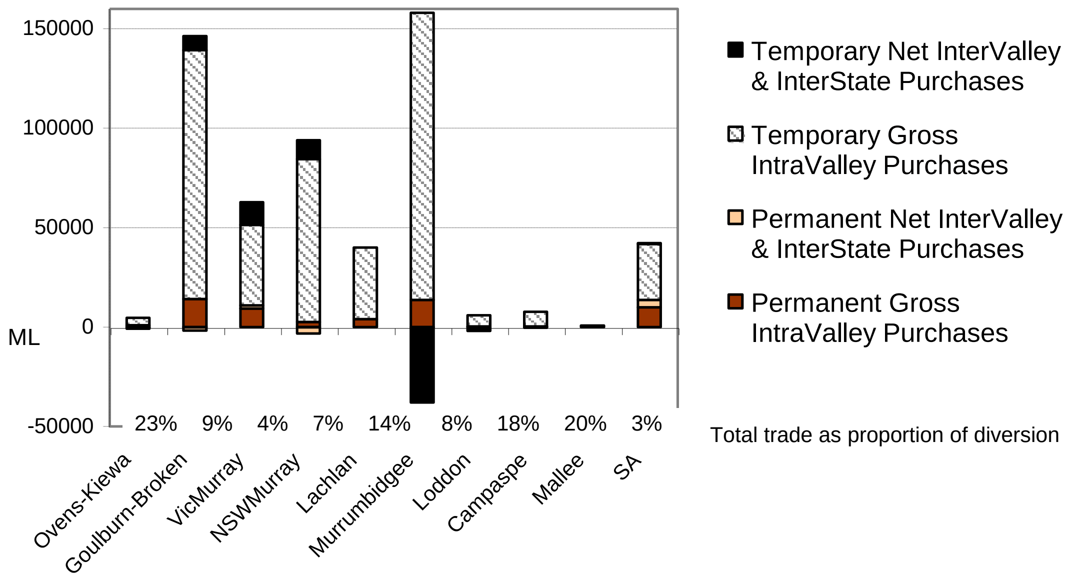


Figure 2: Water trade in the southern Murray Darling Basin



Benefits of a water market

In simplistic terms, trade in water entitlements will result in water shifting toward those uses in which it yields the highest marginal return, net of transfer costs. Comparatively high marginal returns in an area may reflect for example, relatively high prices for production, or an absence of problems such as high saline water tables, unreliable water supply, reduced water quality or soil degradation which reduce the productivity of inputs to production. Fitzpatrick (2001) and Bjornlund and McKay (1995) suggest that water markets have already enabled water to move out of highly saline mixed farming areas in Kerang and Pyramid Hill and into higher value producing areas, such as dairy farming.

Further benefits from trade may be obtained through increased incentives for greater water use efficiency as irrigators are able to sell water that they do not use. For example, Kemp and Hafi (2001) note that in the Murrumbidgee Irrigation Area, there is significant potential for on-farm water savings, with total surface runoff and groundwater seepage from the Mirool and Yanco Irrigation Areas averaging around 131GL per year, or 5 per cent of total MIA diversions. Irrigation in these areas contributes 71 per cent of total surface runoff from large area farms and 82 per cent from horticultural farms.

A further significant benefit of a water market is the framework it provides to redistribute water between competing uses when there is a significant change in the quantity of water demanded or supplied. The most significant increase in demand in recent years has come from an expansion of vineyards in South Australia, Victoria and New South Wales (Shepherd 1998). The anticipated high profit margins allowed grape growers to outbid most other irrigation activities in the water market.

Environmental flows are likely to be a significant new demand for water in the near future. Under COAG, all jurisdictions are required to give priority to determining allocations or entitlements to water, including allocations to the environment as a user of water. As water in most river systems across the MDB is fully committed and has an opportunity cost, choices will have to be made as to which catchments source environmental flows (McClintock and Topp 2000).[2] If the demands of the environment to water is ascertained to be a competitive right that allows tradeoffs among economic, social and environmental objectives, then to the extent that these tradeoffs are reflected in the price which society is willing to pay for environmental flows, a water market may lead to an efficient allocation of water between the environment and irrigators.

Regardless of whether water markets are utilised to source environmental flows, the creation of environmental demand will reduce the availability of water for irrigation and the required adjustment can be facilitated by a greater use of water markets to redistribute remaining irrigation water.

Capturing the benefits from trade

The extent to which the potential benefits of trade can be realised by those trading will hinge on a number of factors. These factors include the definitional scope of entitlements to water, administrative restrictions on who may trade and with whom; timeliness of trade execution and delivery; physical constraints imposed by the capacity of delivery infrastructure such as channels and pumps; proliferation of market information and extent of bargaining power held by market participants.

