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Property rights and externalities in water trade

Anna Heaney and Stephen Beare
Australian Bureau of Agricultural and Resource Economics

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As water becomes a more scarce resource in the Murray Darling Basin, the need to establish an efficient water market will become increasingly important. However, introducing trade with poorly defined property rights may generate externalities that impose indirect costs or benefits to water users and the environment, leading to an inefficient allocation of water resources. This paper examines the importance of establishing property rights to return flows from irrigation.

Return flows from irrigation contribute a substantial proportion of river flows and water entitlements held by downstream users in the Murray River system. Return flows also have a significant impact on water quality as a large proportion of the salt load in the Murray River comes from the discharge of saline drainage and ground water flows from irrigation. Water trade between irrigation regions can alter the pattern of return flows, imposing indirect benefits and costs on downstream users and the environment. If these indirect benefits and costs are not internalised in the institutional arrangements that govern trade, the full net economic gains from trade will not be realised.

A simulation model has been developed at ABARE to evaluate both the internal and external costs and benefits of trade in irrigation water in the Murray Darling Basin. The model incorporates the relationships between land and water use, vegetation cover, surface and ground water hydrology and agricultural returns. The model consists of a network of land use units linked through overland and ground water flows. Land use units are defined according to the characteristics of the ground water system and each unit is managed independently to maximise returns given the level of salinity of available land and water resources, subject to any land use constraints.

The model is used to simulate bilateral trade between several irrigation areas in the Murray Darling Basin. The results indicate that water trade can generate significant external benefits and costs to downstream water users. As these impacts vary continuously along the river depending on the source and destination of the trade, the transaction costs associated with fully internalising the externalities through site specific conditions attached to trade are likely to be prohibitively high. However, administering taxes and subsidies or water exchange rates for trades between irrigation regions may lead to a more efficient allocation of water.

Introduction

In the mid-1990s the Council of Australian Governments recommended a number of water reforms, including a cap on water use and the development of water property rights and the establishment of markets for water trading (COAG 1994). One objective was to encourage use of water such that the highest total benefit from all consumptive (for example, irrigation) and nonconsumptive uses (for example, environmental flows) is obtained. However, the physical and economic environment in which water property rights are being introduced is complex. Irrigation affects the volume and quality of water available to downstream users and the riverine environment more generally. Introducing trade with poorly defined property rights may generate externalities that impose indirect cost or benefits on water users and the environment, leading to an inefficient allocation of water resources.

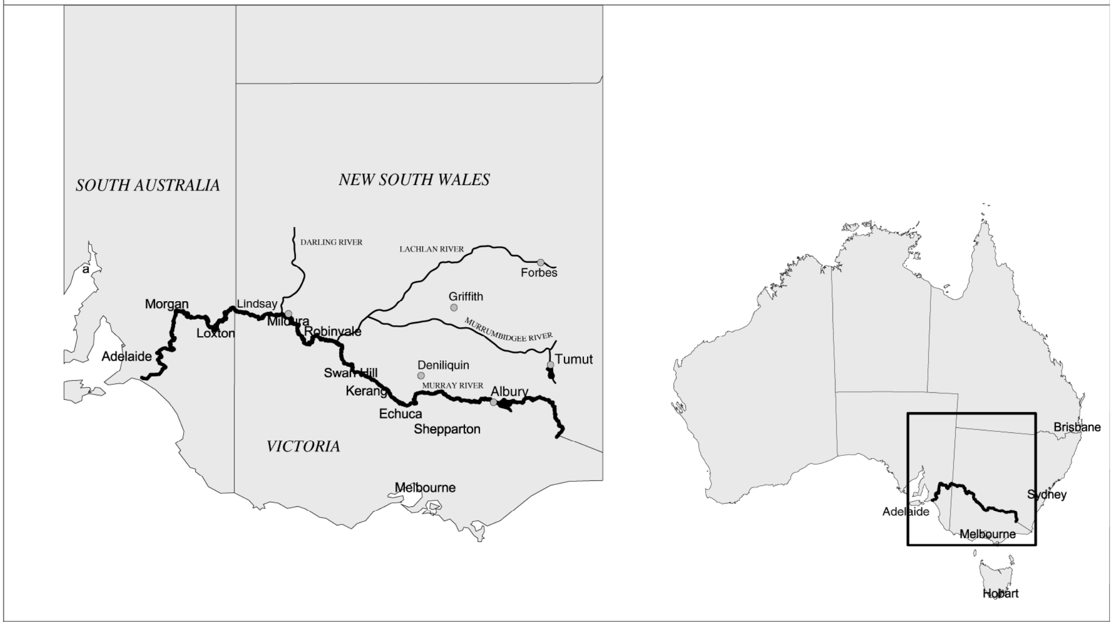
One aspect of water rights that may warrant considerably more attention in the Murray River system is irrigator rights to use and discharge return flows. At present these rights are not clearly defined. Return flows from irrigation represent a substantial proportion of river flows and have a significant impact on water quality in the Murray River. Water trade can alter the pattern of return flows affecting the volume and quality of downstream flows. This may affect the entitlements and productivity of water available for downstream users as well as the riverine environment.

The main quality issue in the Murray River system has been increasing river salinity. A salinity audit, released by the Murray Darling Ministerial Council in 1999, projected that salt mobilisation in the basin would double from 5 million tonnes a year in 1998 to 10 million tonnes in 2100. The audit also reported that the average salinity of the Murray River at Morgan, upstream of the major offtakes of water to Adelaide, South Australia, will exceed the 800 EC[1] World Health Organisation threshold for desirable drinking water quality in the next fifty to one hundred years (MDBMC 1999). A substantial proportion of the salt load in the Murray River comes from the additional discharge of saline ground water flows from irrigation.

