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Irrigation, water quality and water rights in the Murray Darling Basin, Australia

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While irrigation has facilitated the development of high value agricultural production in Australia's Murray Darling Basin, it has also generated significant externalities in terms of water quality. Irrigation has substantially increased the amount of water entering ground water systems, leading to rising water tables. As water tables rise, there is an increase in mobilised salt that is discharged into the Murray River.

To evaluate the costs and benefits of changes in irrigation practices and technology in the Murray Darling Basin, a simulation model has been developed at ABARE in cooperation with the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The model incorporates the relationships between land 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 the characteristics of the ground water system and each unit is managed independently to maximise returns given the level and salinity of available land and water resources, subject to any land use constraints.

The results indicate that water trade and improvements in irrigation efficiency can generate significant external benefits and costs to downstream water users. Internalising these benefits and costs in water property rights can improve economic returns through more efficient water allocation.

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Introduction

A central tenet of water policy reform in Australia is to establish property rights to facilitate trade, allowing water to be redirected to its highest valued use. The potential economic benefits from water trade are significant. It has been estimated that interregional and interstate trade in water in the Murray Darling Basin of Australia, which accounts for more than 70 per cent of Australian irrigated agriculture, could increase agricultural returns by almost $50 million a year (Hall, Poulter and Curtotti 1994; MDBC 2001). However, the physical and economic environment in which water property rights are being introduced is complex. Defining water property rights that account for the full economic costs and benefits of water use has proven to be difficult. Irrigation affects the volume and quality of water available to downstream users and the riverine environment more generally. The extent to which trade will lead to efficiency gains depends, in part, on how well these rights account for the externalities associated with irrigation.

The main quality issue in the Murray River system has been increasing river salinity. The results of a salinity audit, released by the Murray Darling Ministerial Council in 1999, suggest 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). As a substantial proportion of the salt load in the Murray River comes from return ground water flows from irrigation, changes in irrigation water use through trade or improvements in irrigation efficiency may contribute to mitigating the problem of increasing river salinity.

To evaluate salinity management options in the Murray Darling Basin more generally, a simulation modeling framework that incorporates the interrelationships between land use, vegetation cover, surface and ground water hydrology and agricultural returns was developed at ABARE in cooperation with the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Initially the model was used to examine the impact of targeted land use changes to reduce saline ground water discharge from dryland agriculture (Heaney, Beare and Bell 2000). The model was developed further to incorporate irrigation management options in the Riverland region of South Australia, allowing estimates of the benefits of improved irrigation efficiency as a tool for salinity management in irrigation areas (Heaney, Beare and Bell 2001). Here, the model was extended to examine salinity mitigation options in the irrigation areas of the Murray River and its major southern tributaries. The geographic area under consideration is shown in map 1.

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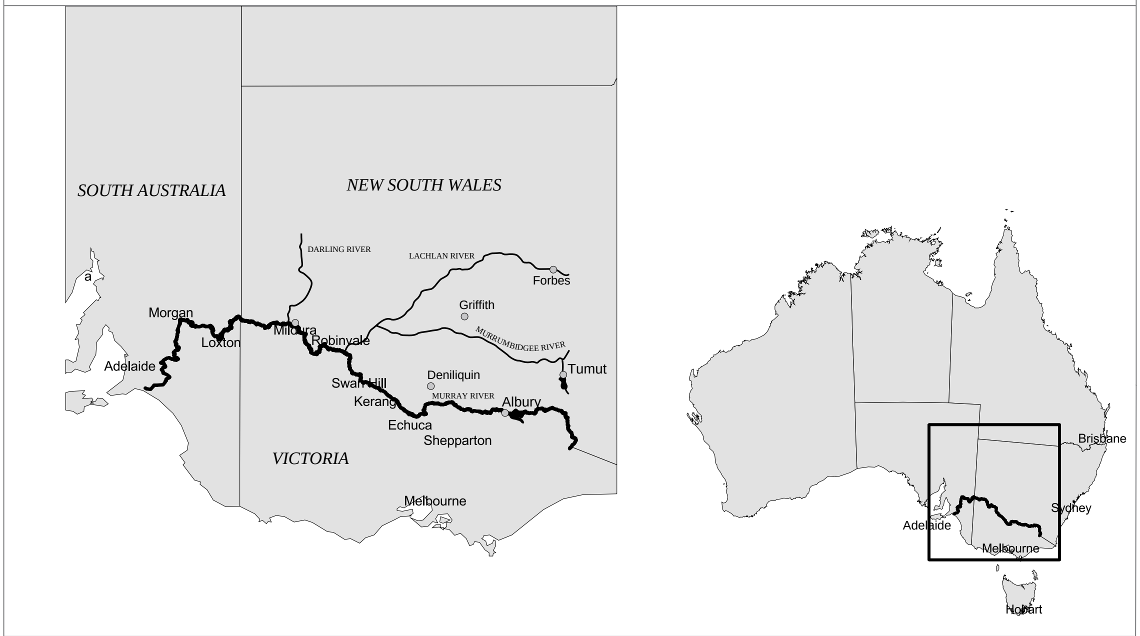
[1] The most widely used method of estimating the salinity concentration in water is by electrical conductivity. To convert 1 EC to mg/L total dissolved salts, a conversion factor of 0.6 generally applies.

