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Integrated Water Resources Management In The Murray Darling Basin, Australia

Qureshi M. E., Kirby, M. and Mainuddin, M.

CSIRO Land and Water, Acton ACT 2601

Abstract

The Murray Darling Basin is a vital region of Australia - producing a significant proportion of the nation's food, supporting rural populations, and providing many recreational and cultural values. Water is central to the wealth and regional growth, and indeed all benefits generated in the Basin. However, rising environmental consciousness among society along with scientific evidence indicate that irrigation and dryland salinity are major threats to the sustainable use of natural resources in the basin. Also, there is concern that climate change may reduce the quantity of water in the rivers and the groundwater aquifers. Sustainable use of natural resources in the basin requires a balance between extractive and nonextractive uses, and this could lead to a reduction in water for irrigation. Less water for irrigation will have major impact on the regional and the national economy unless a significant effort is made to increase the value of water by not only maximising the efficiency of the current system but also by changing the future water use patterns. This study adopts an integrated biophysical and economic modelling framework that accounts for the interactions between water allocation, farmer input choice and economic gains from improvement in the allocation and efficiency of water use. A biophysical model estimates rainfall runoff, water used by agricultural activities, stored in dams, flood into floodplains and wetlands and discharges into ocean, and several scenarios are simulated under alternative land use patterns. An optimisation model is being developed to estimate true economic value of (irrigation) water use in different sectors and regions. With the model, we examine the impacts of alternative policy options on several sectors and regions.

Keywords: water quantity, quality, optimisation, biophysical, economic, modelling.

Introduction

The Murray-Darling Basin (MDB) is Australia's most important agricultural region, accounting for around 41 % of the nation's gross value of agricultural production. The Basin supports almost one third of the nation's cattle herd, half of the sheep flock, half of the cropland and almost three-quarters of the nation's irrigated land (ABS Agricultural Census 1996-97, see figure 1).

The Murray Darling Basin is the third largest of Australia’s 12 main hydrologic divisions, and covers just over one million square kilometres, or about 1/7 of Australia (Figure 1). It includes Australia's three longest rivers, the Darling, the Murray, and the Murrumbidgee.

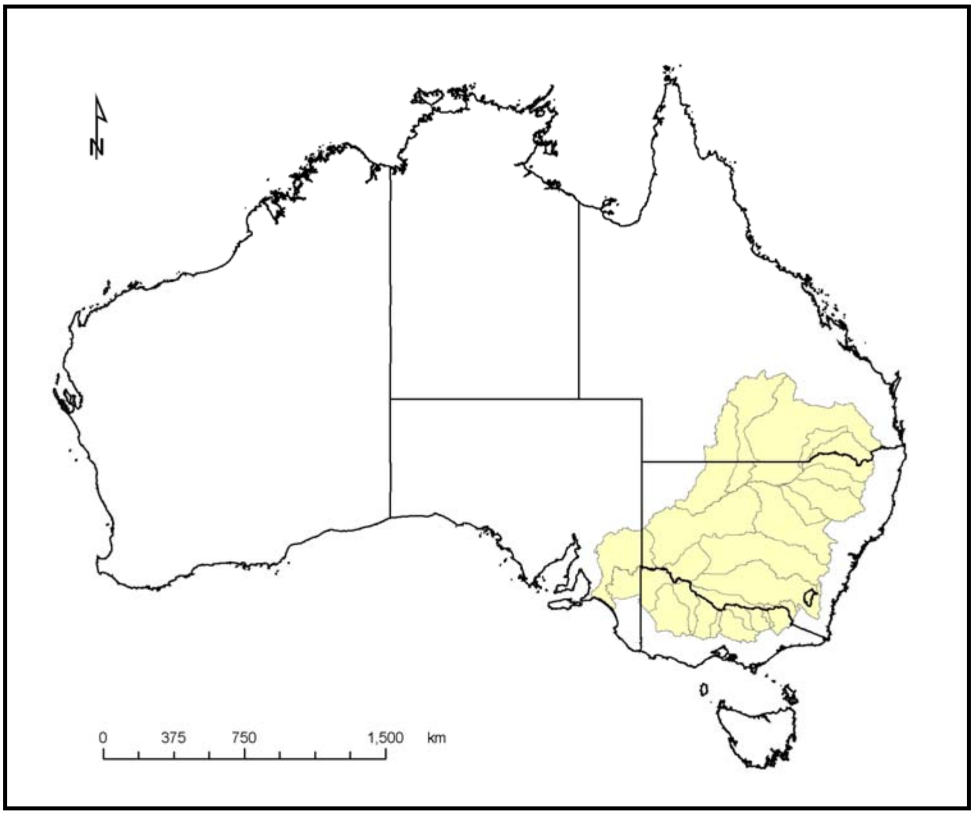


Figure 1: The shaded area represents the location of the Murray Darling BasinThe borders of the Australian states are also shown.

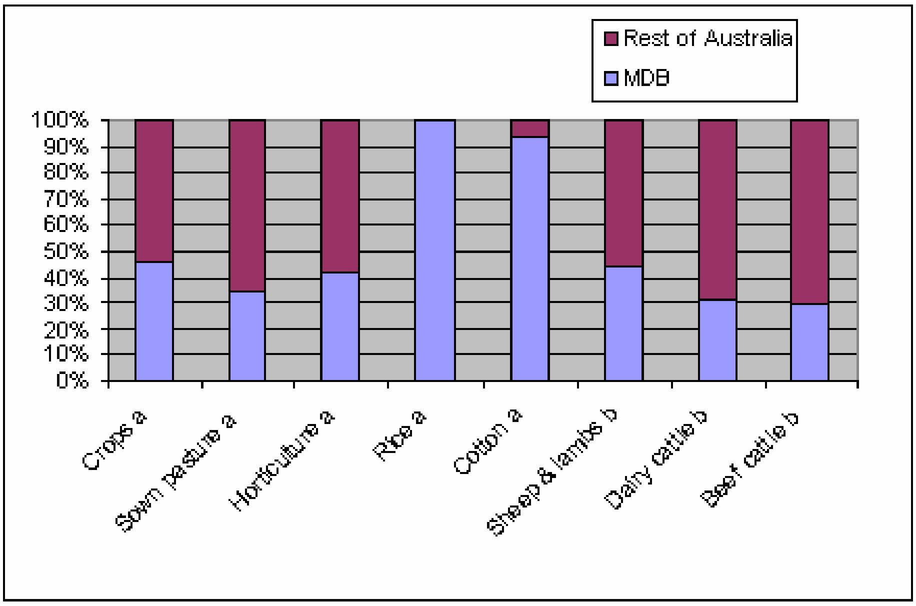


Figure 2: Proportion of activity contained within MDB Source:Estimates drawn from the ABS Agricultural Census 1996-97. a) Area of activity (ha). b) Number of livestock.