Definitional scope of water entitlements

In order for trade to maximise the net benefits of water use, water entitlements would need to be defined such that the full costs and benefits of all water use could be assigned to a water entitlement holder. That is, every unit of water, at each point in the storage, delivery and hydrological system where it has value, would need to be under entitlement. However, the common pool nature of water within the storage systems and delivery channels and the diffuse and uncertain nature of impacts associated with water

[2] See Siebert, Young and Young (2001) for a discussion of the administrative arrangements necessary in order for environmental flows to be tradable.

use means that water entitlements are unlikely to ever be defined in terms of full costs and benefits of water use (Bell and Beare 2000).

The current system of water rights limits participation in water markets, particularly by those who do not hold an existing licence, by landholders on unregulated streams, and by those with riparian rights. In Victoria, irrigation water can only be transferred between those who own land that can be irrigated. In New South Wales, water use is tied to land but ownership of water shares is not. This introduces the potential for speculation in water rights.

In regulated systems, a central irrigation trust or company own water entitlements and receive a bulk entitlement. Bulk entitlements provide authorities with water to meet water rights held by irrigators in their district plus losses incurred by the authority in distributing water from the source to clients. Once a trade has occurred, the bulk entitlement for the authority is amended to reflect the change in volume and irrigators generally retain any internalised benefits associated with trade. In some regions, such as the West Corugan Private Irrigation District, individual irrigators simply receive a share of the company bulk entitlement and have no incentive to undertake permanent inter-valley trade, in particular, even if it is not restricted, because any profits from such a trade are distributed between all shareholders.

Irrigation companies are legally obligated to maximise benefits to irrigators (shareholders) within their own region. When there exists external impacts associated with water trade or trade out of the valley, this obligation may not be consistent with maximising the net benefits from trade realised over all regions.

Use of water for irrigation for example, can have external impacts on both the volume and quality of water available to downstream users and the riverine environment more generally (Murray Darling Basin Commission 1999). Water associated with an irrigation diversion that returns to the hydrological system as surface runoff from flood irrigation, irrigation drainage, channel seepage or ground water discharge from irrigation areas is called a return flow. Irrigators presently hold an implicit right to return flows in that they can trade water entitlements without consideration of downstream externalities (Beare and Heaney 2001). Not explicitly including rights to return flows within the scope of water entitlements may result in an allocation of water, after trade, that costs society more than it gains (Bell 2001).

The existence of substantial evaporative losses may further reduce the benefits of trade, if these losses are not linked to entitlements to water and thus are not reflected in the cost of traded water. There may be large evaporative losses in transporting water through open channels to farms near the end of an irrigation system compared with delivery to farms close to water storages. There may also be significant quantities of water used but not accurately measured. If differences in delivery costs between farms are not taken into account when trading water entitlements then trade does not lead to an efficient allocation of water (Hafi, Klijn and Kemp 2001). Conveyance losses in the diversion of water to irrigation areas in northern Victoria have been estimated to be as high as 27 per cent (Fitzpatrick 2001).

Administrative restrictions on trade

Many irrigation authorities impose restrictions on interregional trade in water entitlements. The reasons for administrative restrictions vary between regions. Western Murray Irrigation for example, prohibits permanent trade out because they view surplus water as an incentive to encourage new investors into the region (Western Murray Irrigation 2002). Goulburn-Murray Water restrict trade out on the basis of the potential for external third party impacts and some concern over stranded assets (Goulburn-Murray Water 2002). First Mildura Irrigation Trust prohibits transfers from low salinity impact zones to high salinity impact zones on either a temporary or permanent basis.

While some broad restrictions may increase the benefits realised from trade – for example, if out of scheme trade exacerbated environmental problems such as salinity or led to higher conveyance losses – it appears that many of these restrictions have been imposed to simply retain water within an irrigation system. Goesch (2001) suggests that some irrigation authorities may impose restrictions to protect against the prospect of stranded assets, to maintain the economic viability of the region in which they operate, or because of expectations by some irrigation authorities of higher water prices in the future. Each of these possible reasons for trade impediments indicates that the traded price of water is not high enough to cover external costs associated with trade and consequently, the full potential benefits of trade will not be realised.

At a state level, water authorities in Victoria can refuse permanent out of area transfers if annual net transfers out of an area exceed 2 per cent of water rights in that area. Further, Victoria has banned inter state temporary trade following the end of the irrigation season, in response to differences between states in carry over provisions and in who is allowed to own water rights (National Competition Council 2001). This measure is designed to prevent temporary transfers of unused water from Victoria to New South Wales at a low cost late in the irrigation season. Such a transfer may reduce water available in Victoria in the following season or result in the water being reintroduced at higher prices by speculators during the peak demand period of the following season.

