

groundwater and surface water use
in the dumaresq river valley:
a hydroeconomic model



abare research report 06.17

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november 2006

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ISSN 1037-8286
ISBN 1 920925 72 4

Hafi, A., Brownlowe, N. and Welsh, W. 2006, *Groundwater and Surface Water Use in the Dumaresq River Valley: A Hydroeconomic Model*, ABARE Research Report 06.17. Prepared for the Bureau of Rural Sciences and Natural Resource Management, Australian Government Department of Agriculture, Fisheries and Forestry, Canberra, November.

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ABARE is a professionally independent government economic research agency.

ABARE project 2932

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introduction

Recent groundwater modeling by the Queensland Department of Natural Resources and Mines showed that groundwater pumping in the Dumaresq River Valley at the full allocation of 30 gigalitres a year could result in significant depletion of the river (QDNRM 2003). This link between groundwater pumping and surface water flows has implications for the security of surface water allocations for downstream irrigators and for the way in which water resources are managed. In particular, there is the potential that some groundwater has been allocated to both (or shared between) groundwater and downstream surface water users.

While the current rate of groundwater pumping is substantially lower than total allocations, a number of economic factors could result in an increase in groundwater pumping in the valley. For example, Dumaresq River Valley irrigators could sell surface water to irrigators downstream within the Border Rivers catchment in response to change in economic conditions. In turn, this could lead to an increase in groundwater pumping if Dumaresq River Valley irrigators substitute groundwater for surface water. If a significant volume of surface water entitlements in the valley is traded out, it could potentially increase pumping of groundwater and consequently lower the groundwater table, resulting in increased river depletion.

In this report a hydroeconomic model is developed for the Dumaresq River Valley to investigate the impact of an increase in demand for groundwater pumping on stream depletion. The model has three linked components: an economic component, a hydrogeological component and an institutional component.

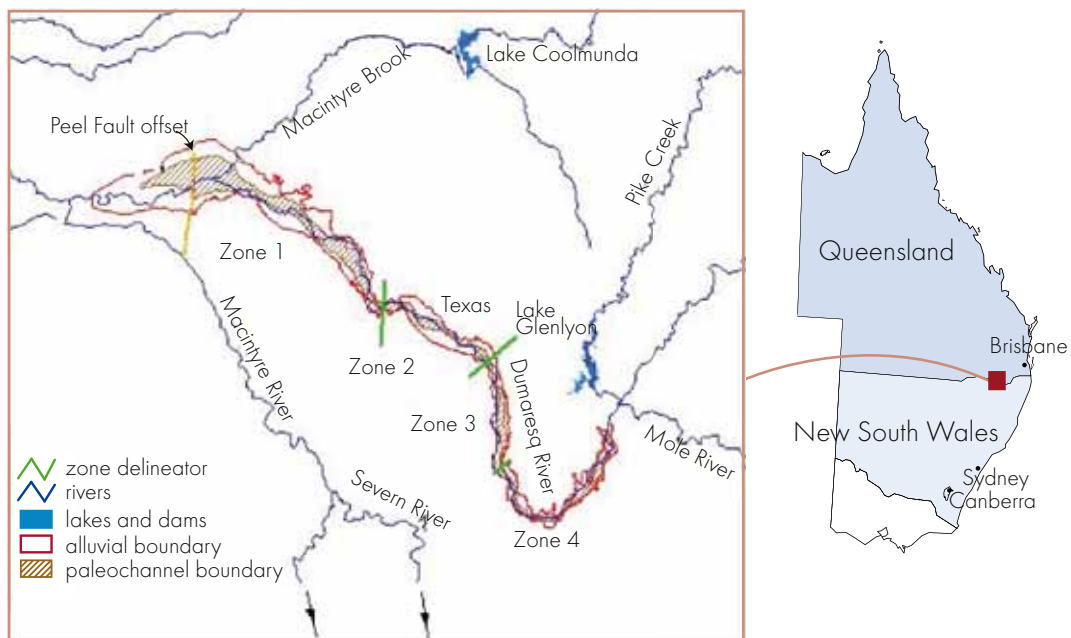
In the next section of the report the current use of land and water resources in the Dumaresq River Valley is discussed. Second, the specifications of the Dumaresq River Valley hydroeconomic model are outlined. Third, results of an application of the model to evaluate the impact on the groundwater table of a potential transfer of surface water through trade to downstream irrigators are examined. Finally, the implications of a falling groundwater table on stream depletion and downstream surface water rights are highlighted.