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 its highest valued use. However, this did not limit irrigation development; 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 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 restrains further increases in water diversions, it does not constrain new developments provided the water for them is obtained 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 and delivery infrastructure, a scarce resource and has created 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. 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 the problem of changing from a centrally administered system of water allocations to a set of privately held water rights. These include the equity issues associated with allocating rights and the sovereign risks associated with those rights. Beare and Bell (1998) demonstrated that access rights to infrastructure are also an important aspect 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 fixed costs associated with 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. However, to date the property rights issues associated with return flows from irrigation have not been considered. 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 and improvements in irrigation efficiency affect 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. Conversely, a reduction in return flows from upstream irrigation areas may increase the salinity of water supplies, imposing costs on downstream users. Irrigators presently hold an implicit right to return flows in that they can trade or save water without consideration of the downstream externalities. Undertaking these actions without explicit recognition of the downstream impacts generates externalities and leads to an inefficient allocation of water and investment in improving irrigation efficiency.

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 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. The impact of an investment that increases irrigation efficiency can also produce complex impacts on water quality. This is discussed in more detail in the results section.

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

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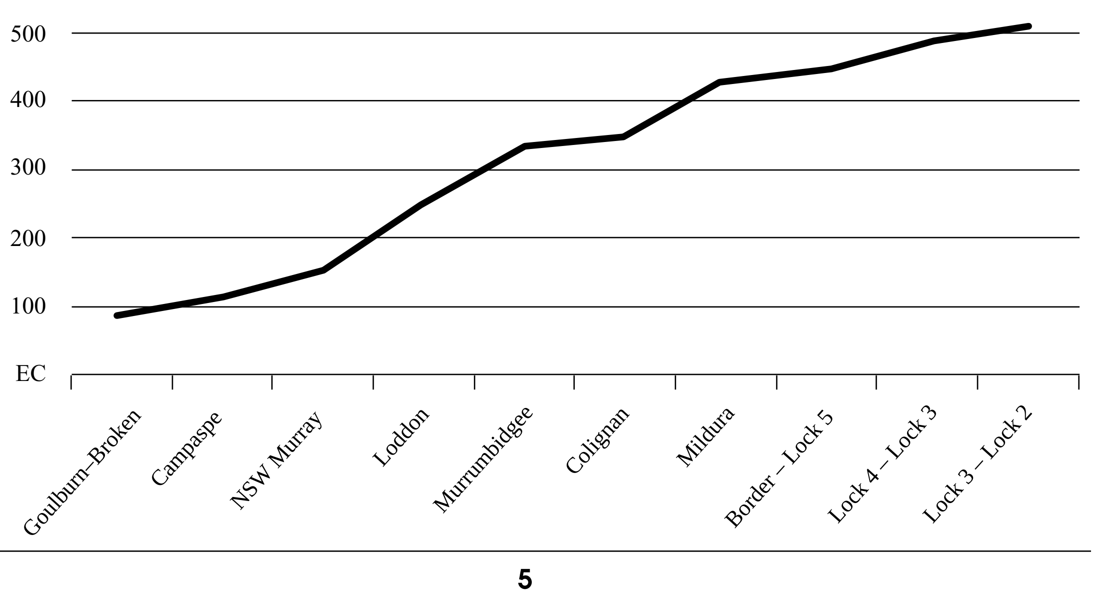


The transaction costs associated with trying to fully internalise all the downstream impacts may be prohibitively high. Nevertheless, establishing site specific conditions on property rights associated with return flows may still lead to an improvement in economic welfare. To determine the potential magnitude of benefits of establishing such rights, a catchment scale model within which the direct and downstream impacts of changes in irrigation practices was developed.