In New South Wales, there exists state wide water transfer principles from which water management committees determine local trading rules (Cleary 2001). The most significant administrative restrictions on trade are listed in appendix table 1.

Timeliness of trade execution and delivery

As with any input to production, time delays between when the input is needed to maximise the benefits of its use and when it is received have the potential to reduce its value in production. While it is possible to order water in advance of when it is needed for irrigation, uncertain weather conditions may make this a costly option. The speed of processing for temporary trades has the potential to increase substantially with separation of water use approval from water extraction in New South Wales and the establishment of online water exchanges in Victoria. However, long delays in the execution of permanent trades still occur due to the need for environmental assessment of the impact of trades. Partly reflecting this, there has been a trend in recent years toward 'temporary' trades for water for periods in excess of a single irrigation season, sometimes up to five years (Marsden Jacobs Associates 1999).

Infrastructure constraints

Even with increased speed of trade processing in recent years, there remains some uncertainty as to the timing of water delivery, particularly in the peak of the irrigation season. Beare and Bell (1998) demonstrate that the full potential benefits of trade are unlikely to be achievable when the value of water use varies throughout the irrigation season and the timing of delivery is constrained by the capacity of the delivery system.

Infrastructures that may limit the extent to which trade can redistribute water along the Murray River are detailed in appendix table 2. The most significant constraints (from a water system management perspective) on the Murray River are those imposed by the Barmah Choke and the stretch of river between Hume Dam and Yarrawonga Weir (figure 1).

Relative bargaining power

It is evident that there is often substantial price dispersion within markets at any time (Marsden Jacob Associates 1999). This dispersion may reflect, for example, rapid changes in the marginal value of water, or may be due to differences in the relative bargaining power of market participants. There is considerable scope for differences in bargaining power, as bilateral trades handled directly by irrigators comprise the bulk of temporary water trade. However, a lack of competition in a water market is not necessarily detrimental to maximising benefits from water trade. Bell (2001) notes that in the presence of externalities such as salinity and asymmetric information between market participants, a competitive market is unlikely to generate maximum benefits from trade.

Nevertheless, the thinness of markets for permanent trades in particular has been seen as a cause for the exploitation of sellers by opportunistic buyers (Marsden Jacob

Associates 1999). Formal markets or water exchanges have emerged in many parts of the southern Murray Darling Basin (Chandler 2000; Marsden Jacob Associates 1999).[3] These water exchanges bring buyers and sellers together on a regular basis, provide information on traded prices and thereby reduce the extent of potential asymmetry in bargaining power between market participants.

Model framework

A modelling framework was developed in which to examine the key constraints facing water trade. Each river valley in the southern Murray Darling Basin (figure 1) is subdivided into a number of irrigating and dryland regions. For each of these regions, economic models for land use are integrated with a representation of the hydrological processes.

Each region and river valley is linked through surface and ground water flows and through trade in a common water market. In the agroeconomic component of the model, agricultural land is allocated within each river valley to maximise economic return from the use of land and irrigation water. Land use can shift between activities with changes in both the availability and quality of land and water resources. With water trade between river valleys, water use can shift, subject to physical and administrative constraints, between valleys in response to differences in economic returns associated with water use.

The model is developed using the Extend™ simulation engine (Imagine That Inc 2000). In each simulated year, the first step in the simulation is to derive demand curves for surface water. The water market is then resolved, with each irrigating region receiving notification of the quantity of water available for use in production, and the traded price of that water. The final step in the simulation is the sequential allocation of land within each catchment and subsequent determination of surface runoff and discharge into the groundwater system.

Bell and Klijn (2000), Bell and Heaney (2000) and Beare and Heaney (2001) describe the basic economic and hydrological components of the model in the absence of water trade. The water trade component is detailed below.

[3] For example, the Southern Riverina Water Exchange was established in 1997 to service irrigators in the Murray district, and the Northern Victoria Water Exchange was formed in 1998 for trade by irrigators in the Goulburn-Murray and Sunraysia regions. The Murrumbidgee Irrigation Area Council of Horticultural Associations is also involved in trade of high security water in the southern horticultural sector. By April 2002, it is expected that a state wide water exchange, Watermove, will be operational in Victoria.