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the Dumaresq River Valley

The Dumaresq River Valley is located near Texas and sits across the New South Wales–Queensland border in an area more widely called the Border Rivers Region (map 1). It lies within the Dumaresq River subcatchment in the Border Rivers Basin and contains the Dumaresq and McIntyre Rivers and their tributaries. A wide range of crops are grown in the valley, including lucerne, barley, oats, soybean, maize, annual pasture, cotton and vegetables (table 4 in appendix B). The valley covers an area of 333 square kilometres and overlies a two-layer alluvial aquifer containing an estimated 4500 gigalitres of fresh groundwater at depths up to 90 metres. Groundwater is pumped from the aquifer, mainly during drought, to supplement water pumped from the Dumaresq River at an average rate of 5.2 gigalitres a year for irrigation. Surface water is provided on demand through releases from the Glenlyon Dam upstream. Average annual surface water use is estimated to be around 12 gigalitres for the Queensland and 5 gigalitres for the New South Wales sides of the valley (table 1).

map A **Dumaresq River Valley aquifer**



The current rate of groundwater pumping (5.2 gigalitres a year) is significantly lower than the total allocations of 30 gigalitres a year, which is shared between New South Wales and Queensland. The Dumaresq River and its tributaries are connected to the shallow aquifer, with water leakage to and from the aquifer occurring depending on the aquifer water table relative to the river water levels.

The New South Wales Department of Infrastructure, Planning and Natural Resources (DIPNR) and Queensland Department of Natural Resources and Mining (QDNRM) jointly manage the water resources in the valley in consultation with the Dumaresq and Barwon Border Rivers Commission (DBBRC). Groundwater allocation for the valley coming under each jurisdiction is capped at 15 gigalitres a year (Tennakoon 2002). The two States also have a total entitlement of 21 gigalitres a year of surface water to be pumped from the Dumaresq River (table 1).

On the New South Wales side of the Valley, a third of groundwater licensees have groundwater only licences, with the remainder having licences to use groundwater and surface water conjunctively. About two-thirds of the total New South Wales groundwater allocation for the valley is held by irrigators who hold groundwater only licences.

table 1 **groundwater and surface water allocation and use in the Dumaresq River Valley**

		groundwater		surface water	
		NSW	Qld	NSW	Qld
licences	no.	47	29	83	123
total allocation	ML/yr	18 046	12 011	5 176	15 689
average allocation	ML/yr	384	414	62	128
actual pumping (av 1993–2000)	ML/yr	2 262	2 898	5 100	11 600
share of allocation used	%	13	24	99	74

Source: Tennakoon (2002).

3

the model

The model has three linked components: an economic component, a hydrogeological component and an institutional component. The economic component models the use of water in the study area. The hydrogeological component models the groundwater and surface water flow processes and their interaction. The institutional component manages groundwater and surface water resources through institutional arrangements on the allocation of water resources and charging for the use of water.

The use of groundwater and surface water resources in the valley is regulated through water entitlements and the water authorities having control over water allocations made against these entitlements. It is assumed that these institutional arrangements are designed to achieve sustainable use of both resources. It is assumed that in each year, the irrigator's objective is to maximise annual profits from the use of groundwater, surface water and land resources subject to constraints on their availability. It is also assumed that:

- > irrigators pay water charges levied by water authorities
- > the prices of outputs and non water inputs are taken as given
- > the cost of pumping groundwater depends on the height of the groundwater table which is influenced by irrigators' pumping activities in the past
- > the height of the water table also influences river leakage.

An open access behavior within a regulated environment is modeled – that is, future costs imposed by current pumping activities are not directly incorporated.

For simplicity, moving from downstream to upstream the valley was divided into four contiguous zones (map 1). A planning horizon of thirty years is assumed. For each zone and each year, the model derives profit maximising land and water uses for alternative crops subject to surface water and groundwater allocations, recharge to the aquifer and leakage from or to the river. For each year, the model also factors in rainfall and crop evaporative demands during different times of the year. The decision variables include, for each year and zone, allocation of available land between alternative crops and allocation of available surface water and groundwater between months and for each month between crops. The allocation of available surface water within a year is important in the Dumaresq River Valley as crop evaporative demand far exceeds annual precipitation. An algebraic representation of the model is given in appendix A.

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data

A survey of water users in the Dumaresq River Valley was conducted in March 2005 to collect farm specific data. The survey collected data on:

- > land resources available
- > surface water and groundwater entitlements
- > crops grown in summer and winter under irrigation
- > surface water and groundwater use by crop
- > water application technology by crop
- > crop production technology
- > impediments and constraints in achieving higher incomes.