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 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 is depends, among other things, on 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 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 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, *j*, specified: 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) $$\sum_j sw_j \le sw^*,\ \sum_j gw_j \le gw^* \text{ and } \sum_j L_j \le L^*.$$

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 for irrigation and cgw is the unit cost of ground water 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)
$$\alpha_{swj}(t) = \frac{\alpha_{sej}^{\max}}{1 + \exp\left(\mu_{0j} + \mu_{1j} EC\right)}$$

where μ_0 and μ_1 are productivity impact coefficients determined for each activity and $\alpha_{swj}{}^{max}$ is the level of the technical coefficients 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 evapotranspiration, surface water runoff and ground water recharge. Evapotranspiration is 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 evapotranspiration. In horticultural areas such as western Victoria and the South Australian Riverland, irrigation efficiency ranges between 75 and 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 can approach 50 per cent.

The excess, precipitation and irrigation water less evapotranspiration, 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 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.

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, which 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.

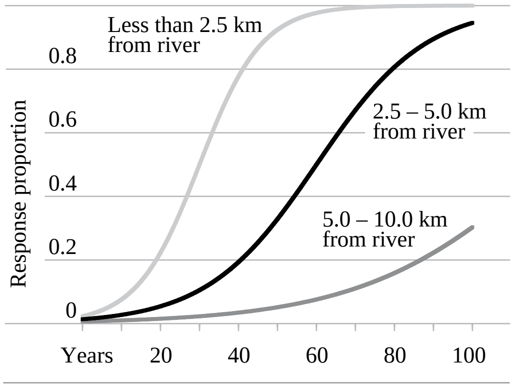
Assuming the contributions of recharge are additive and uncorrelated over time, it is possible to model gross discharge directly, thereby avoiding the need to explicitly model ground water levels. In the approach adopted here, total discharge rate *D* in year *t* is a logistic function of a moving average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

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

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.

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.

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



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.

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 water. That is:

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

where

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

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

Irrigation area	Main irrigated activities	Water allocation Murray	Water allocation Tributary	ET fraction [a]	Recharge fraction [b]	Ground water salinity
		GL	GL	%	%	mg/L
Goulburn–Broken	Pasture, cropping and horticulture	320	853	65	50	1 000
Campaspe	Pasture and cropping	207	75	50	60	5 000
New South Wales Murray	Pasture and cropping	2 464	0	65	75	2 000
Loddon Barr Creek, Cohuna	Pasture and cropping	371	30	65	75	2 000
Loddon Tragowel	Pasture and cropping	455	0	55	75	9 725
Murrumbidgee	Pasture, cropping and horticulture	0	2 045	65	80	1 000
Colignan	Horticulture	59	0	80	100	10 000
Mildura	Horticulture	188	0	80	100	25 000
Border – Lock 5	Horticulture	85	0	80	100	25 000
Lock 4 – Lock 3	Horticulture	93	0	80	100	21 000
Lock 3 – Lock 2	Horticulture	71	0	80	100	33 000

a The percentage of irrigation was lost to evapotranspiration. **b** The percentage of excess water (irrigation water and precipitation less evapotranspiration) that enters the ground water system.

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 for irrigation and $c\tilde{g}w$ is the opportunity cost of ground water for 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 then 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 agricultural 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 fifty 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 567 EC currently to 650 EC by 2050. This increase in salt concentration is expected to result in a decline in agricultural returns of almost $300 million, in net present value terms (NPV) using a discount rate of 5 per cent, and to impose costs to agricultural, urban and industrial water users downstream of Morgan of $42 million NPV over the fifty year period.