Most of the agricultural land in the MDB is devoted to grazing and around 12 per cent, or 9.8 million hectares, to crops. While the landscape is dominated by dryland agriculture, irrigated agriculture also plays an important role in the economic development of the Basin. Most irrigated land is used for pasture, but there are also significant areas of irrigated crops such as cereals, cotton, rice, fruit, vegetables, grapes, oilseeds and legumes (Figure 2).

In summary, the development and management of the Basin has been a major contributor to national income and community well being. However, in realising these benefits some undesirable legacies, in the form of land, water and vegetation degradation, have been left for current and future generations. While the magnitude of environmental problems in the MDB is becoming increasingly well understood, actions to address these problems are not costless.

Water is central to the wealth and regional growth patterns, and indeed all benefits, generated in the Basin. Managing and utilising the water resources efficiently is a challenge to the management authorities. Given limited water resources and inefficient utilisation of water, water scarcity and mismanagement will certainly hamper the growth and development of regional and national economies along with significant damage to the environment. Plans to increase the environmental flows to enhance river health mean that some economic benefits from irrigation will be forgone. Many issues must be addressed to effectively manage water resources. These include a better understanding of significance of increased environmental flows in enhancing environmental quality as well as identification of the relative costs and benefits of these actions to society.

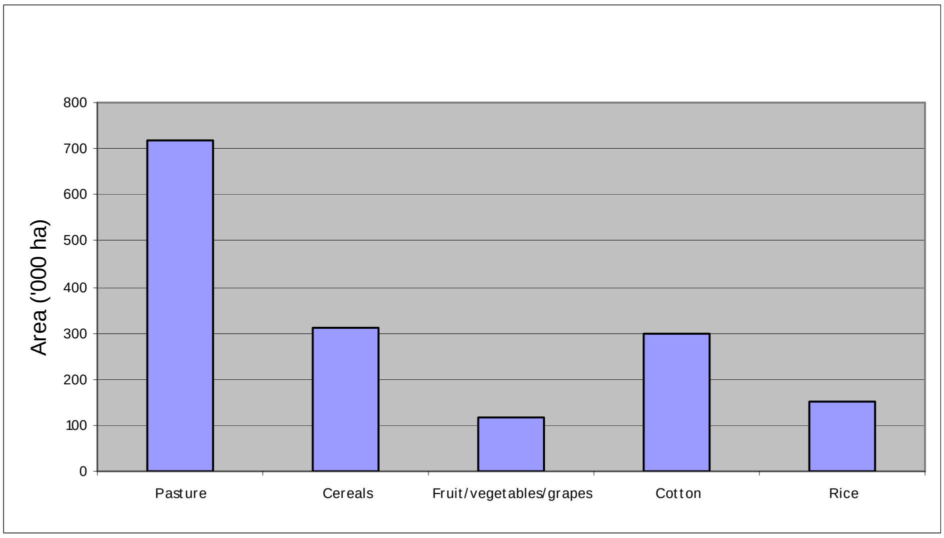


Figure 3: Irrigated area (ha) by activity in MDB

Water authorities face a great task in better water resources management, especially in irrigated agriculture, along with maintaining or enhancing environmental quality of the basin. This requires a balance between competing uses and can only be achieved when water is allocated to uses where returns are highest. To achieve sustainable water management, both demand and supply management strategies should be integrated into water management policies. Better water management can reduce the increasing gap between water available (supply) and water required (demand) for agricultural and non-agricultural uses and help meet the increasing demand for water in-stream (or environmental) uses. Economics can guide the development of water resource management strategies which have potential to increase the value of water. However, for a comprehensive analysis that can provide insights into why these problems emerged, how they might be solved at least cost, or indeed whether it is worth solving them at all is essential.

We have developed an integrated biophysical-economic model for the basin which optimises water allocation based on an objective function and accompanying constraints. The output of biophysical simulation modelling is used as input to the optimisation model with several cost and benefit functions. Though the aim of the whole project (and the on-going research) is to account for all costs and benefits, this paper focuses only on irrigation water use and optimal allocation in several agricultural activities in several regions of the basin.

Economic and environmental importance of MDB

The Basin provides drinking water for about 3 million people, including one million outside its borders. The Basin has many landscapes, ecosystems, land uses and climates. Within the Basin are 11 Ramsar wetlands.

Changes to land use and river management have lead to pressure on the Basin's resources, and concern over water quality and ecosystem health (MDBC, 2001). One indicator of changed river management is that the median annual flow to the sea is now only 27% of the natural (pre-development) flow. Competition for scarce water resources is increasing between agricultural, urban and environmental uses. Increased knowledge and strengthened institutional arrangements are seen as necessary for long-term sustainability of the Basin.

Land use and river management are more intensively developed in the Murray Basin, which is the southern one third of the Murray Darling Basin. About 83 % of the irrigation water use in the Murray Darling Basin is in the Murray Basin. Changed river flows have led to community concern about river health, and the Murray Basin is the focus of much current planning for environmental health and sustainability (MDBC, 2002).