The results of this survey are summarised in appendix B.

For each of the four zones in the valley, data on land availability, groundwater and surface water entitlements and areas planted to different crops in 2003-04 were obtained from the survey results and information provided by DIPNR and QDNRM. In the model, lucerne, barley, oats, soybean, maize, annual pasture, cotton and vegetables are all identified as separate crops. For each crop, data on variable cost (\$/ha), harvest cost (\$/t), price of produce (\$/t) and maximum yield (t/ha) were obtained from crop budgets prepared for the northern New South Wales region by the New South Wales Department of Agriculture. For each crop, data on crop factors and yield response to moisture stress at different growth stages are obtained from Doorenbos and Kassem (1979). Historical data on rainfall and evaporative demand recorded at Bonshaw Post Office for the past thirty years was used to provide a realisation of the weather pattern.

For each zone, parameters of the relationship between the groundwater table, pumping and river leakage are required. These parameters were estimated by running the MODFLOW model developed for the Dumaresq River Valley, as explained in appendix A. For simplicity, it was assumed that interferences between pumping actions of individual zones through their impacts on respective groundwater levels are negligible. In other words, groundwater pumping by irrigators in the upstream zones does not affect the water table in downstream zones. The

justification for this assumption is that when groundwater licences are issued, water authorities attempt to minimise such interferences.

For each zone, the hydrogeological data required included:

- > the height of groundwater table
- > elevation
- > parameters defining the relationship between the groundwater table, pumping and river leakage.

For simplicity, the model treats the aquifer as one layer.

5

an application of the model

The model was applied to investigate the impacts on the groundwater table of trading surface water out of the valley and the resulting impact on surface water flows. If a significant volume of surface water entitlements is traded out of the valley, groundwater pumping could increase and result in the lowering of the groundwater table and an increase in river depletion. The downstream region has an average surface water allocation of around 300 gigalitres a year, compared with 13 gigalitres a year for the upstream region. For simplicity, it is assumed that the impact of sales of water to the downstream region has a negligible impact on the traded price of water.

scenarios

The model was run to produce a number of scenarios:

- > a base case in which it is assumed that surface water cannot be traded
- > a second scenario in which it is assumed that surface water can be traded temporarily (leased) at \$70 a megalitre to downstream users
- > a third scenario that repeats the second scenario with a water price of \$100 a megalitre.

The analysis is based on the assumption that irrigators will be able to access their full groundwater entitlement and receive 60 per cent of their surface water entitlement. Aquifer recharge from rainfall and runoff from hill slopes is held constant across the scenarios.

results

For each scenario simulated, the year to year variability observed in aggregate incomes, surface and groundwater use, volume of surface water traded and the level of the groundwater table are largely explained by the year to year variability in rainfall, crop evaporative demand and groundwater pumping cost. In each year, the groundwater pumping cost depends on the height of groundwater table at the

end of the previous year. The results on the water table are averaged across the four zones, while all other variables are aggregated across zones. In the base case, annual groundwater extraction levels over the next thirty years are projected to result in a drawdown of groundwater stocks (figure A).

In the base case, assuming adequate supplies, surface water will be used until the value of marginal product (VMP) of water use equals the water delivery charge. With a market for surface water downstream, surface water use will be reduced from the base case level to the point where the VMP equals the price of water in the downstream market less the delivery charge. The excess supply of surface water – the difference between the availability and the use determined at the price offered by the downstream market – is sold. The access to an alternative source of water supply in the form of groundwater facilitates trade of surface water out of the valley as groundwater substitutes for surface water in irrigation. Consequently, a market for surface water downstream is expected to reduce surface water use and increase groundwater use in the valley.

At a price of \$70 a megalitre, the bulk of the surface water available would be sold temporarily in each of the first twenty years (figure B). The use (sale) of