Agroeconomic component

The problem considered is that of maximising the economic return from the use of agricultural land by choosing between alternative steady state land use activities in each year. Five possible land use activities (j) are considered on land suitable for agriculture: irrigated crops; irrigated pasture; irrigated horticulture; dryland crops; and dryland pasture. Each region is assumed to allocate its available land each year between these activities to maximise the net return from the use of the land in production, subject to constraints on the overall availability of irrigation water from rivers sw^* (administrative allocation plus available return flow) and from groundwater sources gw^* and suitable land L^*. That is, for each year (omitting time subscripts),

(1) $$\max \sum_j \frac{p_j}{r} x_j(L_j, sw_j, gw_j) - \frac{csw}{r} \sum_j sw_j - \frac{cgw}{r} \sum_j gw_j$$

subject to

(2) $$\sum_j sw_j \le sw^*, \quad \sum_j gw_j \le gw^* \quad and \quad \sum_j L_j \le L^*$$

where x_j is output of activity j, L_j is land used in activity j, sw_j is surface water and gw_j is groundwater used for irrigation of activity j, r is a discount rate, csw is the unit cost of surface water for irrigation and cgw is the unit cost of groundwater for irrigation. The net return to output for each activity is given by p_j and is defined as the revenue from output less the cost of inputs, other than land and water, per unit of output.

For each activity, the volume of output depends on land and water use (or on a subset of these inputs) according to a Cobb-Douglas production function

(3) $$x_j = \begin{cases} A_j L_j^{\alpha_{Lj}} sw_j^{\alpha_{swj}(t)} gw_j^{\alpha_{gwj}(t)} & 0 < \alpha_{Lj} + \alpha_{swj} + \alpha_{gwj} < 1 \quad for\ j = 1,2,3 \\ A_j L_j^{\alpha_{Lj}} & 0 < \alpha_{Lj} < 1 \quad for\ j = 4,5 \end{cases}$$

where A_j, α_{Lj}, α_{swj} and α_{gwj} are technical coefficients in the production function. For simplicity, time subscripts have been omitted from this component of the model description. However, the technical coefficients α_{Lj}, α_{swj} and α_{gwj} are time dependent as they are affected by both irrigation and dryland salinity. The costs to irrigated agriculture and horticulture resulting from yield reductions caused by increased river salinity are modeled explicitly. The impact of salinity on the productivity of plants is assumed to occur by the extraction by plants of saline water from the soil. The electroconductivity (EC) of the soil reflects the concentration of salt in the soil water and reduces the level of output per unit of land input and per unit of water input. This is represented by modifying the technical coefficients α_{ij} in the production function for each activity from the level of those coefficients in the absence of salinity impacts α_{ij}^{max}, for *i=L, sw, gw*. That is,

(4) $$\alpha_{swj}(t) = \frac{\alpha_{swj}^{\max}}{1 + \exp\left(\mu_{oj} + \mu_{1j} EC(t)\right)}$$

where μ_0 and μ_1 are productivity impact coefficients determined for each activity.

The data required to calibrate the model are extensive and the procedure is detailed in Bell and Heaney (2000) and Beare and Heaney (2001). Land use and irrigation data were obtained from a wide range of sources, including ABARE farm survey data and regional water authorities such as Goulburn-Murray Water and SA Water.

Hydrology component

There are two parts to the hydrology component of the model. The first part is the distribution of precipitation and irrigation water in each subcatchment between surface runoff, evapotranspiration and groundwater recharge. Evapotranspiration is determined as a function of precipitation, ground cover, irrigation application rates and efficiency. Annual water application rates in the southern Murray Darling Basin are around 10 megalitres per hectare for horticulture, whereas annual average application rates for pasture are 4 to 6 megalitres per hectare (Gordon, Kemp and Mues 2000). The excess of precipitation and irrigation water over evapotranspiration is split between surface water runoff and ground water recharge using a constant proportion (recharge fraction) for the principal soil type and terrain in the river valley. Irrigation areas are generally located in flat terrain and have relatively high recharge fractions. On heavier soils in the upland river catchments, recharge fractions are assumed to range from 50 to 60 per cent. On the sandier soils in the South Australian Riverland, recharge fractions are 100 per cent. Historical flows and salt loads were obtained from Jolly et al. (1997).

The second part of the hydrology component is the determination of groundwater discharge. The equilibrium response time of a groundwater flow system is the time it takes for a change in the rate of recharge to be fully reflected in a change in the rate of discharge. The total discharge rate each year is a function of a moving average of recharge rates in the current and earlier years, as detailed in Dawes et al. (2001). The moving average formulation allows the accumulated impacts of past land use change to be incorporated as well as to model prospective changes.

As the distance from the river increases, the time before a change in the level of recharge is fully reflected in the level of ground water discharge increases substantially.