Water available

The annual average rainfall, averaged spatially over the basin, is about 480 mm, giving a total of just under 500,000 GL of water. Over 90% is consumed as evapotranspiration (ET) by native vegetation, forests, crops and pastures. The remainder, about 24,000 GL, runs off into streams and lakes, and enters the river system. The water in the lakes and rivers evaporates, drains into groundwater systems, and drains to the sea. About half is diverted for use as shown in Table 1.

Table 1: Diverted water in the Murray Darling Basin and Murray Basin (the southern, more intensively developed, one third).

Diversions, GL	Murray Darling Basin		Murray Basin	
Period	Total	Irrigation	Total	Irrigation
1994-2003 (Annual average)	11,343	10,727	9,550	8,970
1996-7 (wet year)	12,298	11,825	10,304	9,862
2002-3 (dry year)	8,079	7,445	6,727	6134

(Source: MDBC, 2004)

Water uses

Irrigation

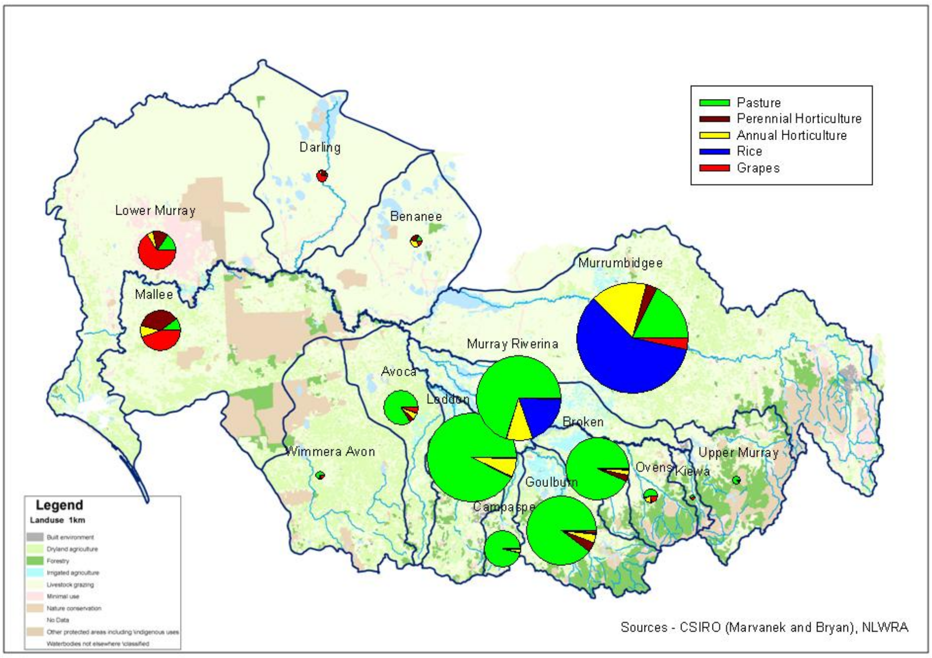
The main irrigation uses within the Murray Basin are shown in Figure 2. Pasture and rice dominate water use and production in the east and central part of the basin. Horticultural crops, vines and tree crops are grown in the central portions and dominate in the western part of the basin. These are generally higher value crops than pasture and rice, and water use and production of these crops is increasing. Many irrigation methods are practised. Flood irrigation is used, particularly for pasture and rice. Furrow irrigation is used on many horticultural, field, vine and tree crops, particularly in older schemes for vines and trees. More recent developments generally use sprinkler, drip or subsurface irrigation. Flood irrigation is the least efficient (more water is required for a unit of production) and, all other things being equal, causes the greatest environmental problems such as rising water tables and increasing salinity. Sprinkler, drip and subsurface irrigation are the most efficient irrigation technologies. Use of low efficiency flood and furrow irrigation is declining, whereas use of the more efficient, but more capital intensive methods, are increasing.

Hydropower generation

Some of the water in the Basin is used to generate hydroelectricity. However, this is not a consumptive use and the water remains available for other uses. We do not account for hydroelectricity here.

Urban-industrial water uses

Other uses, primarily urban water supply, are small, generally amounting to no more than about 600 GL, or about 6 % of total use.



Sources - CSIRO (Marvanek and Bryan), NLWRA

Figure 4: Major irrigation water uses in the Murray Basin (southern one-third of the Murray Darling Basin).

Urban-industrial water uses

Other uses, primarily urban water supply, are small, generally amounting in addition to above direct uses of water, the river system's waterways provide recreation in the form of indirect uses such as swimming, fishing, boating and camping. The river systems also provide a range of environmental amenities such as flora and fauna, estuarine, heritage and cultural links along with providing a sink for waste disposal and a mode of transport. Often direct use and indirect use values conflict, because of the competing uses for the limited water resource. Even within irrigation, which is largest user by volume, there is competition amongst different sectors in several parts of the basin (Freebairn, 2001).

Strategies for sustainable water resources

State and Federal Governments through the Murray Darling Basin Commission (MDBC),[12] are responding to these emerging issues. Since 1989they have established a limit on water diversions (the Cap), promoted salinity management and greater technical efficiency on farms, and established environmental flows through the recent Living Murray initiative of the Murray-Darling Basin Ministerial Council which is aimed at restoring the health of the River Murray and the Murray-Darling Basin (MDBC, 2002).

Finding a balance between extractive and nonextractive uses (such as the riverine environment) has been highlighted in an audit of water use in the Murray Darling Basin. Achieving this balance may require a reallocation of water away from irrigation to the environment. Recently, the Council of Australian Government committed $500 million over five years to address the issues of overall allocation and/or reduction in allocation (Goesch and Heaney, 2003).

Governments will need to consider a range of alternatives when addressing these issues, achieving maximum return from the investment and maintaining sustainable use of water resources. The overall aim of the governments will be to increase the social welfare either through investment and/or through reallocation of water from low to high value activities. This is because economic efficiency criterion requires allocation of water to the point where marginal social benefits in one activity, location and time equals the marginal social benefit, or opportunity costs, in other activities, locations or times.