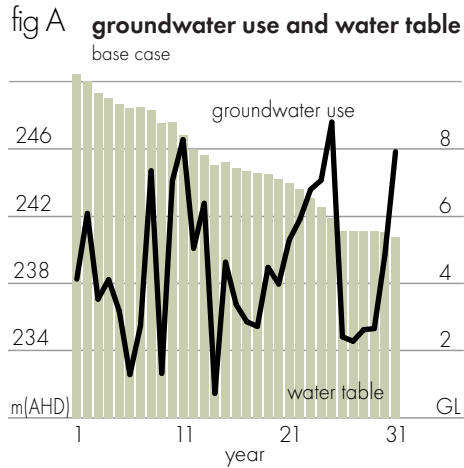


fig B **surface water use at various water prices**

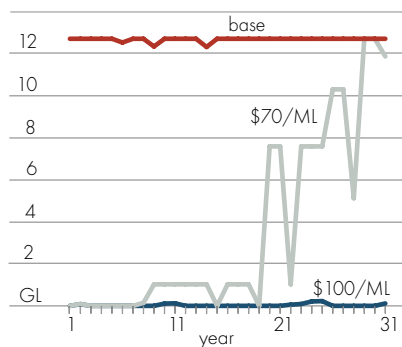
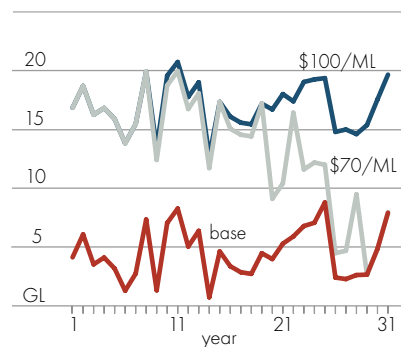


fig C **ground water use at various water prices**



surface water increases (decreases) during the last ten years of the planning horizon as the cost of extracting groundwater increases as the groundwater table falls. As expected, groundwater use increases with trading out of surface water (figure C).

A market for surface water downstream creates new income opportunities for irrigators in the valley even though water trading could result in a reduction in net incomes generated from on-farm agricultural activities. However, income earned from selling water is expected to more than offset any reduction in farm profits and consequently total net farm incomes are expected to increase (figure D). At a price of \$70 a megalitre, farm incomes are higher in the first twenty years compared with the base case but slightly lower in the next nine years owing to an increase in the cost of groundwater pumping and a sharp reduction in incomes from selling water. In this scenario, higher pumping levels in the early years result in a drawdown of groundwater stocks (figure E) and the sale (use) of surface water decreases (increases) sharply in the latter years (figure B). With a market for

fig D impact on aggregate farm income of surface water transfers out of valley

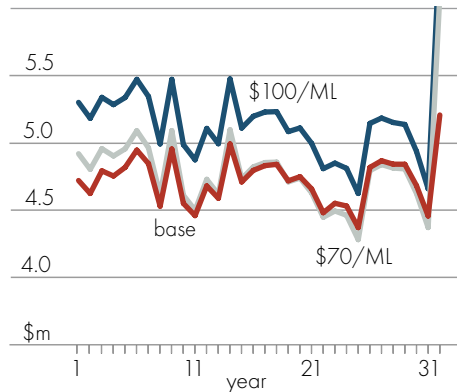


fig E impact on groundwater table of surface water transfers out of valley at various water prices

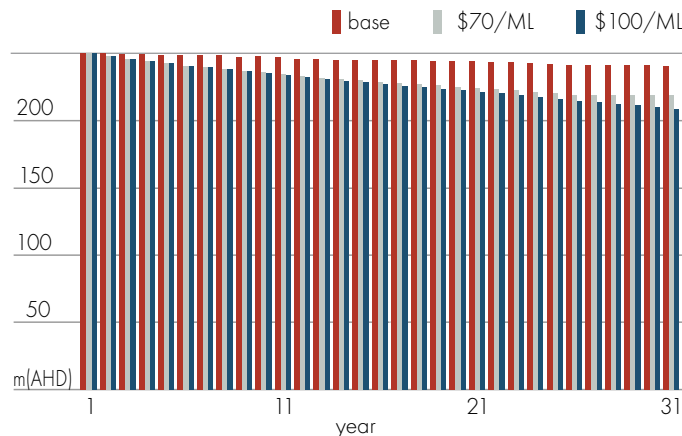
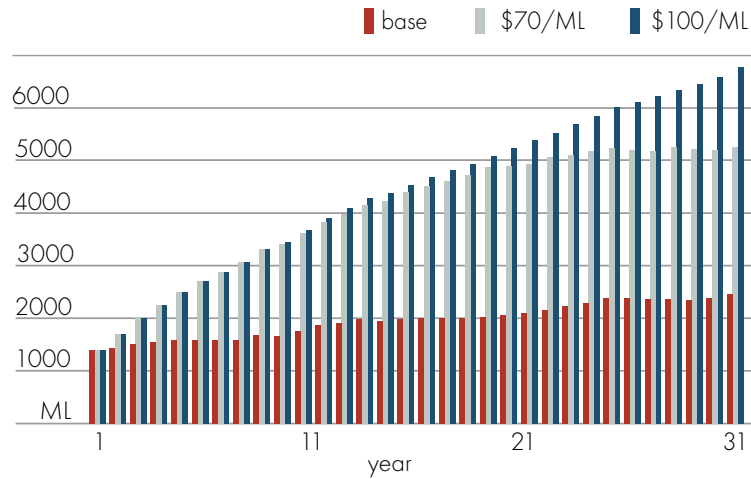