As a part of a project to evaluate land and water management options in the Murray Darling Basin a simulation model was developed to examine the impact of irrigation and river flows and salinity. Within the modelling framework, the interrelationships between land and water use, vegetation cover, surface and ground water hydrology and agricultural returns are represented. The model, described in more detail in Bell and Heaney (2000), was developed at ABARE in cooperation with the Commonwealth Scientific and Industrial Research Organisation (CSIRO). It was initially used to estimate the benefits of improved irrigation efficiency as a tool for salinity management in the Riverland region of South Australia (Heaney, Beare and Bell 2001). For this paper, the model was extended to examine the impact of water trade in the irrigation areas of the Murray River and its major southern tributaries. The geographic area under consideration is shown in map 1.

[1] The most widely used method of estimating the salinity concentration of water is by electrical conductivity. To convert 1 EC to mg/L total dissolved salts, a conversion factor of 0.6 generally applies.

Map 1: **Major irrigation areas in the southern Murray Darling Basin**



Background

The development of irrigation in the Murray Darling Basin was supported by public investment in infrastructure that began in the early 1900s. Two objectives of this investment were to increase agricultural exports and to move people back to rural Australia. This infrastructure has supported a large amount of low returning irrigated activities with low rates of irrigation efficiency. As irrigation water allocations were initially tied to the land, this inefficiency was preserved as these restrictions prevented water being redirected to higher valued uses. However, this did not limit the use of water for irrigation purposes; water diversion from river systems in the Murray Darling Basin rose dramatically between the 1950s and mid-1990s. In 1995, an audit of water use in the basin showed that if the volume of water diversions in the basin continued to increase, river health problems would be exacerbated, the security of water supply for existing irrigators in the basin would be diminished, and the reliability of water supply during long droughts would be reduced. Consequently, a cap was imposed on the volume of water that could be diverted from the rivers for consumptive uses. While this cap limits further increases in water diversions, it does not constrain new developments provided their water requirements are met by using current allocations more efficiently or by purchasing water from existing developments.

The cap on diversions has effectively made water, as opposed to storage capacity and delivery infrastructure, the scarce resource thus creating the need for an effective water market. However, there have been a number of impediments to the formation of a fully functioning water market and, to date, there has not been a substantial change in water use through trade. Within the Goulburn–Murray region, temporary and permanent trade accounted for around 5 per cent of total allocations in 1996-97 (Earl and Flett 1998). Trade between irrigation regions, however, has been very limited, with some districts refusing to allow water to be traded out.

Most of the impediments to trade can be attributed to changing from a system of water allocations and administered prices to one based on water rights. This change led to equity issues associated with the redefinition of rights and the sovereign risks associated with these rights. There are a number of issues associated with how private water rights are defined that will affect the potential gains from trade. Many of these issues have been discussed in economic literature.

Dudley and Musgrave (1988) considered the potential advantages of defining property rights in terms of capacity shares on regulated river systems in Australia. The work demonstrates the link between access rights and storage infrastructure. Beare and Bell (1998) demonstrated that access rights to infrastructure are also an important aspect of the value of a water right when the timing of delivery is constrained by the capacity of the delivery system. It has also been noted that failure to link water rights to the costs of infrastructure can lead to the stranding of irrigation assets. Hence, while trade within irrigation areas is becoming established, there has been a reluctance to allow trade between regions that do not share a substantial proportion of their delivery infrastructure.

In a study of an irrigation region near the Murrumbidgee River, Hafi, Kemp and Alexander (2001) examined the importance of accounting for conveyance losses in water allocations. Water entitlements in Australia are commonly defined at the point of use. Trading water rights defined at the point of use, as opposed to the source, generates externalities in that all users who derive their entitlements from the source share the conveyance losses or gains resulting from trade.

Return flows, externalities and trade in irrigation water

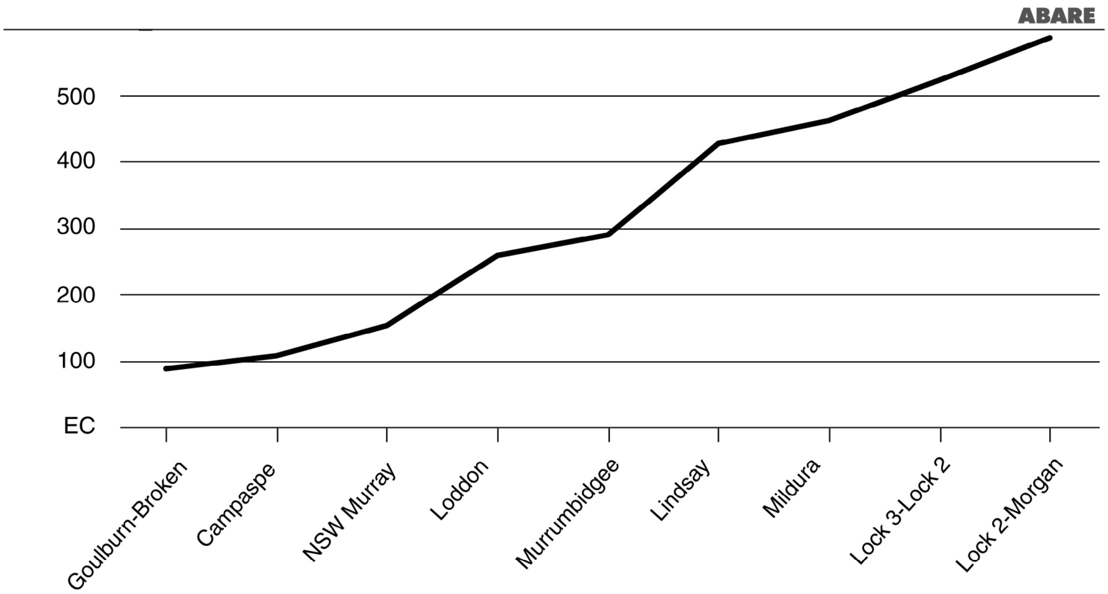
Return flows consist of surface runoff from flood irrigation, irrigation drainage and ground water discharge from irrigation areas that reach the Murray River system. Water trade affects return flows that, in turn, affect the quantity and quality of water used downstream. Reflecting the large volume of water that is diverted from the Murray River and its tributaries in the upstream irrigation areas and relatively low rates of irrigation efficiency, return flows form a substantial part of water available for downstream users. Further, return flows from irrigation areas with relatively low underlying ground water salt concentrations may provide dilution flows downstream. In that case, a reduction in return flows from upstream irrigation areas may increase the salinity of water supplies downstream, imposing costs on downstream users. Irrigators presently hold an implicit right to return flows in that they can trade water without consideration of the downstream externalities. Undertaking these actions without explicit recognition of the downstream impacts generates externalities and may lead to an inefficient allocation of water.