Market forces of price coordination are believed to achieve an efficient allocation if there are well defined property rights, minimal relevant external benefits and costs, the absence of sustained market power, and reasonable information. The issues to be considered for proper market functioning and for the sustainable use of water resources include:

- accounting for impacts of upstream uses on water quantity and quality and hence on downstream uses;
- accounting for return flows from irrigation, and their impact on water quality;
- accounting for social and environmental benefits and costs, as well as economic benefits and costs of water use;
- supply and demand management;
- water property rights and allocation rules;
- market mechanisms and other institutional arrangements for water planning and management; and
- changes to future water supply due to climate change and land use change (with increasing reafforestation in upland regions considered likely to reduce river flows).

An integrated modelling framework which accounts for biophysical and economic components is essential to understand and quantify these issues. However, many challenges remain. Water resource allocation and management water studies have generally been dominated by hydrologic analysis for flood control management and water resources planning from an engineering perspective.

At the same time, economic or policy analysis studies have usually focussed solely on profit maximisation of water uses for irrigation, industrial, and domestic purposes, conditioned on the amount of water supplied at the off-take or delivery point. Often, little information is exchanged between hydrologic and economic model components due to differences in the modelling techniques, namely simulation and optimisation (Ringler, 2001).

Integrated river basin model

In this paper we restrict attention of the modelling to the Murray Basin. Most (approximately 83 %) of the irrigation water use is in the Murray Basin (Table 1). The focus is on how water trading is resulting in shifts in water use within, and increasingly between, agricultural sectors and geographic regions in the Murray Basin.

We use an integrated biophysical and economic model. In the hydrology component, rainfall is partitioned into evapotranspiration and runoff. Runoff enters the rivers, where it may be diverted, lost to evaporation or other sinks, spill onto the floodplain, or flow out of the mouth. In a production component, irrigated crop yield is derived from diverted water and rainfall via production functions. The economic component seeks to optimise economic output of crop production, constrained by the available water.

Hydrology component

The model is based on annual rainfall and flows, and is shown schematically in Figure 3.

Land use, rainfall, evapotranspiration and run-off

Each of the sub catchments of the Murray Basin is divided into several land uses including forests, grazing, dryland cropping, irrigated pasture (dairy), irrigated rice, irrigated grapes, urban, and open water. Land use, distributed spatially, is the first set of input data.

Rainfall, distributed spatially, is the second set of input data. Rainfall is partitioned into evapotranspiration and run-off using the relationships developed by Raupach et al. (2001), using a method similar to that of Zhang et al. (1999).

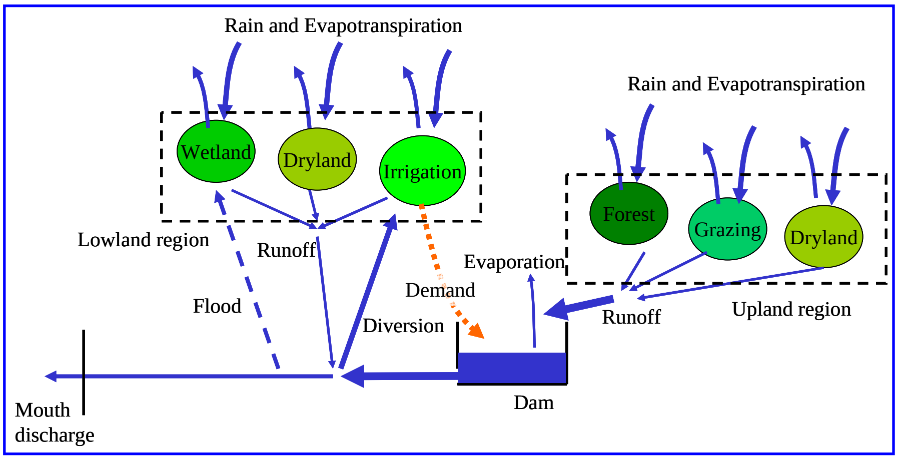


Figure 5: Schematic representation of prototype spatial model, land use and hydrology components. Two regions are shown, with three land uses each, whereas the model has 39 regions with several land uses each.

$$ET = ET_{Pot}\left(\frac{\left(P/ET_{Pot}\right)^{a}}{\left(1+\left(P/ET_{Pot}\right)^{a}\right)}\right)^{1/a} \qquad (1)$$

Where ET is the actual evapotranspiration, ET_{Pot} is the potential evapotranspiration, P is precipitation, and a use an adjustable parameter which takes values from 1.5 for grass catchments to 2.48 for forested catchments. Equation 1 requires the spatial potential evapotranspiration, which is the third set of input data. Run-off, RO, is calculated from:

$$RO = P - ET \qquad (2)$$

Evaporation from open water, E, is calculated from a simple proportionality with potential evapotranspiration:

$$E = C_1 ET_{Pot} \qquad (3)$$

C1 is the proportion of actual evapotranspiration to potential evapotranpiration of each crop in each region. The evapotranspiration demand of irrigation is based on spatial water use data, taken from Bryan and Marvanek (2004).

River flows, diversions, floods, and discharge from the mouth

The run-off is partitioned into diversions (*D*), floods (*F*) and discharge from the mouth (*M*):

$$RO \quad = \quad D + F + M \qquad (4)$$

Floods are considered net of return flows and thus become ET of wetland vegetation.

Floods partly spill onto floodplain / wetland areas, and partly result in greater discharge at the mouth. The link between diversions and irrigation supply and demand is given in the below.

The mouth discharge is water remaining after other uses is satisfied, though we assume that in drought years irrigation use is moderated so that some water still discharges from the mouth.