table 2 impact of water trade out of Dumaresq River Valley

		base	water sales at	
			\$70/ML	\$100/ML
change in groundwater table over thirty years	m	-10.29	-32.37	-43.75
average groundwater extraction	ml/yr	4 366	12 991	16 749
average surface water use	ml/yr	12 657	3 817	31
average surface water sale	ml/yr	0	9 298	13 085
aquifer drawdown over thirty years	gl	140	416	536
present value of aggregate farm income	\$m	74.69	75.81	81.67

fig F impact of surface water transfers out of valley on river leakage, at various water prices



surface water downstream, irrigators rely more on groundwater stocks to irrigate crops, leading to the groundwater table falling faster than under the base case (figure E). As the falling groundwater table induces more river water to leak into the aquifer, the river leakage at the 30th year is expected to increase from 2300 megalitres in the base case to 7000 megalitres with a temporary surface water price of \$100 a megalitre (figure F). These estimated river leakages are nearly half of the respective groundwater extraction levels.

The results obtained for the thirty year simulation period, are summarised in table 2. The temporary sale of surface water at \$100 a megalitre is estimated to result in an additional aquifer draw down of 396 gigalitres over a thirty year period, leading to groundwater table falling by a further 34 metres. The additional income opportunities offered by water trade estimated at \$7 million over the thirty year period needs to be compared with the cost to third parties from stream depletion caused by the falling groundwater table.

6

future work

The percentage of shared water in a groundwater entitlement determines the external cost of groundwater pumping and thus can be used as the basis for developing market based instruments to efficiently reallocate shared water. One of the limitations in the use of the model developed in this paper is that the four zones have been demarcated based on contiguous sections along the river. However, as the shared water percentage declines with distance away from the river, to be more useful in policy simulations the zones should be demarcated so that all entitlements in a given zone have an equal shared water percentage.

The process of allocating surface water and groundwater for conjunctive water users based on the storage level of the Glenlyon dam and expected stream flows needs to be incorporated in the model, as uncertainty surrounding the availability of surface water is a key driver of groundwater pumping.

The model can be used to simulate the impact of a number of economic and institutional drivers on stream depletion, including the impact of commodity price fluctuations; changes to input prices (such as fuel); and changes to surface water allocations. The model can also be used to explore existing institutional arrangements. Examples of such uses include simulation of the impact of alternative groundwater allocations for conjunctive and groundwater only users and changes to the existing water charging regime.

a model of the surface water and groundwater system in the Dumaresq River Valley

The hydroeconomic model outlined below has three linked components: an economic component; a hydrogeology component; and an institutional component. For each zone, the economic component models the use of water while the institutional component specifies existing institutional arrangements for the allocation of surface and groundwater and charging for delivery of surface water. For each zone, the model derives the optimal allocation of land, surface water and groundwater resources in agricultural production subject to the availability of surface water, groundwater allocation, recharge to the groundwater aquifer, rainfall and crop evaporative demand at different times of the irrigation year. For each zone, the groundwater flow process is specified by a state transition equation developed using results of simulations done with the MODFLOW model of the valley.

groundwater process

For simplicity, it is assumed that each zone has only one bore. It is also assumed that hydrological connections between groundwater tables in all such zones are negligible as permits are issued so that there is minimal interaction between zones. For each zone i and each year t , the hydraulic head is given in equation 1:

$$(1) \quad h_{i,t+1} = h_t - \kappa_i(h_t) \left(x_t^g - l_i(h_t) - r_t \right)$$

Where;

$\kappa_i(h_t)$ = coefficient for converting volume to head for zone i in year t (metre/ML).

- h_t = the hydraulic head of the groundwater table in the aquifer in zone i at the beginning of year t (metres, Australian Height Datum – AHD).
- x_t^g = the volume of groundwater pumped from the aquifer by zone i in year t (ML).
- $l_t(h_t)$ = leakage from river to aquifer in zone i in year t . (ML).
- r_t = recharge to aquifer in zone i in year t (ML).