Irrigation areas in western Victoria and the South Australian Riverland were divided into three land use bands according to distance from the river, as described in Beare and Heaney (2001).

Water trade component

The introduction of water trade into the above framework enables irrigators in each river valley to profit from higher or lower demand for irrigation water, in response to changes in water quality and productivity, water use efficiency, or increased demand for environmental flows. For example, in areas where the application of irrigation water to saline soils significantly reduces productivity, irrigators may increase their net returns by the sale of their water allocation and a switch toward salt tolerant crops.

For the purposes of the model, it is assumed that irrigators can only trade with their annual surface water allocation. The use of both ground water and return flows for irrigation reduces overall demand for surface water, but are not tradable. In the modelling framework, return flows are specifically calculated as a flow between land use units within a river valley. Return flows into each subcatchment are determined from surface runoff and groundwater discharge from upstream subcatchments into the surface water. While a proportion of return flows are assumed to augment the surface water available for irrigation, diversions for irrigation remain capped at regulated levels. Expected return flows are assumed to reduce the demand for water above allocation, but subcatchments do not have a right to return flows that can be sold in a water market. Hence, an increase in surface water runoff from the upper part of a river valley due to the introduction of less water intensive land use activities may reduce demand for water above allocation downstream in the valley, but this additional runoff cannot be sold in the water market by the downstream irrigators.

To determine trade within and between river valleys, a demand curve for surface water, in excess of the surface water allocation, is constructed at the start of each irrigation season for each sub-valley agricultural unit. From equation (1) to (3), this requires equilibrating the opportunity cost of surface water λ to the expected marginal return from surface water use, based on the productivity of water in the previous season. That is,

(5) $$\lambda = \frac{\alpha_{swj} p_j}{sw_j r} x_j - \frac{csw}{r}$$

Over a range of values for λ, demand for surface water q^D in each region *m*, is determined from (2), (3) and (5) as

(6) $$q_m^D = \sum_j sw_j = \sum_j \left(\frac{r\lambda + csw}{p_j \alpha_{swj} A_j L_j^{\alpha_{Lj}} gw_j^{\alpha_{gwj}}} \right)^{\frac{1}{\alpha_{swj} - 1}}$$

Initial demand for surface water in each region is simply the region's allocation plus any surface runoff. Over a range of plausible values for demand (from 70 per cent of initial surface water use to 170 per cent of use), a linear approximation to the nonlinear demand function in (6) is used, evaluated at the land areas, groundwater and input productivity values of the previous season.

Following Takayama and Judge (1971), when supply of water is fixed independent of price, a concave quasi-welfare function for each region is given by the area under the demand curve for water from the initial no-trade level of surface water use to the level of surface water use after trade. That is,

(7) $$W_m = \int_{\hat{q}_m{}^D}^{\bar{q}_m{}^D} \left(a_m - b_m q_m^D\right) dq_m^D$$

where $\bar{q}_m^D$ is the initial no-trade level of surface water use, $\hat{q}_m^D$ is the post-trade level of surface water use, and *a* and *b* are parameters in the linear approximation to the demand curve (6).

Welfare is assumed to be additive over all regions and there are assumed to be transfer costs t_{nm} associated with the quantity of water q_{nm} moved from region *n* to region *m*, and evaporative and seepage losses which results in a conveyance efficiency rate η_{nm} for delivery infrastructure of less than one. A competitive market is simulated as the solution to maximising the sum over all regions of welfares net of transfer costs between regions, subject to water balance constraints and constraints on water transfer between regions. That is,

(8) $$\max \ W = \sum_m W_m - \sum_m \sum_n t_{mn} q_{mn}$$

subject to

(i) the quantity of water demanded in each region does not exceed supply into that region from allocation q^{alloc}, expected accessible return flows q^{return}, and net trade

(9) $$q_m^D \leq q_m^{alloc} + q_m^{return} + \sum_{n,n \neq m} \eta_{nm} q_{nm} - \sum_{n,n \neq m} q_{mn} \qquad for \ 0 \leq \eta_{nm} \leq 1$$

(ii) transfers between regions must meet channel capacity and administrative constraints (*K*)

(10) $$0 \leq q_{mn} \leq K_{mn} \ \ \forall m \neq n$$

From (8) and (9), if the quantity of water demanded within a region is less than supply from administrative allocation, accessible return flows and net trade inflow, then the cost of the flow constraint in (9) is zero. Similarly from (8) and (10), if water transferred from region m to region n is less than the constraint K_{mn}, then that particular channel capacity and administrative restriction imposes no cost on irrigators.