These externalities have implications for both consumptive uses and environmental flows. For consumptive use, rights to return flows are an equity, as opposed to an efficiency, issue so long as these rights are well defined. However, as irrigators are not required to account for a loss in return flows as a result of their actions, reductions in the volume of return flows are simply absorbed as an additional diversion imposed above the cap, which may be at the expense of desired environmental flows. Hence, the balance between rights to consumptive use and environmental flows needs to be specified with explicit consideration given to rights to return flows.

However, a significant efficiency issue exists with the impact of return flows on water quality — in particular, the salt concentration of surface water flows. The extent to which return flows affect water quality depends on several factors, including ground water recharge rates and the ground water salinity underlying the irrigation areas. Soils throughout most of the irrigation areas in the southern Murray Darling Basin are shallow. The deep percolation of irrigation water through the soil has led to a large increase in the rate of recharge into the ground water system. The volume of water entering the ground water system is higher in areas with low rates of irrigation efficiency. Increased ground water recharge has led to rising water tables and increased ground water discharge. Ground water discharge transports salt to the river by direct seepage or by surface discharge that eventually reaches the river system. The volume of salt transported to the river depends to a large extent on the salinity of the ground water. The salinity of ground water discharge in the Murray River and its tributaries is generally low in the upland catchments. Ground water salinity levels tend to increase moving downstream and reach levels approaching seawater in low-lying regions of South Australia.

The associated increases in the levels of stream salinity in the Murray River can be seen in figure 1. Water trade may have an impact on river salinity. For example, trade that moves water from an irrigation area with relatively low recharge rates and low ground water salinity to a downstream irrigation area with high recharge rates and high ground water salinity can produce a series of impacts on water quality. Immediately downstream of the seller, the transfer may increase stream flows and reduce salt concentration in the Murray River. However, as recharge rates are higher in the downstream area, surface runoff will be lower, reducing the volume of return flows available downstream of the buyer. Further, as ground water salinity is higher downstream, salt concentrations will be increased as more salt is transported to the river system.

Figure 1: **Salt concentration of the Murray River at tributary confluences, 2000**



The change in the level of discharge of saline ground water due to irrigation has important spatial as well as temporal characteristics that make it difficult to internalise the downstream benefits and costs associated with a change in irrigation practices. As the level of salinity in ground water discharge is location specific, similar irrigation application rates and levels of irrigation efficiency can have substantially different impacts on the level of salt mobilised and the concentration of river system. Hence, a change in location of irrigation through water trade should be related to changes in return flows and salt loads. Externalities associated with site specific sources and impacts of effluent discharge have received considerable attention in economic literature on pollution abatement (Montgomery 1972; Atkinson and Tietenberg 1987; Malik, Letson and Crutchfield 1993). Considering the problem in this context helps to illustrate the need to develop appropriate institutional arrangements to achieve efficient allocation of water.

The impact of saline ground water discharge depends on the location of the source. Generally, upstream irrigators will impact on a greater number of assets than downstream irrigators and hence have a higher marginal return from a given level of abatement. In addition, downstream impact will vary from location to location due, for example, to differing salt tolerance of irrigated crops or differing industrial uses. The benefits of a reduction in salinity need to be accounted for in terms of a specific set of downstream sites affected by the change.

In considering emissions permits, Montgomery (1972) established that a separate property right must be defined in terms of the damages generated from a specific source at each affected site downstream to achieve an economically efficient outcome. However, a market solution based on a set of site specific (spatially differentiated) tradeable property rights, such as a salinity mitigation credit, faces three problems. First, downstream benefits are non-appropriable (the right is non-exclusive). If an individual can not capture the benefit of an upstream investment in irrigation efficiency, private markets can not function efficiently (Hartwick and Olewiler, 1986). Second, there is considerable uncertainty associated with the level and timing of impacts of an upstream investment in improved irrigation efficiency. When individuals lack information on how upstream activities impact on downstream users, a market may not operate efficiently (Hartwick and Olewiler, 1986). Third, several authors have noted that while a system of traded spatially specific property rights may be a first best policy in theory, the potential complexity and costs of transactions means that it is not practical to implement (Atkinson and Tietenberg 1987; Stavins, 1995; Hanley, Shogren and White 1997).

Given the complications associated with implementing a spatially differentiated salinity credit scheme, a partially differentiated or undifferentiated scheme may be an effective second best solution. An example may be allowing trade in salinity mitigation credits between irrigation areas as opposed to individual irrigators. Trading arrangements may be supplemented by administered restrictions such as trading ratios or exchange rates between irrigation areas (Malik, Letson and Crutchfield, 1993). However, the potential benefits from any specific intervention will depend on the physical and economic characteristics of the problem.

The potential impact of water trade on salinity has been considered in the Murray River system (MDBC 2001). The Murray Darling Basin Salinity Management Strategy requires that the salinity impacts of interstate water be accounted for by a system of state level debits or credits. In Victoria, high impact areas have been identified and water trade into these areas has been prohibited. In addition, a levy has been introduced on water transferred into the Sunraysia district in the Victorian Mallee near Mildura (Young et al. 2000).

However, there is considerable variation in the indirect effects of changes in return flows between regions and states. An objective of the work presented in this paper is to estimate the internal and external benefits arising from trade. The results are intended to provide an indication of the potential economic benefits of developing a consistent institutional framework to account for return flows. These benefits could include direct economic gains from, for example, charges that reflect the cost of changes in river salinity, as well as providing environmental benefits at least cost.