Two series of simulations were conducted for each of the major irrigation areas on the Murray River system to allow a comparison of the internal and external costs or benefits of changes in irrigation allocations and practices relative to the baseline scenario. The irrigation areas under consideration are listed in table 2 in upstream to downstream order and shown in map 1. Internal impacts are derived within the irrigation area undertaking the action whereas external impacts are those derived downstream of the area undertaking the action. In the first series, water allocations were reduced by 20 gigalitres in each irrigation area. These reductions were sourced from the Murray River as opposed to the tributary rivers. The internal and external costs and benefits associated with a reduction in water allocations and return flows were then calculated over a fifty year time 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 and Cohuna	Kerang
Loddon – Tragowel Plains	Kerang
Murrumbidgee	Griffith
Colignan	Robinvale
Mildura	Mildura
South Australian border to Lock 5	Loxton
Lock 4 – Lock 3	Loxton
Lock 3 – Lock 2	Loxton

In the second series of simulations, irrigation efficiency was increased by 5 per cent. With the increase in efficiency the fraction of irrigation water applied that reduction in the volume of irrigation water applied results in the same crop yield. It was assumed that irrigators retain all water savings and use those savings to expand irrigated production. Hence the reduction in surface water and ground water recharge will be less than 5 per cent, depending on the absolute level of irrigation efficiency. This series illustrates the impact of changes in volumes of water available for irrigation, as downstream allocations are determined as shares of available flows. Again, the internal and external benefits and costs were calculated over a fifty year time period.

Results

Reduction in water allocation

The external impacts of a reduction in allocation on water quality arise from two sources that may produce either benefits or costs at different locations along the river system. 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, a reduction in ground water recharge owing to the reduction in irrigation allocation results in reduced discharge from the ground water system and will lower salt loads over time. The effect on salt concentration of the Murray River will depend on the difference in salt concentration between ground water and stream flows at different points along the river.

The internal costs and the external benefits derived from 20 gigalitre reduction in irrigation water allocations are shown for each irrigation area in figure 3. The internal costs are a result of forgone irrigated production, with the highest costs incurred in the areas dominated by horticulture.

The external benefits from a reduction in water allocation vary substantially between irrigation areas. In the upper catchments of Victoria and New South Wales where recharge is high owing to low rates of irrigation efficiency, the external benefits are high relative to the value of water use despite low levels of ground water salinity. This, in part, reflects the location of these irrigation areas in the upper reaches of the river system and the predominance of low value irrigated agriculture.

In contrast, in the South Australian Riverland and Western Victoria, the external costs of water use are large because of the high levels of ground water salinity. The reduction in the ground water discharge component of irrigation return flows reduces the volume of salt transported to the river and improves the quality of water for downstream uses.

Figure 3: **External benefits and internal costs per megalitre of a 20 gigalitre reduction in water allocations**

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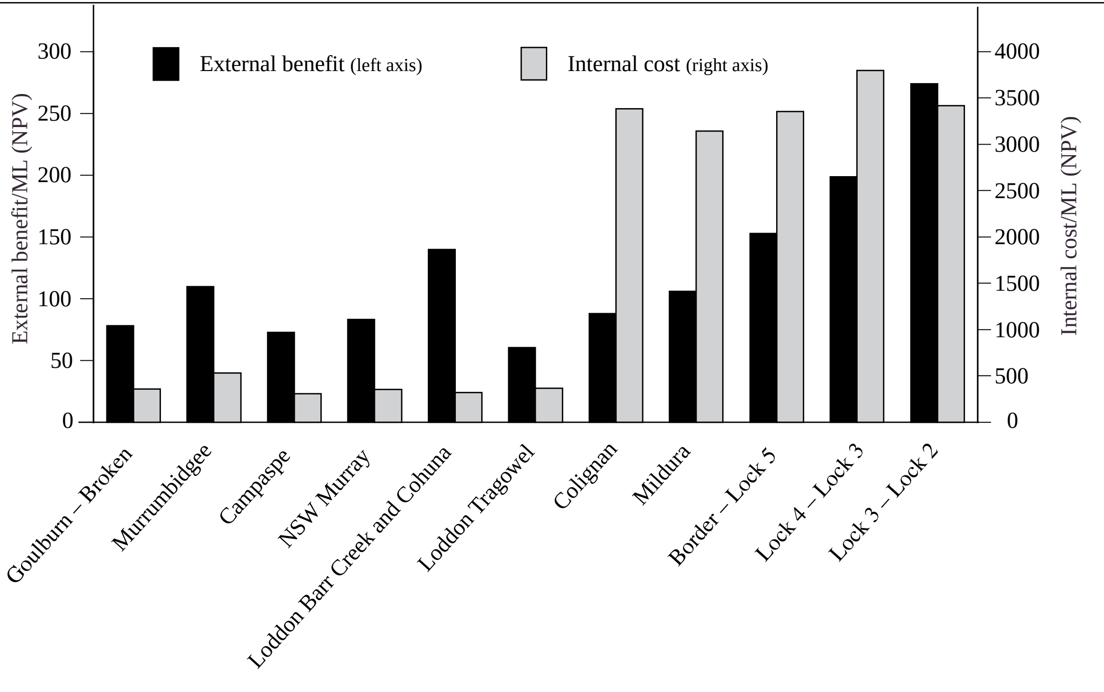