We used a quadratic yield - ET crop response function to reproduce the non-linear form observed in studies such as those on wheat and sorghum by Keating et al. (2002), and on wheat, barley, and sugarcane by Gulati and Murty (1979) who reported that Y-ET relations for these crops are best described by quadratic functions of the form:

Agronomic component

$$ylda_{(rj)} \quad = \quad a_{(r,j)} + b_{(r,j)}\left(ETa_{(r,j)}\right) + c_{(r,j)}\left(ETa_{(r,j)}\right)^2 \qquad \textbf{(5)}$$

where

R	Irrigation demand sites (regions)
J	Cropping activities
$ylda$	Actual yield (t/ha)
ETa	Actual evapotranspiration (mm)
a, b, c	Crop yield response coefficients, which vary from crop to crop and from region to region.

The coefficients in equation (5) were derived by combining field data on yield and water requirements from Bryan and Marvanek (2004) and the slope of the FAO crop yield response function (Doorenbos and Kassam, 1979), and fitting the quadratic.

Economic component

The Objective Function

The economic component of the model seeks to determine the optimum allocation of constrained resources among competing uses or activities. It does this with a mathematical programming model to maximise an objective function of the aggregate net profit from water use for irrigation over the corresponding regions. These models are widely utilised in studies of resource allocation, including water allocation.

The net profit (π) from regions is equal to the aggregate revenue minus fixed cost, variable cost and water supply cost:

$$\begin{aligned} \max \quad \pi = & \sum_r \sum_j p_{(r,j)} \, ylda_{(r,j)} \, A_{(r,j)} \\ & - \sum_r \sum_j FC_{(r,j)} \, A_{(r,j)} \\ & - \sum_r \sum_j VC_{(r,j)} \, A_{(r,j)} \\ & - \sum_r \sum_j WCh_{(r,j)} \, A_{(r,j)} \, w_{(r,j)} \end{aligned} \qquad \textbf{(6)}$$

Where

p	Crop price (\$/ha)
$ylda$	Actual yield (t/ha)
A	Harvested area (ha) – the decision variables
FC	Fixed cost (\$/ha)
VC	Variable cost (\$/ha)
WCh	Water charge (\$/ml)
w	Water delivered (ml/ha)

Water delivered ($w_{(r,j)}$) for region *r* and activity *j* (ML/ha) is calculated as:

$$w_{(r,j)} = \frac{\left(ETa_{(r,j)} - EffRain_{(r,j)}\right)\big/100}{IrriEff_{(r,j)}} \qquad (7)$$

where for each irrigation region *r* and cropping activity *j*

ETa	Actual evapotranspiration (mm)
$EffRain$	Effective rainfall (mm)
$IrriEff$	Overall irrigation efficiency

Water Constraints

Water availability constraints are of the general form:

$$\sum_r \sum_j w_{(r,j)} A_{(r,j)} \leq TotWat \qquad (8)$$

where *TotWat* is the total available water (ML), and is taken to equal *D*, the water available for diversions. This water constraint ensures that the sum of the amount of water required by all crops *j* and region *r* will not exceed the total amount of water available.

$$\sum_j w_{(r,j)} A_{(r,j)} \leq WatR_r \qquad \forall\ r \qquad (9)$$

where $WatR_r$ is the water available for each region (ML), assumed to equal D_r, the water available for diversions in any region. These water constraints ensure that the total of the water quantities required by all crops in any region will be limited by the total water available in that region.

Land Constraints

The equations for land availability constraints are of the form:

$$\sum_r \sum_j A_{(r,j)} \leq TotLand \qquad (10)$$

where *TotLand* is the total available area for irrigation (ha). This land constraint ensures that the sum of the land areas required by all regions *r* and crops *j* will not exceed the total available area for irrigation.

$$\sum_j A_{(r,j)} \leq LandR_r \qquad \forall\ r \qquad (11)$$

where $LandR_r$ is total available area for irrigation for each region (ha). These land constraints ensure that the sum of the land areas of the crops under each region will not exceed the area available for irrigation in each region.

A non linear programming (NLP) structure has been selected instead of the more common linear programming approach primarily because of the nonlinearities involved in the relationships between crop water stress and crop yields. The NLP obviously offers much greater flexibility in model structure. The model has been coded in the modelling language of the General Algebraic Modelling System (GAMS) (Brooke et al., 1988). GAMS is a high level modelling system for mathematical programming problems. A nonlinear solver MINOS5 has been used in model simulation.

While the volume of water trade has increased in recent periods, trade in permanent water entitlement remains small – less than 1 per cent of diversions in 2001-02. Further, less than 1 per cent of the volume traded in both temporary and permanent entitlements was traded between regions (MDBC, 2003). The main reason for these low levels of interregional trade is the constraints imposed on trading water out of local valleys and interstate by irrigation authorities or corporations (Heaney et al., 2004). Therefore, the model developed here, represents short term possibilities by allowing only intraregional trade of water.

Nine agricultural activities which occupy most of the Murray basin are considered in the analysis, including vegetables, oilseeds, fruits, cereals, legumes, pasture for beef and pasture for dairy. These activities may compete for water and land resources in a catchment depending on total land under each activity and required volume of water. In the short run, these land areas are constant for each activity. The model assumes that output is a function of water only (i.e. water yield response function) and no contribution of land and capital is considered in the analysis. A single irrigation efficiency value is used for all agricultural activities and regions in the analysis. Once more information about on farm irrigation efficiency for each activity and region is available and accounted for, the optimal allocation of water and/or land usage will change. Due to lack of scientific information, external impacts of irrigation water by each agricultural activity at each site/region are also not considered in the analysis and their incorporation will also change the values determined for optimal allocation. Also, the model does not account for non-market values of water in the region. In our continuing research we plan to address these issues once the relevant biophysical and economic information is available. Of the thirteen regions (catchments) of the basin – Upper Murray, Kiewa, Ovens, Broken, Goulburn, Campaspe, Loddon, Avoca, Murray-Riverina, Murrumbidgee, Mallee, Wimmera-Avon and Lower Murray, only 11 regions are used to assess the impact of water trade. The irrigation in the other two regions - Upper Murray and Avoca - is minor, and we do not consider them in the model.