Inclusion of trade into the model defined by (1) to (4) has the effect of modifying the surface water constraint in (2) such that,

(11) $$sw_m^{\ *} = q_m^{\ alloc} + q_m^{\ return} + \sum_{n,n \neq m} \eta_{nm} q_{nm} - \sum_{n,n \neq m} q_{mn}$$

The maximisation of (8) subject to (9) and (10) is a standard quadratic programming problem with a competitive spatial equilibrium price and allocation solution. In a competitive market, expected marginal return from water use, net of transaction costs and conveyance losses, will be equilibrated (when it is efficient to trade) between those regions that are physically and administratively able to exchange water.

A two region example is described in figure 3, with the shaded areas representing the maximand in (8) and $D_m(q_m)$ representing a linear approximation to the demand curve (6) for region m. The price of water in region m should not exceed the price of water in region n, plus the transfer cost t_{nm} and any cost φ_{nm} of infrastructure and administrative impediments (shadow price for constraint equation 10), adjusted for transmission losses between m and n. That is,

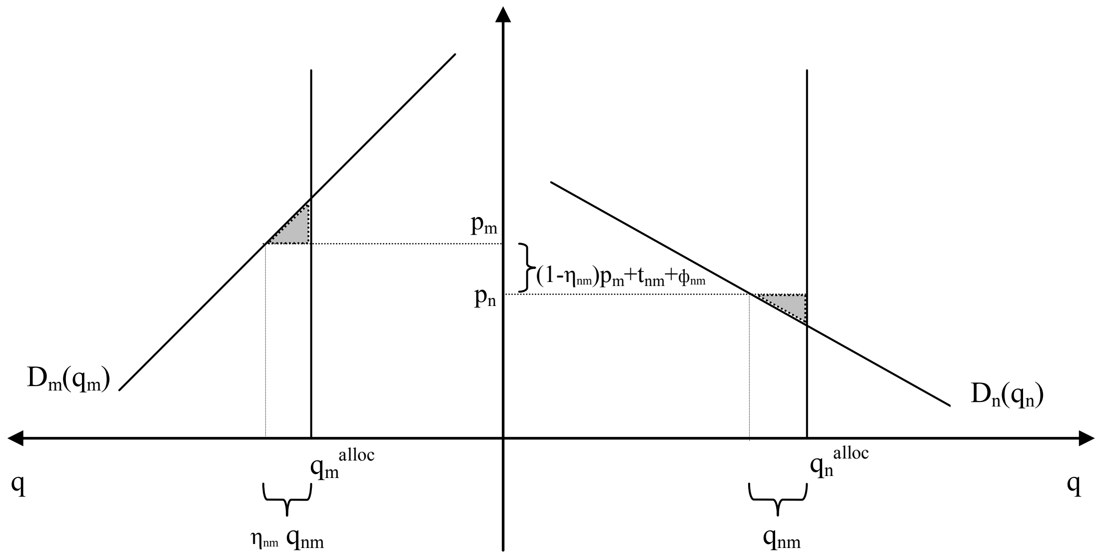
(12) $$p_m \leq \frac{p_n + t_{nm} + \varphi_{nm}}{\eta_{nm}}$$

and

(13) $$q_{nm}\left(p_m - \frac{p_n + t_{nm} + \varphi_{nm}}{\eta_{nm}} \right) = 0 \qquad for \ q_{nm} \geq 0$$

From (12) and (13), if there is no constraint on the quantity of water that can be transferred between two regions, then the purchase price of water to region m may be lower than when trade is restricted.

Figure 3: Trade resolution between two regions with impediments



Judge and Takayama (1975) provide a detailed description of spatial equilibrium models in water and other markets. A similar approach to that used in this paper was adopted by Eigenraam et al. (1996) to model water pricing in Victoria. However, Eigenraam et al. did not take into account the existence of return flows, nor the impact of salinity on demand for irrigation water. In the model described above, return flows are explicitly included in the water balance constraint (9) and in the surface water availability constraint for each subcatchment (11). Salinity impacts on surface water demand are captured by reducing the productivity of inputs to production, as in (4), and thereby reducing the marginal return from surface water use (5). It is important to note that any salinity impacts resulting from production decisions made upstream are not taken into account by those water users upstream who generate the impacts. The introduction of water trade may lead to a shift in water use away from areas most impacted by salinity, but does not result in an internalisation of the costs of salinity.

The water trade component of the model is calibrated using water transfer information from MDBC (2000a) and from regional water authorities, and the administrative and infrastructure capacity information detailed in appendix tables 1 and 2.