However, the internal costs incurred as a result of forgone irrigated activity are also high as these regions are dominated by high value horticultural production.

These findings demonstrate the potential impacts of trade in water between irrigation areas. Trade in water rights between regions would alter the distribution of internal costs and external benefits. If water from the Goulburn–Broken was traded to the reach between Lock 3 and Lock 2, for example, the cost of forgone agricultural production in the Goulburn–Broken would be around $355 a megalitre. The net effect of trade would be to increase the external costs of irrigation by almost $200 a megalitre, from around $75 a megalitre in the Goulburn–Broken to around $275 a megalitre between Lock 3 and Lock 2. To put this into perspective, the price of permanent water entitlement in a South Australian irrigation area has been reported to be around $500 a megalitre (Samaranayaka, Freeman and Short 1998). To fully account for the externality associated with trading from the example above, the price of permanent water allocation would need to increase by 40 per cent to around $700 a megalitre.

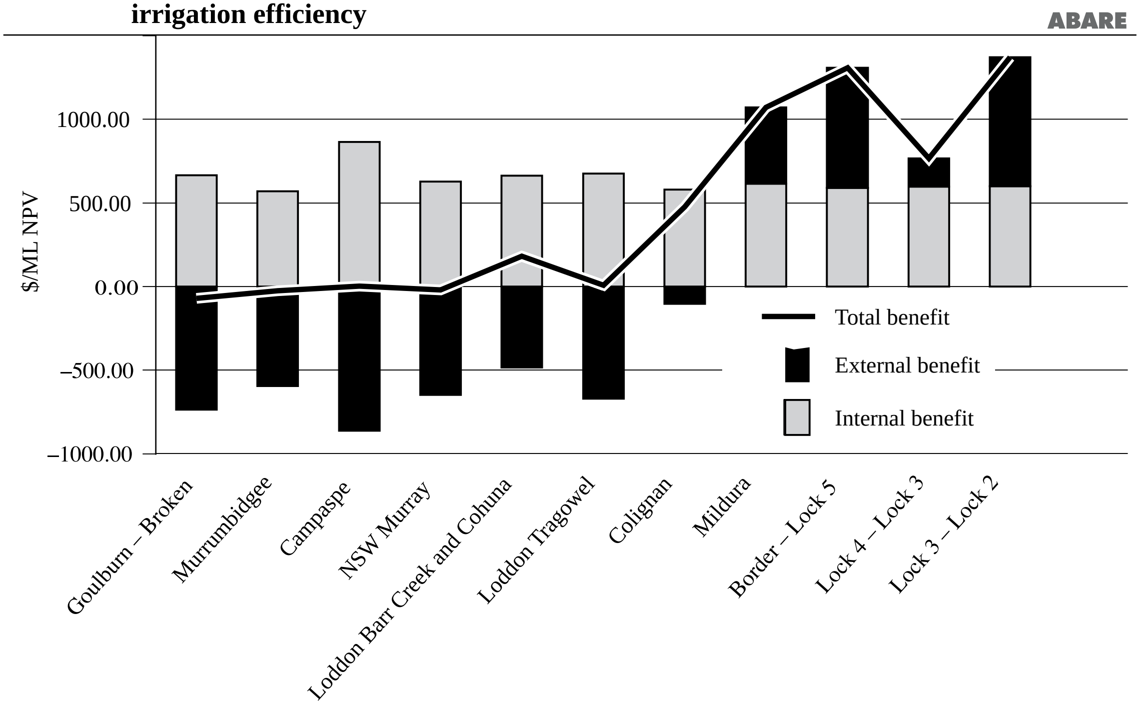
In contrast, while trading water upstream from, for example, the Loddon Bar Creek and Cohuna irrigation areas to the New South Wales Murray would not substantially alter the agricultural returns to irrigation, it would generate an external benefit. This benefit arises because the externality associated with irrigation in the Loddon Barr Creek and Cohuna area is higher than that associated with the New South Wales Murray. The net reduction in the external cost of irrigation as a result of upstream trade between these two areas would be around $60 a megalitre.