Model specification

Within the modeling framework, economic models of land use are integrated with a representation of hydrological processes in each catchment. The hydrological component incorporates the relationships between irrigation, rainfall, evapotranspiration and surface water runoff, the effect of land use change on ground water recharge and discharge rates, and the processes governing salt accumulation in streams and soil. The interactions between precipitation, vegetation cover, surface water flows, ground water processes and agricultural production are modeled at a river reach scale. In turn, these reaches are linked through surface and ground water flows. In the agroeconomic component of the model, land use is allocated to maximise economic return from the use of agricultural land and irrigation water. Incorporated in this component is the relationship between yield loss and salinity for each agricultural activity. Thus, land use can shift with changes in the availability and quality of both land and water resources. The modeling approach is described in more detail in Bell and Heaney (2000) and Bell and Klijn (2000).

The rate at which salt stored in ground water is transported to the river system depends on, among other things, the size of an irrigation development, irrigation efficiency, the underlying geology of the irrigated area, and the distance between the irrigation development and the river valley. The methodology developed to assess the impact of changes in these parameters on salt loads in South Australian irrigation developments (Watkins and Waclawik 1996; AWE 2000) has been adapted to catchments in Victoria and New South Wales. Two specific changes were made. First, drainage schemes that discharge into the river system in many irrigation areas were incorporated. In general, flows from these drains carry surface water runoff from rainfall, flood irrigation and ground water discharge. Second, the Murray River meanders in the Victorian Mallee (between the confluence of the Murrumbidgee and the South Australian border shown in map 1). As a consequence, in some irrigation areas ground water may be either flowing toward or away from the river affecting the level of saline stream discharge. This was incorporated by allowing a fraction of the recharge to move into a deep aquifer that does not discharge into the Murray River.

As the clearance of native vegetation has contributed to increased recharge in the dryland agricultural areas in the upland reaches of the catchments, the model also has land management units for rain-fed activities. However, as these areas are not affected by irrigation, they will not be considered here.

Agroeconomic component

The management problem considered in the agroeconomic component of the model 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. There are five land use activities: irrigated crops, irrigated pasture, irrigated horticulture, dryland crops and dryland pasture.

Each region is assumed to allocate its available land each year between the above 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**, and from ground water sources, *gw**, and suitable land, *L**:

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

subject to

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

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 ground water used for irrigation of activity *j*, *r* is a discount rate, and *csw* is the unit cost of surface water used for irrigation and *cgw* is the unit cost of ground water used 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) $$x_j = \begin{cases} A_j L_j^{\alpha_{Lj}} sw_j^{\alpha_{swj}(t)} gw_j^{\alpha_{gwj}} & 0 < \alpha_{Lj} + \alpha_{swj} + \alpha_{gwj} < 1 \quad for\ j = 1,2,3 \\ A_j L_j^{\alpha_{Lj}} & 0 < \alpha_{Lj} < 1 \quad for\ j = 4,5 \end{cases}$$

where A_j, α_{Lj}, α_{swj} and α_{gwj} are technical coefficients in the production function. Note, the technical coefficients on surface irrigation water are time dependent to capture the impact of changes in salt concentration in the Murray River.

The costs to irrigated agriculture and horticulture resulting from yield reductions caused by increased river salinity are modeled explicitly. The impact of saline water on the productivity of plants is assumed to occur by the extraction by plants of saline water from the soil. The electro-conductivity of the soil, *EC*, reflects the concentration of salt in the soil water and reduces the level of output per unit of land input (land yield) and per unit of water input (water yield). This is represented by modifying the appropriate technical coefficients, α_{swj}, in the production function for each activity from the level of those coefficients in the absence of salinity impacts, that is:

(4) $$\alpha_{swj}(t) = \frac{\alpha_{swj}^{\max}}{1 + \exp\left(\mu_{0j} + \mu_{1j} EC\right)}$$

where μ_0 and μ_1 are productivity impact coefficients determined for each activity and $\alpha_{swj}{}^{max}$ is the level of the technical coefficient in the absence of salinity.

Hydrological component

There are two parts to the hydrological component of the model. The first is the distribution of precipitation and irrigation water between evaporation and transpiration, surface water runoff and ground water recharge. evaporation and transpiration are determined as a function of precipitation and ground cover, as well as irrigation application rates and efficiency. Water application rates in the southern Murray Darling Basin for horticulture are around 10 megalitres per hectare a year, equivalent to 1000 mm of precipitation, whereas average application rates for pasture are between 4 and 6 megalitres per hectare a year (Gordon, Kemp and Mues 2000). Irrigation efficiency is defined as the proportion of irrigation water applied that is returned to the atmosphere through evaporation and transpiration. In horticultural areas such as western Victoria and the South Australian Riverland, irrigation efficiency can approach 75 to 80 per cent for horticulture (A. Meisner, Department of Environment, Heritage and Aboriginal Affairs, personal communication, November 2000). In areas where there is widespread use of flood irrigation on pasture, irrigation efficiency is of the order of 50 per cent.

The excess of precipitation and irrigation water over evaporation and transpiration, is split between surface water runoff and ground water recharge using a constant proportion (recharge fraction). The volume of irrigation water entering the ground water system depends largely on terrain and soil structure. Irrigation areas are generally located in flat terrain leading to reduced runoff and consequently higher recharge fractions. On heavier less permeable soils in the upland river catchments, recharge fractions are assumed to be in the range of 50 to 60 per cent. On the sandier more permeable soils in the South Australian Riverland recharge fractions are 100 per cent.

Some soils have intervening layers of clay that impede drainage into the ground water system. Tile drainage is used in these areas to avoid waterlogging. Tile drainage is represented in the model though a combination of an increase in irrigation efficiency where drainage is reused or allowed to evaporate, or as a return flow to the river system. Saline ground water discharge can be intercepted through ground water pumping for subsequent disposal in evaporation ponds. In some irrigation areas, such as the South Australian Riverland, there is ground water discharge to the flood plains that is mobilised in flood events and does not contribute to the problem of high salt concentrations. Reductions in average saline discharge from these effects are accounted for in calculating river salt and water balances.