Data required for this modelling were collected from various sources as shown in Table 2. Water charges, charging strategies, and rules for security of supply all differ from region to region, and are under review in response to water reform (COAG, 2004; Heaney et al., 2004). For convenience, we assume that a single charging regime operates: this will show the main principles without the complication.

Results and policy analysis

The model simulations were structured to assess the economic impact of intraregional trade among competing agricultural activities under alternative water charging regimes. Given profit maximising behaviour of irrigators, it is expected that the land and water will move from low value crops to high value crops until the incremental return among all activities is equal. Cropping may also change towards agricultural activities which do not require irrigation water in those regions with effective rainfall high enough for crop evapotranspiration.

Table 2: A summary of data sources

Data	Source
Rainfall and reference crop evapotranspiration	Raupach et al. (2001)
Crop coefficient	Doorenbos and Pruitt (1984)
Yield response factor	Doorenbos and Kassam (1979)
Crop growing period	Lazenby and Matheson (1987), Lovett and Lazenby (1979), Jayasuriya and Crean (2000)
Runoff and irrigation water diversion	MDBC (2004)
Crop area, crop price, actual yield, fixed cost, variable cost and water costs	Bryan and Marvanek (2004)

Basin optimising solution (existing water charges)

In the existing charging system, different water costs (charges) are payable by irrigators to the water authorities. These charges (t/ha) estimated by Bryan and Marvanek (2004) vary from less than a dollar per ha to more than $300/ha. These are the charges that irrigators pay to the irrigation authorities and/or corporations in different regions for growing different agricultural activities. Using these charges, the model determined optimal level of water and land use by each activity in each region as presented in Table 3.

These results are the theoretical optimal areas for each crop, under the simplifying assumptions of the analysis that a decision-maker allocates water to most profitable uses. These results do not necessarily compare to the current actual areas, since these are not necessarily optimal, and also have arisen under conditions different from our simplifying assumptions. Only 33% of the existing area is used for agricultural production. Crops that demand large amounts of water and/or have lower economic values account for relatively less area in the model compared to the ones that demand small amounts of water and/or have higher economic values. The large reduction arises because some crops are no longer grown in some areas, and the water is no longer required. In reality, the unused water would be taken up by higher value crops, but that prospect was restricted in this scenario (we examine it in the next scenario).

Table 3: Optimal areas under each crop when base case water charges are used

	Rice	Grape	pBeef	Oilseeds	Fruits	Legumes	Cereals	Vegetables	Total area	Given area
Kiewa			132						132	1268
Ovens			482						482	6065
Broken	1259		11029		3808		4036	822	20954	111015
Goulb			12927				2812	2871	18610	129304
Campas			4045				1021	40	5106	37831
Loddon		537	5082	451	879		16480	3569	26998	204292
MRiver		761	14099	1070	150	180	53665		69925	243741
Murrum	80841	13047		4925	6421	2611	88028		195873	296319
Mallee					226			4760	4986	49655
WimAvon					60			308	368	5858
LMurray		14810	1132		3625				19567	31471
Total	82100	29155	48928	6446	15169	2791	166042	12370	363001	1116819

Basin optimising solution (existing water charges with no limit on area under each crop)

In this scenario, we relax the restriction of the area of each crop type in a region, and examine the situation when the base case water charges are used, but keeping the constraint on the maximum area available for all agricultural activities in the region. In this case areas are estimated to increase from the base case of 33% to 53%. Combination of crops and optimal areas are estimated to significantly change.

For example, legumes and cereals fall out of production from all regions. Pasture for beef is produced in Kiewa region only while grapes are produced in Ovens. The scenario is unlikely to be realised in practice, because of the time and capital required for such an adjustment. Lack of information, market failure, government failure and lack of property rights along with risk averse behaviour of individual growers/irrigators will also. However, the scenario does indicate the direction in which adjustment might progress (bearing in mind the simplifying assumptions we have made).

Basin optimising solution (constant water charges for all crops and regions)

Next, the model was used for systematic evaluation of the response of agricultural production to water charges ranging from $10/ML to $80/ML. In this analysis the same water charges for all activities in all regions were assumed. The results of the systematic increase of the water charges have been examined and for (selected) regions when only $10/ML were used are presented in Table 4.

When the water charges were increased from $10/ML to $60/ML, the total area under production is estimated to decline. The reduction in areas varies among the crops and the regions. Again this is due to the amount of water required and/or the return from a crop. Though there is difference in reduction of crop area among the crops, total area reduction is about the same as was in the case when existing water charges were used. Further increase in water charges again changes the combination of the existing crops.

Figure 6 shows estimated demand curves of water that depict the relationship between water charges and total quantity of water used in major regions of the basin. At the lower range of water charges considerd water demand is initially inelastic for all regions. In Goulburn, there is no demand for water once the water charges increase beyond $40/ML. The water demand in Murrumbidgee is inelastic until it reaches $80/ML. Then the water demand suddenly declines. Loddon and Compaspe are estimated to have similar water demand response to price changes.

In case of Lower Murray, there is slight change in water demand while Mallee remains inelastic as there is no change in demand of water even at the water charges of $80/ML. This indicates that the value of water for this region is much higher than the cost of additional water charges. Water usage and net profit for the whole basin at varying water charges are shown in Figure 7. Increase in water charges from $10/ML to $60/ML is estimated to reduce total basin net profit from $642 million to $465 million – a reduction of $177 million with a little affect on demand of water until the water charges are increased to $70/ML.

Conclusions

We have developed an integrated biophysical-economic model of a large river basin. The model includes hydrologic, agronomic and economic relationships. The model is applied to the southern part of the Murray Darling Basin, and can be applied in other basins due to its generic form and structure. In this paper, we have concentrated on economic outputs, but the model can be used to examine other aspects, such as the trade-offs between environmental flows and irrigation water use, and the impacts of changed hydrology such as those likely under climate change. Some of these aspects are described by Kirby et al. (2004).

The preliminary modelling presented here estimates possible economic gains to water trade and agricultural water demand response to changes in water prices. The water trade model results show the benefit of moving water from low value crops to high value crops when water rights trading exist. Net profits in irrigated agriculture increase substantially compared to the case of rights for each agricultural activity.