For each zone i , the water table at the beginning of year $t+1$ is equal to the water table at the beginning of year t less the water table equivalent of the net volume of

table 3 estimates of parameters of the state transition equation system

dependent variable	intercept	independent variable		
		h_t	h_t^2	\bar{R}^2
Zone 1				
κ_t	2.69×10^{-3} (7.47)	-2.912×10^{-5} (-7.98)	8.29×10^{-8} (9.10)	0.93
l_t	21 738 (28.42)	-98.69 (25.04)		0.94
Zone 2				
κ_t	1.30×10^{-3} (10.72)	-9.90×10^{-6} (-6.97)	4.72×10^{-8} (12.05)	0.97
l_t	5 504 (53.30)	-22.17 (36.44)		0.97
Zone 3				
κ_t	1.63×10^{-3} (3.09)	-2.72×10^{-6} (-0.56)	5.61×10^{-9} (0.52)	0.04
l_t	5 275 (54.26)	-19.92 (-44.79)		0.98
Zone 4				
κ_t	2.60×10^{-2} (7.63)	-1.99×10^{-4} (-7.82)	3.88×10^{-7} (8.20)	0.76
l_t	4 170 (32.97)	-14.18 (-29.74)		0.96

Note: t statistics are given within parenthesis.

water extracted in year t (the second term on the RHS). The $\kappa_i(h_t)$ term measures the rate of fall in water table (metres) per volume unit (megalitre) of flux (pumping/recharge). The flux components considered in equation 1 include groundwater pumping (x_t^g), river leakage ($l_t(h_t)$) and aquifer recharge (r_t). The factor $\kappa_i(h_t)$ and river leakage ($l_t(h_t)$) depend on the level of the water table (h_t).

A parameter similar to ($\kappa_i(h_t)$) was used in the lumped parameter hydroeconomic models of Knap and Olson (1995); Hafi and Cao (2002) and Hafi (2003), the only difference being that the parameter used by these authors was independent of hydraulic head.

The parameters of $\kappa_i(h_t)$ and $l_t(h_t)$ functions were estimated using data generated with the MODFLOW model of the valley. To generate these data the MODFLOW model was run over forty years with a uniform pumping shock each year. A constant medium annual recharge was assumed over the simulation period. A number of different specifications was trialed in estimating the parameters of these functions. Finally a quadratic specification for $\kappa_i(h_t)$ and a linear specification for $l_t(h_t)$ were selected. The estimated parameters for these specifications are listed in table 3.

short run farm profits

In a conjunctive surface water and groundwater system, water from surface sources such as rainfall and river flows is used along with aquifer water as well as land in commercially viable agricultural production, thereby giving the water and land resources their economic value.

In estimating annual profits, the problem of deciding on areas planted to different crops, the allocation of water between crops and over months of the year is addressed as follows:

- > As yield response to moisture stress varies through the year, the growing season is divided into distinct growth stages such as establishment, vegetative, flowering and yield formation.
- > For each year, crop and month, the optimal use of groundwater and surface water is derived for given commodity prices, water administrative charges, pumping costs, variable costs of crop production and harvesting and constraints on surface water and groundwater allocations and land availability.

- > The model accounts for moisture stress and consequent yield reductions rather than abandonment of whole or part of the irrigated crop area to dryland status. The intrayear irrigation policy is driven by attempting to strike a balance between crop yield and area planted.
- > An open access behavior within a regulated environment is modeled – that is, future costs imposed by current pumping activities are not directly incorporated.

optimal crop yield under water stress

For each year t , zone i , and crop c , the optimal yield, sometimes defined as the actual yield in the agronomy literature, $Y_{ic,t}^a$ can be lower than the maximum yield, $Y_{ic,t}^m$, due to moisture stress. Moisture stress is measured, for each month, by the difference between 1 and the ratio of actual evapotranspiration, $ET_{icm,t}^a$, to maximum evapotranspiration, $ET_{icm,t}^{\max}$. For each crop and month, the sensitivity of yield to moisture stress, ky_{mct} depends on the crop and the growth stage. Parameters describing the sensitivity of yield to moisture stress were obtained from Doorenbos and Kassem (1979).