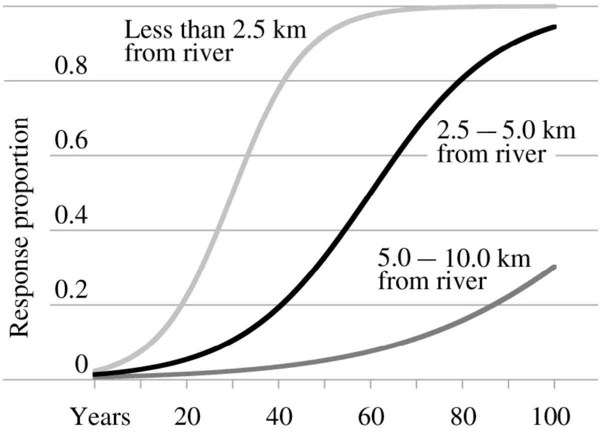
The second part of the hydrology component is the determination of ground water discharge. The equilibrium response time of a ground water flow system is the time it takes for a change in the rate of recharge to be fully reflected in a change in the rate of discharge. The equilibrium response time does not reflect the actual flow of water through the ground water system but the transmission of water pressure. The response time increases rapidly with the lateral distance the water flows in areas such as the South Australian Riverland owing to the flat terrain and resultant low hydrological pressure.

Assuming the contributions of recharge are additive and uncorrelated over time, it is possible to model gross discharge directly, thereby avoiding the need to explicitly model ground water levels. In the approach adopted here, total discharge rate D in year t is a logistic function of a moving average of recharge rates in the current and earlier years according to:

(5) $$D(t) = R(0) + \sum_{i=t-m}^{t} \frac{R(i) - R(i-1)}{1 + \exp[(v_{half} - i)/v_{slope}]}$$

where $R(0)$ is the initial equilibrium recharge rate, m is the number of terms included in the moving average calculation, and υ_{half} and υ_{slope} are the time response parameters. The moving average formulation allows the accumulated impacts of past land use change to be incorporated as well as to model prospective changes.

Figure 2: **Weighting function for contribution of past recharge to discharge**



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. Typical response profiles for the three land use bands are shown in figure 2. Parameters for the ground water response functions in these irrigation areas were obtained from Watkins and Waclawik (1996). Similar ground water response functions were assumed for the remaining irrigation areas based on discussions with CSIRO and other hydrologists. Response times were assumed to be longer the larger the irrigation area. However, in areas with substantial areas of high water tables, response times were reduced.

Model calibration

The data required to calibrate the model are extensive. The procedure is presented in detail in Bell and Heaney (2000). Summary data for the irrigation areas are provided in table 1. Additional information is available from the authors on request. Historical flows and salt loads were obtained from Jolly et al. (1997). Projected salt loads were obtained from the national salinity audit (MDBMC 1999), Barnett et al. (2000) and Queensland Department of Natural Resources (QDNR 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.

Table 1: **Summary data for the irrigation areas studied**

Irrigation area	Main irrigated activities	Water allocation Murray GL	Water allocation Tributary GL	ET[a] fraction %	Recharge fraction[b] %	Ground water salinity mg/L
Goulburn–Broken	Pasture, cropping, horticulture	320	853	65	50	1 000
Campaspe	Pasture, cropping	207	75	50	60	5 000
NSW Murray	Pasture, cropping	2 464	0	65	75	2 000
Loddon Barr Creek	Pasture, cropping	163	0	65	75	20 000
Murrumbidgee	Pasture, cropping, horticulture	0	2 045	65	80	1 000
Robinvale	Horticulture	31	0	80	100	10 000
Mildura	Horticulture	188	0	80	100	25 000
Lindsay	Horticulture	15	0	80	100	30 000
Lock 3-Lock 2	Horticulture	71	0	80	100	33 000

a the percentage of irrigation subject to evaporation and transpiration. *b* the percentage of excess water, irrigation water and precipitation less evapotranspiration, that enters the ground water system.

To calculate initial values for the production function parameters in (3), the total rent at full equity accruing to each activity was first calculated as the summation of rent associated with the use of land and other fixed inputs to production and surface and ground water. That is:

(6) $$RentTotal_j = RentL_j + RentSW_j + RentGW_j + RentOther_j$$

where

(7)
$$\begin{aligned} RentL_j &= L_j(0)p_{\min} \\ RentSW_j &= sw_j(0)c\tilde{s}w \\ RentGW_j &= gw_j(0)c\tilde{g}w \\ RentOther_j &= L_j(0)(p_j - p_{\min}) \end{aligned}$$

where p_{min} is the net return to land and other fixed capital structures in their marginal use and $c\tilde{s}w$ is the opportunity cost of surface water used for irrigation and $c\tilde{g}w$ is the opportunity cost of ground water for used irrigation in the initial period. Not all regions have ground water sources suitable for irrigation. The opportunity cost of surface and ground water used for irrigation is assumed to be $50 a megalitre for areas with predominantly pasture production and $200 a megalitre for horticultural areas.

Initial values for the production function coefficients for each activity were then determined as:

(8)

$$\alpha_{Lj}(0) = \frac{RentL_j}{RentTotal_j}$$

$$\alpha_{swj}(0) = \frac{RentSW_j}{RentTotal_j}$$

$$\alpha_{gwj}(0) = \frac{RentGW_j}{RentTotal_j}$$

$$A_j = L_j(0)^{1-\alpha_{Lj}(0)} sw_j(0)^{-\alpha_{swj}(0)} gw_j(0)^{-\alpha_{gwj}(0)}$$

Within a simulation, these coefficients are adjusted from the initial values according to equation (4). The coefficients in equation (4) were derived from estimated yield losses caused by irrigation salinity (MDBC 1999) by equating the decline in average physical product of irrigation water with the yield loss function.