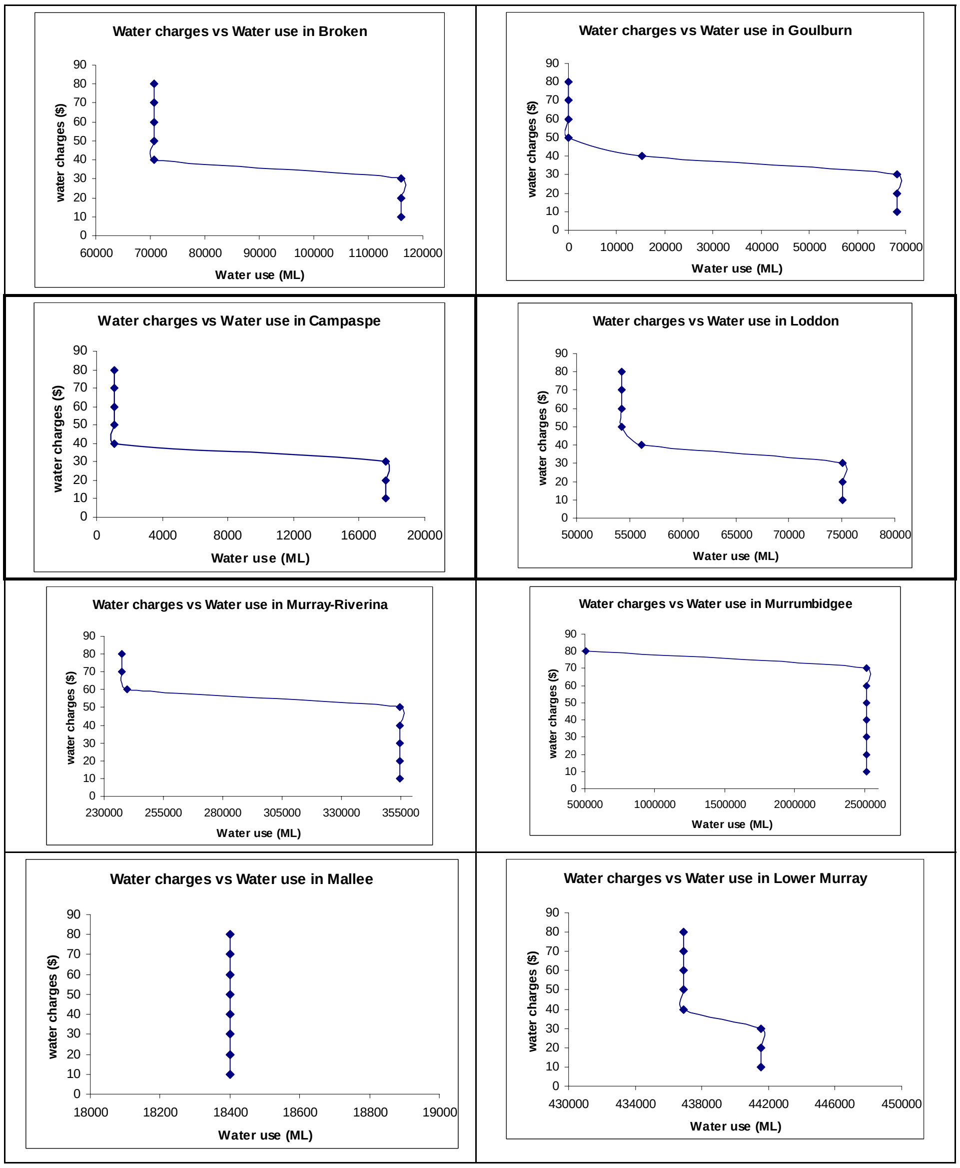


Figure 6: Water demand curves of selected regions in Basin

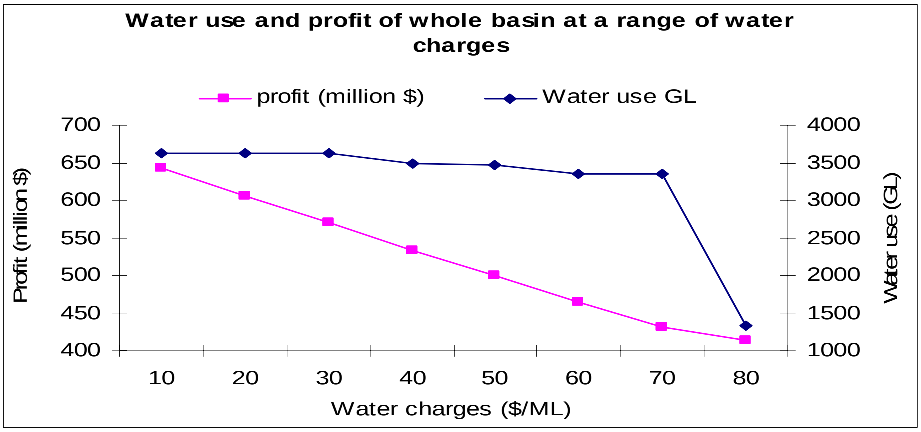


Figure 7: Aggregate water usage, profit at varying water charges in the basin

Table 4: Optimal areas under each crop and region when water charges are $10/ML.