The yield response to different levels of $ET_{icm,t}^a$ is given in equation (2). Both $ET_{icm,t}^{\max}$ and $ET_{icm,t}^a$ are measured in megalitres per hectare.

$$(2) \quad Y_{ic}^a \leq Y_c^{\max} \left[1 - \sum_m ky_{cm} \left(1 - ET_{icm,t}^a / ET_{icm,t}^{\max} \right) \right]$$

determination of actual evapotranspiration

For each month and crop, actual evapotranspiration is determined by the depth of soil moisture available, which includes the soil moisture added through irrigation with surface water, $q_{ilmc,t}^s$, groundwater pumped, $q_{ilmc,t}^g$ and effective rainfall, $ER_{im,t}$.

$$(3) \quad ET_{ilmc,t}^a \leq q_{ilmc,t}^s + q_{ilmc,t}^g + \min(ER_{im,t}, ET_{ilmc,t}^{\max})$$

$$(4) \quad q_{ilmc,t}^g + q_{ilmc,t}^s \leq ET_{ilmc,t}^{\max} - \min(ER_{im,t}, ET_{ilmc,t}^{\max})$$

other constraints

For the whole irrigation year, the quantity of surface irrigation water used cannot exceed the volume of surface water delivered (X_i^s). It is assumed that, in each year, irrigators will receive 60 per cent of their surface water entitlement.

$$(5) \quad \sum_c \sum_m q_{itmc}^s = x_{it}^s \leq X_i^s, \text{ for } t$$

Over an irrigation year, the quantity of ground water used cannot exceed the volume of ground water allocated (X_i^g). It is assumed that, in each year, irrigators will be able to access their full groundwater entitlement.

$$(6) \quad \sum_c \sum_m q_{itmc}^g = x_{it}^g \leq X_i^g, \text{ for } t$$

For the irrigation year the total area cropped cannot exceed the total land area available (X_i^l).

$$(7) \quad \sum_{c=1}^n a_{itc} \leq X_i^l$$

objective function

The objective function given in equation (8), which specifies profits for each zone and year, is maximised subject to constraints (1) – (7).

For each year, aggregate farm profit is the gross revenue obtained from selling agricultural produce net of the cost of harvesting, the cost of pumping of surface water from the river, the cost of pumping groundwater from the underlying aquifer and other variable costs of production. Prices of agricultural produce and non water inputs used in production are assumed to be unaffected by the actions of water users individually and collectively. However, the unit pumping cost of groundwater increases with the pump lift ($h_i^{\max} - h_{it}$), so that the lower the ground water table (h_{it}) the higher the unit pumping cost. For each zone and year, the unit cost of groundwater pumping is defined to be equal to the unit cost of pumping, before the extraction policy was implemented (greenfield situation, with groundwater table at h_i^{\max}) plus the increase in the cost of lifting water with the current water table being at h_{it} . The unit cost of groundwater pumping is given in equation (9).

$$(8) \quad \sum_c a_{itc} \left\{ Y_c^{\max} \left[1 - \sum_m ky_{cm} \left(1 - ET_{itcm}^a / ET_{itcm}^{\max} \right) \right] (P_c - HC_c) - VC_c^a \right\} \\ - \sum_{c,m} q_{itcm}^s P^{SW} - \sum_{c,m} q_{itcm}^g P^{GW}$$

$$(9) \quad P_t^{GW} = \gamma_0 + \sigma (h_i^{MAX} - h_t), \text{ for } t$$

where

ET_{ilcm}^a = actual evapotranspiration in zone i in year t by crop c in month m (ML/ha).

ET_{ilcm}^{max} = potential evapotranspiration in year t by crop c in month m (ML/ha).

q_{ilcm}^s = quantity of surface water used by zone i in year t for crop c in month m (ML/ha).

q_{ilcm}^g = quantity of ground water used by zone i in year t for crop c in month m (ML/ha).

ky_{cm} = ky factor for crop c in month m (percentage decline in yield due to 1 per cent moisture deficit).

a_{ilc} = area planted to crop c by zone i in year t (ha).

Y_c^{max} = maximum yield of crop c (t/ha).

Y_{ilc}^a = actual yield of crop c in zone i in year t (t/ha).

P_c = price of produce of crop c (\$/t).

HC_c = cost of harvesting produce of crop c (\$/t).

VC_c = other variable costs of crop c (\$/ha).

σ = unit pumping cost per metre drop in the hydraulic head (\$/m/ML).