Model applications

The model will be utilised to examine the potential benefits and costs to agriculture of obtaining environmental flows via a water market. There are a raft of restrictions on trade which have the potential to limit the benefits associated with trade, and these will be examined in the model simulations. In particular, model simulations will focus on administrative regulations that restrict trade between river valleys and between states, as detailed earlier. In the context of the model framework, this can be simulated by specification of K_{mn} in constraint (10).

There is also potential to examine the impacts of water trade on river salinity in the southern Murray Darling Basin. If the external salinity impacts of water trade are significant, then trade may result in an allocation of water that costs society more than it gains from trade.

Young et al. (2000) hypothesise that interstate trading in particular, may have a negative impact on river salinity, with trade resulting in water transferred to South Australian land that has not been previously irrigated. Beare and Heaney (2001) analyse the salinity impacts associated with a shift in water use from the Goulburn Broken catchment into a number of alternative (higher value production) regions downstream on the Murray. They conclude that such a transfer would potentially reduce the amount of saline ground water discharge reaching the Murray River between the Goulburn Broken catchment and the downstream destination, but increase salt concentration downstream of the destination.

Concluding remarks

The model developed in this paper provides an integrated framework in which both the impact of restrictions on water trade and the salinity impacts of trade can be assessed. This will be particularly important if the introduction of environmental flows results in greater use of water markets for redistribution of irrigation water. The initial calibration of the model to major irrigation areas within river valleys will provide an indication of the broad scale annualised costs of existing restrictions on inter valley, inter state and to some extent, intra valley, water trade. Expansion of the framework to enable the simulation of trade on a more frequent basis may be developed in the future.

Acknowledgements

The authors acknowledge the assistance of Jonathan Newby in gathering the information on administrative arrangements governing trade.

Appendix 1

Table 1: Administrative restrictions on water trade

General

- Trading of water from above to below Barmah Choke is forbidden by both the NSW and Victorian governments.
- Transfers not permitted to or from the Murray and lower Darling upstream of Wentworth Weir pool.
- Transfers not permitted from the lower Murray or lower Darling to any unregulated streams.
- Transfers are permitted within the lower Murray River from the junction with the Murrumbidgee River to the SA border, and also to/from this section to the lower Darling within the influence of the Wentworth Weir pool.
- Permanent net transfers out of an irrigation area in Victoria can be refused if total transfers out exceed 2 per cent of water rights in that area in the year (to 30 June)
- Temporary transfers from Victoria to NSW are banned following the end of the irrigation season in Victoria.
- Maximum water traded from the Murrumbidgee to Murray systems is 100GL per season. No water is traded on permanent basis from the Murray to the Murrumbidgee systems. Trade from the Murray to the Murrumbidgee on a temporary basis is permitted from the start of the irrigation season in July/August until the end January each year.
- Water rights may be permanently transferred from the Murray system to the Goulburn system if the transfer does not result in there being a net transfer from the Murray to the Goulburn. Similarly for transfers from the Goulburn system to the Campaspe system.
- Under the Murray Darling cap, sales (water in excess of allocations which is available for sale) are not to exceed 30 per cent of water rights in gravity fed irrigation areas.
- Under the MDBC Pilot Interstate Trading Project, transfers between NSW, Victoria and SA are limited to high security water. Transfers out of SA are subject to a 10 per cent reduction factor to reflect the relative security of supply to SA.
- No permanent transfer of water towards the cone of depression (North Adelaide Plain) is permitted.

Western Murray Irrigation, NSW

- Western Murray Irrigation receives a bulk entitlement. Each irrigator within the area has a defined volume entitlement within the Irrigation Corporation.
- Trade into Irrigation Corporation is permissible
- Temporary trade out are permissible provided allocation volumes do not fall below a defined level for the Irrigation Corporation
- Transfers involving conversion between low and high security are not allowed
- Permanent trade out not permitted

Murray Irrigation Ltd, NSW

- Murray Irrigation Ltd receives a bulk entitlement. Each irrigator within the area has a defined volume entitlement within the Irrigation Corporation.
- Trade into Irrigation Corporation is permissible
- Temporary trade out are permissible provided allocation volumes do not fall below a defined level for the Irrigation Corporation

- Permanent trade out possible provided that the transfer does not reduce the basic entitlement of the Corporation below 1.4472 million ML.