	Rice	Grape	pBeef	Oilseeds	Fruits	Legumes	Cereal	Vegetables	Total area	Given area
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Broken	1259		11029		3808		4036	822	20954	111015
Goulb		1512	12927				2812	2871	20122	129304
Campas			4045				1021	40	5106	37831
Loddon		537	4636	451	879	452	16480	3569	27004	204292
MRiver	4626	761		1070	150		53665	1009	61281	243741
Murrum	80806	13047		4925	6421		88028	7258	200485	296319
Mallee					226			4760	4986	49655
WimAvon					60			308	368	5858
LMurray		14810	1132		3625			2036	21603	31471
Total	86797	32167	34234	6446	15169	452	166042	22673	363980	1116819

Although these preliminary results show the effectiveness of the model for policy analysis and water allocation across the crops in the basin, additional research is needed. Still several qualitative conclusions can be drawn:

1. The optimum area in irrigated crops is likely to decline in some areas of Basin. In our modelling as water charges increase in such region one crop after another becomes uneconomic and total water demand is significantly reduced.
2. Overall, increases in water charges (price) may not have a significant affect on irrigation water demand in the Basin, our modelling indicates that the irrigation water demand may only be price elastic at relatively high prices.
3. In reality, not all farmers have identical cost and capital structures, nor do they have equal management ability and hence revenue structures, so actual response to water price changes will likely be smooth not in abrupt steps as predicted here - further improvements in modelling are planned that should better account for this.
4. Reduction in allocation of water for irrigation may also have impact on other sectors and/or regions which are not
5. directly involved in irrigation. Computable General Equilibrium modelling is planned to examine these impacts on several sectors, regions and national economy.
6. The optimal areas by crop and region predicted here are unlikely to be realised in practice, at least not for a long time, because of capital, infrastructure issues and institutional restriction on water trade.
7. The optimal area and water usage may change once information about external impacts of irrigation (such as impact on water quality and other externalities) caused by each crop at each site is available and both private and social costs and benefits are incorporated in the analysis.
8. In modelling with restrictions on what might be grown where different optimal states are predicted than in unrestricted scenarios - indeed this can dictate whether the total area grows or shrinks.
9. There is likely to be pressure for change in property rights, as results presented here suggest that the current distribution of water by region is not optimal under current water charges.

References

Brook, A., Kendrick, D., and Meeraus, A., 1988. GAMS: A User's Guide, Scientific Press, San Francisco, California.

Bryan, B.A. and Marvanek, S., 2004. Quantifying and valuing land-use change for ICM evaluation in the Murray-Darling Basin 1996/97 – 2000/01. CSIRO Land and Water Stage 2 Report for the Murray-Darling Basin Commission.

COAG 2004. Intergovernmental Agreement on a National Water Initiative, An agreement between the Commonwealth of Australia and the Commonwealth of New South Wales, Victoria, Queensland, South Australia, the Australian Capital Territory.

Doorenbos, J. and Kassam, A. H., 1979. Yield Response to Water: FAO Irrigation and Drainage Paper 33, FAO, Rome.

Doorenbos, J. and Pruitt, W. O., 1984. Crop Water Requirements: FAO Irrigation and Drainage Paper 33, FAO, Rome.

Freebairn, J., 2001. Utilising water: some economic issues, 4th AARES Annual Symposium, Melbourne.

Goesch, T. and Heaney, A. 2003. Government purchase of water for environmental outcomes, ABARE ereport 03.22, prepared for the Natural resource management Business Unit of the Australian Government Department of Agriculture, Fisheries and Forestry, ,Canberra.

Gulati, H. S. and Murty, V. V. N., 1979. A Model for Optimal Allocations of Canal Water based on Crop Production Functions: Agricultural Water Management, 2(1), 79-91.

Heaney, A., Thorpe, S., Klijn, N., Beare, S. and Want, S., 2004. Water charges and interregional trade in the southern Murray Darling Basin, Establishing Australian water Markets Symposium, Melbourne.

Jayasuriya, R. and Crean, J., 2000. The Agricultural Impacts of Environmental Flow Rules in the Murrumbidgee Valley: NSW Agriculture.

Keating, B. A., Gaydon, D., Huth, N. I., Probert, M. E., Verburg, K., Smith, C. J. and Bond, W., 2002. Use of Modelling to Explore the Water Balance of Dryland farming Systems in the Murray-Darling Basin, Australia: Europ. J. Agronomy, 18, 159-169.

Kirby, M., Qureshi, M.E., and Mainuddin, M., 2004. Catchment behaviour and countercyclical water trade: an integrated model. Paper accepted for 2004 World Conference on Natural Resource Modelling, Melbourne, Australia, 12-15 December 2004.

Lazenby, A. and Matheson, E. M. (Eds.), 1987. Australian Field Crops 1: Wheat and Other Temperate Cereals: Angus and Robertson Publishers, London.

Lovett, J. V. and Lazenby, A. (Eds.), 1979. Australian Field Crops 2: Tropical Cereals, Oilseeds, Grain Legume and Other Crops: Angus and Robertson Publishers, London.

MDBC 2001. Integrated Catchment Management in the Murray Darling Basin 2001-2010: Delivering a Sustainable Future. Murray Darling Basin Commission, Canberra.

MDBC 2002. The Living Murray: a discussion paper on restoring the health of the River Murray. Murray Darling Basin Commission, Canberra.

MDBC 2003. Water Audit Monitoring Report 2001/02, Canberra.

MDBC 2004. Water Audit Monitoring Reports. Murray Darling Basin Commission, Canberra, available at http://www.mdbc.gov.au/naturalresources/the_cap/the_WAM_report.htm

Raupach, M.R, Kirby, J.M., Barrett D.J. and Briggs, P.R., Lu, H. and Zhang, L., 2001. Balances of Water, Carbon, Nitrogen and Phosphorus in Australian Landscapes: (2) Model Formulation and Testing. CSIRO Land and Water. Technical Report 40/01. Balances of Water, Carbon, Nitrogen and Phosphorus in Australian Landscapes: (2) Model Formulation and Testing. CSIRO Land and Water. Technical Report 40/01.

Ringler, C., 2001. Optimal Water Allocation in the Mekong River Basin, Number 38 ZEF – Discussion Papers on Development Policy, Bonn.

Zhang, L., Dawes, W.R. and Walker, G.R., 1999. Predicting the effect of vegetation changes on the catchment average water balance. CRC for Catchment Hydrology Report 99/12. Balances of Water, Carbon, Nitrogen and Phosphorus in Australian Landscapes: (2) Model Formulation and Testing. CSIRO Land and Water. Technical Report 40/01.