However, in both of the examples above, the individuals who trade do not accrue all benefits and costs associated with a change in water quality. Hence, even if there was a property right associated with the physical change in return flows at the source and destination, its traded price would not reflect its full value.

Improvements in irrigation efficiency

Internal benefits from increased irrigation efficiency are derived from an increase in agricultural revenue stemming from the increased availability of irrigation water (figure 4). External salinity benefits from improvements in irrigation efficiency are derived from reductions in the discharge of saline water directly into streams, which leads to a reduction in the salt load and concentration of river flows and, hence, an improvement in the quality of water available for downstream users. The extent to which a reduction in salt loads and concentration is achieved depends on, among other things, the volume of the reduction in recharge and the underlying ground water salinity. As a result of the improvement in water quality, agricultural yields and revenue increase. The main driver of the benefit profile is the response time of the ground water aquifer, with shorter response times generating water quality benefits sooner. External benefits are only derived as a result of improvements in

Figure 4: **External benefits and costs per megalitre of a 5 per cent increase in irrigation efficiency**



irrigation efficiency in the lower reaches of the Murray River system where ground water salt concentrations are high and ground water response times are short relative to those in the upper reaches of the system (figure 4).

An improvement in irrigation efficiency in the upper catchments generates an external cost. As these areas are characterised by large volumes of surface water runoff and low ground water salt concentrations, the reduction in return flows from irrigation increases salt concentration in the Murray River reducing the productivity of irrigation water in downstream uses. Further, under conditions where total extractive use is capped, the reduction in return flows reduces the quantity of irrigation water available for use in downstream irrigation areas.

Concluding remarks

Water trade and increased irrigation efficiency can affect return flows and have subsequent impacts on downstream allocations and water quality. These downstream impacts of changes in return flows are very diffuse and, in the case of water quality, generate both positive and negative externalities at different points along the river system. As those who engage in water trade and invest in improved irrigation efficiency do not bear the external costs or benefits of their actions, the level of action undertaken is likely to be suboptimal from the combined perspective of all water users.

Irrigators presently have an implicit right to the return flows in that they can trade or save water without consideration of any downstream externalities that their actions generate. To achieve an economically efficient level of trade or investment in irrigation efficiency, the downstream costs or benefits associated with changes in return flows need to be internalised into the decisions faced by upstream irrigators. Because these impacts are very diffuse, the transaction costs associated with establishing property rights that fully internalise the effect of return flows on downstream users are likely to be prohibitive. However, there may be potential economic gains from attaching site specific conditions to the implicit rights to return flows. In the case of trade, this may take the form of charges or subsidies attached to trade that lead to higher or lower costs associated with downstream changes in river salinity.

In the case of improved irrigation efficiency, investment incentives should reflect the net downstream impacts of reduced return flows. Irrigators' rights to water saved through improved efficiency will influence their incentives to adopt or invest in water saving practices and technology. To have an economically efficient level of investment in improving irrigation efficiency the nature of these rights will be location specific. For example, in the upper catchments where there are negative externalities from reduced return flows, irrigators may be entitled to retain a proportion of the water saved. In the lower reaches of the Murray River where there are positive externalities associated with reduced return flows, irrigators may need to receive compensation in excess of their water savings to generate an efficient level of investment.

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