The Murray Darling Basin Commission has linked its hydrological modeling to estimates based on cost impacts of incremental increases in salinity. Costs downstream of Morgan are imputed as a function of EC changes in salt concentration at Morgan. The analysis considers agricultural, domestic and industrial water uses. Using the cost functions derived in this model, each unit increase in EC at Morgan is imputed to have a downstream cost of $65 000 (MDBC 1999). This cost is included in the analysis presented here.

Simulation Design

The model was initially used to determine a baseline over a 50 year simulation. The estimated cost of salinity in the baseline scenario is measured as the reduction in economic returns from broadacre and horticultural activities from those that are currently earned. Thus, only costs and/or benefits associated with changes in stream flows, salt concentration and the extent of high water tables from current levels are estimated. Salt loads and salt concentration of the Murray River are predicted to rise over the next 50 years as a result of both the clearance of native vegetation to facilitate dryland agriculture and the increased mobilisation of salt associated with irrigated agriculture. The salt concentration at Morgan, a gauging site on the Murray River below the major irrigation areas, is projected to increase from 590 EC currently to 700 EC by 2050. This increase in salt concentration is expected to result in a decline in agricultural returns of almost $260 million, in net present value terms (NPV) using a discount rate of five per cent, and impose costs to agricultural, urban and industrial water users downstream of Morgan of almost $60 million NPV over the 50 year period.

A large number of bilateral trades are possible within the Murray River system. In the analysis presented here, a subset of bilateral trades between several major irrigation areas are simulated to examine return flow property rights issues. The trade simulations were selected to allow a comparison of the internal and external costs or benefits of a downstream trade of irrigation water relative to the baseline scenario. Internal (or direct) impacts are derived within the irrigation areas that trade whereas external (or indirect) impacts are those derived downstream of the areas engaging in trade.

A permanent trade of 20 gigalitres from the source was modeled in each of the simulations. The volume of water available at the trade destination was adjusted to account for conveyance losses. Further, the cap on the volume of water that can be diverted for irrigation is maintained. A decline in irrigation return flows as a result of water being traded from an upstream region will therefore lead to a reduction in water entitlements for downstream users that had previously accessed those flows. However, this reduction can be offset by increases in flows resulting from increased ground water discharge from dryland areas as an ongoing consequence of land clearing.

Two sets of trade scenarios were simulated. First, a set of trade source experiments simulated trade from several upstream sources to a single downstream destination, the irrigation area within 2.5 kilometres of the Murray River between Locks 3–2. A second set of scenarios was developed where irrigation water was sourced from one irrigation area, the Goulburn–Broken, and traded to several different downstream destinations. The impact of trade without the cap on diversions for irrigation was also considered to examine the volumetric and qualitative impacts of a reduction in return flows separately. The irrigation areas under consideration are listed in table 2 in upstream to downstream order and shown in map 1. The trade scenarios are listed in tables 3 and 4. The internal and external costs and benefits associated with trade were then calculated, in net present value terms, over a 50 year period.

Table 2: **Major irrigation areas in the southern Murray Darling Basin**

Irrigation area	Central town
Goulburn–Broken	Shepparton
Campaspe	Echuca
NSW Murray	Deniliquin
Loddon – Barr Creek	Kerang
Murrumbidgee	Griffith
Robinvale	Robinvale
Mildura	Mildura
Lindsay	Lindsay
Lock 3–Lock 2	Loxton

Results

Trade source scenarios

Internal benefits from buying water from other regions accrue to irrigators in the Lock 3–2 irrigation region as a result of increased horticultural production (table 3). As the trade moves water to higher valued production (horticulture as opposed to pasture and cropping in the source irrigation areas), the benefits to the destination region exceed the costs of the forgone irrigated production in the source regions. For example, the internal cost of forgone agricultural production in the Goulburn–Broken catchment as a result of trade is estimated to be $403 a megalitre. The internal benefit in, for example, the Lock 3–2 region is $2326 a megalitre leading to a total net change of $1923 a megalitre. It should be noted, however, that the capital costs associated with expanding irrigated activity are not included in this analysis. Given current demand and supply conditions and the relatively small volume of water being traded, it is likely that the traded price of water will be close to the observed price of a permanent water entitlement in South Australia. This has been reported to be around $500 a megalitre (Samaranayaka, Freeman and Short 1998).

The external benefits from trade vary substantially between irrigation areas (table 3). In each of the simulations presented here, trade results in a negative external benefit as a result of changes in both the volume of water available and water quality. The traded irrigation water is sourced predominantly from pasture production that is generally characterised by low rates of irrigation efficiency. As a result, there is a relatively large reduction in the volume of water available for downstream users directly below the Goulburn–Broken catchment under cap conditions. Further, as recharge rates are higher in the downstream destination regions, surface runoff will be lower, reducing the volume of return flows available downstream of the buyer.

Table 3: **Net internal and external benefits from trade to Lock 3–2, by source**

Source	**Net internal benefits** $/ML NPV	**External benefits** $/ML NPV
Goulburn–Broken	1 923	-302
Campaspe	1 967	-318
Loddon Barr Creek	2 156	-107
Murrumbidgee	2 124	-279
NSW Murray	2 012	-282

The external impacts of water trade on water quality arise from two sources. First, as the water that would have otherwise been used for irrigation is retained in the river, there is an immediate reduction in salt concentration. Second, the source regions are characterised by relatively low recharge rates and low ground water salinity whereas the destination areas have high recharge rates and high ground water salinity. Trading water from the upland regions reduces the amount of irrigation recharge that, over time, reduces the amount of saline ground water discharge reaching the Murray River. The combination of reduced saline discharge and dilution flows after the trade lead to reductions in salt concentration in the Murray River between the source and the destination. As a result of the improvement in surface water quality, the productivity of irrigation water increases in the regions between the seller and the buyer.