Murrumbidgee Irrigation Area, NSW

- Murrumbidgee Irrigation Limited receives a bulk entitlement. Each irrigator within the area has a defined volume entitlement within the Irrigation Corporation.
- Transfers permitted within/between Murrumbidgee River, Tumut River and Yanco Creek system
- Transfers involving conversion from low to high security are allowed with reduction to 50 per cent of volume traded.
- Out of scheme permanent trade prohibited

Coleambally Irrigation Area, NSW

- Coleambally Irrigation receives a bulk entitlement. Each irrigator within the area has a defined volume entitlement within the Irrigation Corporation.
- Permanent trade is restricted by requirement to retain 4ML/ha on farm.
- If 100 per cent of the allocation is traded on a temporary basis, then an assessment of environmental factors must be undertaken every 3 years.
- If water available within the area is less than 632GL, then permanent trade is only permitted within the area. If water available exceeds 632GL, then permanent trade out is allowed up to the total quantity of water entering the area.

West Corugan Private Irrigation District, NSW

- The Scheme has a Group Licence which includes a bulk entitlement. Landholders do not own shares or entitlements, but are entitled to use agreed volumes of water (MDBC 2000b).
- Permanent external trading by individual landholders is permitted but discouraged by common ownership of bulk entitlement within district
- Temporary trade in and out is permitted

Hay Private Irrigation District, NSW

- The Scheme has a Group Licence that includes a bulk entitlement. Landholders do not own shares or entitlements, but are entitled to use agreed volumes of water (MDBC 2000b).
- Temporary trade within the Murrumbidgee region is permitted until end February each year.
- Permanent trade outside of the Murrumbidgee valley is not permitted.

Sunraysia Rural Water Authority, Victoria

- Water entitlements are held by irrigators
- Water cannot be transferred on permanent or temporary basis into defined salinity impact zones.
- At the end of February, all temporary transfers of water from Victoria to New South Wales must cease, and can commence again on 1st July.

Goulburn-Murray Water, Victoria

- Water entitlements are held by irrigators
- Regulated system divided into 11 temporary water trading zones, with trade between zones restricted

First Mildura Irrigation Trust, Victoria

- No limit on temporary trade out of district
- Permanent transfers onto a property limited to 130 per cent of generally accepted crop requirement
- Transfers from low salinity impact zones to high salinity impact zones not permitted either temporarily or permanently.

Renmark Irrigation Trust, SA

- Water entitlement held by Renmark Irrigation Trust
- Temporary trade out permitted when there is a surplus
- Permanent transfers prohibited

Central Irrigation Trust, SA

- Central Irrigation Trust has bulk entitlement that covers 9 irrigation districts.
- Permanent trade out is restricted to a maximum of 2 per cent of original allocation for each district.
- Trade between districts possible.
- Trade in is restricted by current infrastructure capacity.

Table 2: Infrastructure impediments and regulated flows

Location	Constraint (maximum ML/day)
Upper Murray River	
Mitta Mitta River	
(between Hume & Dartmouth Dams, at Tallandoon)	10000
Murray River between Hume Dam and Lake Mulwala	25000
Heywoods gorge downstream of Hume Dam	(600)[a]
Doctors point upstream of Albury	(1200)[a]
Mid Murray River	
Gulf regulator into Barmah forest	2500
Barmah Choke	8500
Barmah forest regulator	2000
Mulwala canal (Yarrawonga Weir to New South Wales)	10000
Yarrawonga main channel (to Murray Valley Irrigation Area)	3200
National channel	
(Torrumbarry Weir to Cohuna, Kerang and Swan Hill)	4400
Edward River offtake	2000
Gulpa Creek offtake and regulator	350
Wakool canal	2350
Cattanach canal	3670
Lower Murray River	
Waranga Western Channel	2447
Swan Hill	(1750)[a]
Mildura	(1500-2000)[a]
Murrumbidgee River	
MIA Main Canal	
(to Yanco and Mirool Irrigation Areas)	6500
Nimmie canal	
(Maude Weir to Lowbidgee Irrigation Area)	2000
Caira canal	
(Maude Weir to Lowbidgee Irrigation Area)	1650
Glendee regulator	
(Redbank Weir north to Lowbidgee Irrigation Area)	1000
Juanbung regulator	
(Redbank Weir north to Lowbidgee Irrigation Area)	1000
Yanga regulator	
(Redbank Weir south to Lowbidgee Irrigation Area)	1000
Wagurah regulator	
(Redbank Weir south to Lowbidgee Irrigation Area)	1000
Coleambally Canal	
(Golgeldrie Weir to Coleambally Irrigation Area)	3700
Sturt Canal	
(Golgeldrie Weir to Mirool Irrigation Area)	1200
Yanco Weir diversion	700
Tory Grand Channel	400
Channel of Lower Darling River	9000
Menindee Lakes release rates (at Weir 32)	10000
	(500)[a]

[a] Minimum mega litres per day

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