These findings indicate there may be economic gains from attaching site specific conditions to the implicit rights to return flows that reflect the cost associated with downstream changes in river salinity. To fully account for the externalities associated with trade between, for example, the Goulburn–Broken and Lock 3–2, the price of a permanent water entitlement would need to reflect the cost incurred by downstream water users. Trade between the Goulburn–Broken and Lock 3–2 has an associated external cost of around $300 a megalitre as compared to the reported trading price previously cited of around $500 a megalitre for the region. A charge raising the traded price of water by 60 per cent to around $800 a megalitre could be imposed to internalise this cost.

Trade destination scenarios

Again, internal benefits are derived from the increase in revenue as a result of the movement of water to higher returning horticultural activities (table 4). As in the source scenarios, the externalities are a complex interaction of water quantity and quality impacts. The volume of water available downstream of the Goulburn–Broken is reduced under cap conditions as a result of the reduction in return flows. The salt concentration of the Murray River is lower downstream of the source as a result of dilution flows and reduced saline discharge from the upstream irrigation region. Generally, salt concentration downstream of the different destinations increases after trade as the underlying ground water salinity is higher in the southern irrigations regions and more salt is transported to the river system. However, the impact on stream salinity differs with the agronomic and hydrological characteristics of the destination regions. Reflective of a ground water salt concentration approaching that of seawater, the negative externality is highest when water is traded to the irrigation area nearest the Murray River in the Lock 3–2 region.

In contrast, trading water to the irrigation area that is more than five kilometres from the Murray River in the Lock 3–2 region generates a positive external benefit over a 50 year time period. As the increase in recharge associated with irrigation is further from the river, it takes longer for the ground water discharge to be transported to the river system consequently delaying the increase in salt concentration.

An external benefit is also derived when water is traded to the Lindsay region in the Victorian Mallee. The underlying geology of this region is such that ground water discharge is transported away from the river system. Any increase in recharge is therefore not reflected in an increase in salt concentration in the Murray River. A site specific condition attached to trade in this scenario could take the form of a subsidy that would reflect the positive effects on water quality of moving irrigation water to this region. In the above scenarios where water quality is improved as a result of trade, subsidies could help offset the increased pumping and capital costs of delivering water to irrigation areas further from the Murray River.

Table 4: **Net internal and external benefits of trade from Goulburn–Broken, by destination**

Destination	**Net internal benefits** $/ML NPV	**External benefits** $/ML NPV
Robinvale	2 124	-51
Mildura	2 230	-54
Lindsay	1 730	99
Lock 3–2 – within 2.5km of Murray River	1 923	-302
Lock 3–2 – more than 5km from Murray River	1 065	129

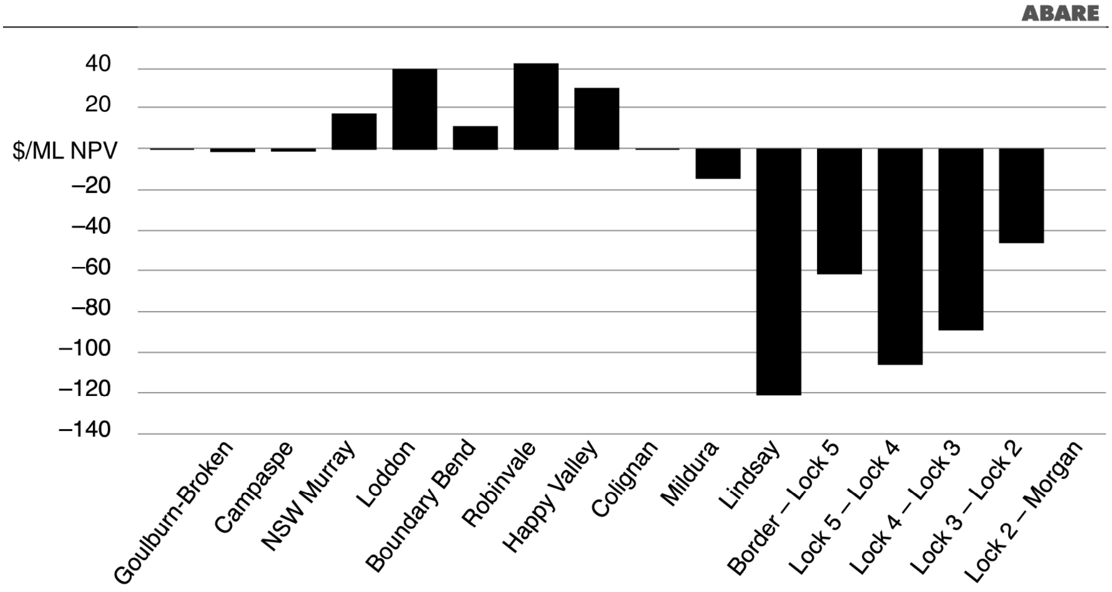
Distributional Impacts

The impact of trade on return flows is reasonably complex as it is both site specific and dynamic. A reduction in irrigation at the source can have an immediate effect on return flows through reduced irrigation drainage. This would be typical of up-river irrigation areas where there are high water tables and flood irrigation is common. The water quality of surface drainage depends on a number of site specific factors including the porosity of the soil, the depth of the drains and ground water salinity levels.

Reduced irrigation at the source will reduce ground water recharge that will eventually result in a reduction in ground water discharge to the river system. This can occur relatively quickly in irrigation areas that are near the river and/or where the ground water system is pressurised due to high water tables. In other areas, the effect of decreased recharge on return ground water flows can be insignificant. Further, as previously noted, the salinity levels of ground water discharge vary along the Murray River system.

At the destination, the effects of trade are a mirror image of the source impacts in qualitative terms. There can be an increase in both surface drainage and ground water discharge. However, the magnitude of these effects will depend on the characteristics of the irrigation area. This continuous variation is likely to make addressing distributional issues difficult. As an illustration, downstream trade between the Goulburn–Broken and Mildura is examined. The indirect benefits along successive river reaches are shown in figure 3.

Figure 3: **Indirect benefits of trade between Goulburn-Broken and Mildura, by irrigation area**

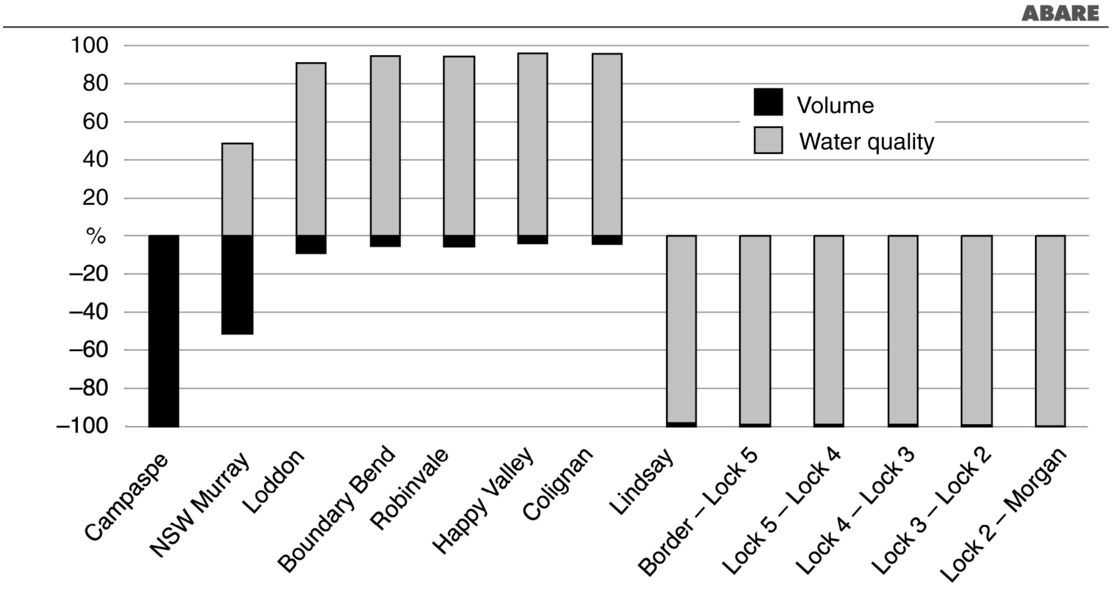


Trade imposes a small indirect cost on the two reaches directly below the Goulburn–Broken catchment. While the trade results in lower salt concentrations downstream due to the increased outflows from the Goulburn–Broken, this is offset by the impact of reduced water availability for irrigation due to the loss of return flows. The distributional impact is reversed further downstream, between the Loddon catchment and Mildura. The effect of reduced salt concentration in the Murray River has a greater impact than the reduction in water available for irrigation. After the trade, the increase in saline return flows from Mildura imposes an indirect cost on downstream users.

The impact of volumetric and qualitative changes

In the simulation experiments presented above, the cap on diversions was maintained resulting in a reduction in allocation for downstream irrigators due to losses in return flows. As a result, external effects on downstream users were a combination of changes in water volume and quality. To examine these effects separately an additional experiment was conducted where the cap on diversions was removed allowing downstream users to maintain their allocation despite a reduction in return flows. The simulation was conducted for a trade between the Goulburn–Broken and Mildura and compared to the corresponding simulation where diversions for irrigation were capped. The relative external benefits and costs of downstream changes in salinity concentrations versus water volumes are shown in figure 4. The total absolute change in costs has been standardised to 100 per cent.

Figure 4: **Indirect trade impacts: water quality and volume, Goulburn-Broken to Mildura**



The impacts of volumetric changes are only significant immediately downstream of the Goulburn–Broken. The decline in the importance of the volumetric effects moving downstream is due to the fact that ground water discharge is increasing over time due to the delayed effects of land clearing. The impact of a 20 gigalitre reduction in irrigation in the Goulburn–Broken on the volume of return flows compared to the overall increase in ground water discharge becomes smaller moving downstream from the Goulburn–Broken. Downstream impacts of salinity dominate the volumetric effects with indirect benefits above Mildura and costs below. The effects below Mildura are predominantly qualitative rather than volumetric for two reasons. First, irrigation efficiency levels are high in Mildura, hence the volume of return flows is low. Second, ground water discharge from this region is highly saline.

Concluding remarks

As water becomes a more scarce resource in the Murray Darling Basin, the need to establish an efficient water market will become increasingly important. At the same time, there is concern about the impact of rising salinity on water quality and river health. However, establishing an institutional framework that will allow efficient water allocation and addresses the externalities associated with irrigation and salinity remains an elusive policy goal.

Two problems stem from the lack of property rights associated with return flows. Return flows from some irrigation areas represent a substantial proportion of the total water applied. These return flows are partially extracted by downstream users. Furthermore, return flows from some irrigation regions have a major affect on the level of river salinity. Water trade can impact on the pattern of return flows affecting both flow volumes and quality.

Water trade can alter the volume of return flows between the source and the destination. Along the Murray, trade downstream generally reduces the volume of return flows. The impact of reduced return flow volumes on downstream users depends on whether the current cap on diversions is strictly enforced and allocations are reduced. At the same time, trade has the potential to reduce salinity and improve the riverine environment, providing the incentives reflect the full economic impact.

Establishing trading regions and exchange rates that account for the volume and salinity impacts of return flows between regions may be a cost-effective means of improving the allocation of water through trade. The potential gains from such an administrative system may be important in achieving efficient water use in the Murray River system. Using the opportunity costs of the water from the trade sources as a reference price, trade into low impact irrigation areas was estimated to generate salinity benefits in the order of 10 to 15 per cent of the direct use value of the water traded. Trade into high impact areas was estimated to generate costs of up to 75 per cent of the direct use value of the water traded.

An effective water market that accounts for salinity impacts from trade may assist in meeting environmental objectives in the Murray River system at least cost. Environmental flows in the Snowy River, for example, may be sourced through the water market. Targeting these purchases to regions that reduce salinity discharge and improve water quality may deliver a better policy outcome.

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