γ_0 = groundwater pumping cost with hydraulic head at h_i^{max} (\$/ML).

application of the model for the current study

The model was run as an annual model but recursively over a planning horizon of thirty years. Each irrigation year commences in August, and ends the following May. Historical rainfall and crop evaporative demand data over the period 1973 to 2003 is used as the weather pattern over the planning horizon. For each zone and each year (other than the first year), the hydraulic head at the beginning of the year is taken as equal to that at the end of the previous year. For each year, the hydraulic head at the end of the year is updated by taking account of ground-water pumping, river leakage and recharge in that year.

results of a survey of water users in the Dumaresq River valley

A survey of water users in the Dumaresq River Valley was conducted in March 2005 to collect farm specific data. The survey collected data on:

- > land area operated
- > crops grown in summer and winter under irrigation
- > crop varieties; surface and groundwater use by season
- > surface water and groundwater entitlements
- > water application technology by crop
- > crop production technology
- > information on impediments or constraints in achieving higher incomes.

According to data provided by the Queensland Department of Natural Resources and Mines, and New South Wales Department of Infrastructure, Planning and Natural Resources, at the time of the survey there were about 40 water users in the Dumaresq River Valley (23 on the Queensland side and 17 on the New South Wales side of the river). A census of these users was planned; however, ABARE was able to interview only 25 water users. The survey was focused on farming activities that were carried out during the irrigation year 2003-04.

The surveyed farms had surface water and groundwater entitlements totaling 15.14 gegalitres and 18.0 gegalitres respectively, accounting for 73 per cent and 60 per cent of the aggregate surface water and groundwater entitlement issued for the Dumaresq River Valley. As 2003-04 was a drought year, the surveyed farms used 7.3 gegalitres of groundwater in that year, which exceeded the long term average aggregate use of 5.2 gegalitres for the valley (tables 1 and 4). Despite being in possession of 15.1 gegalitres (73 per cent) of the surface water entitlement in the valley, the drought resulted in surface water availabilities being restricted in 2003-04, which meant that the surveyed farms used only 3.7 gegalitres of surface water

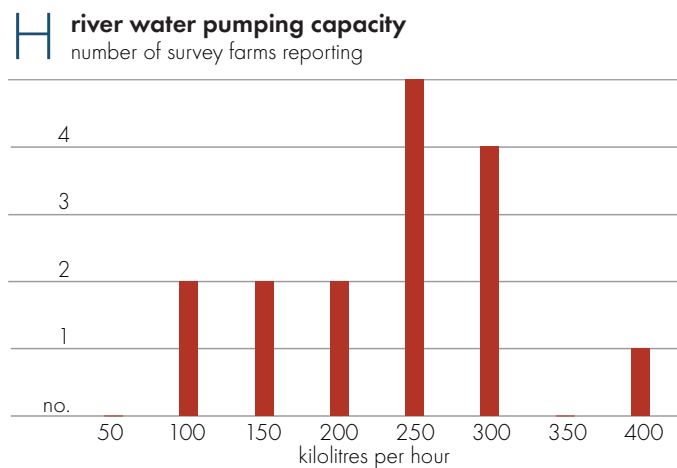
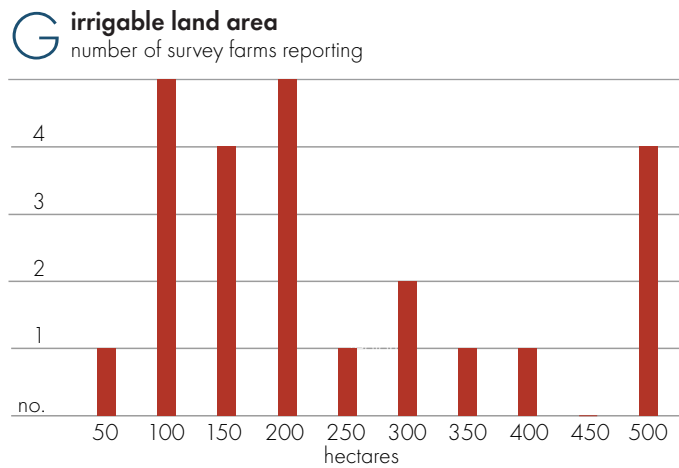
compared with a long term average aggregate use of 17.0 gigalitres for the entire valley (tables 1 and 4). The drought in 2003-04 also restricted cropping on the surveyed farms to 2806 hectares out of a total irrigable area of 6883 hectares.

The results on land and water use, by crop, are summarised in table 4. Frequency distributions of survey respondents by total irrigable land area and use of ground-water and surface water are presented in figures G-K. The average sampled farm had 240 hectares of irrigable land, 688 megalitres of surface water entitlements and 683 megalitres of groundwater entitlements. According to the survey results, in 2003-04, the average sampled farm received only 43 per cent of surface water entitlement.

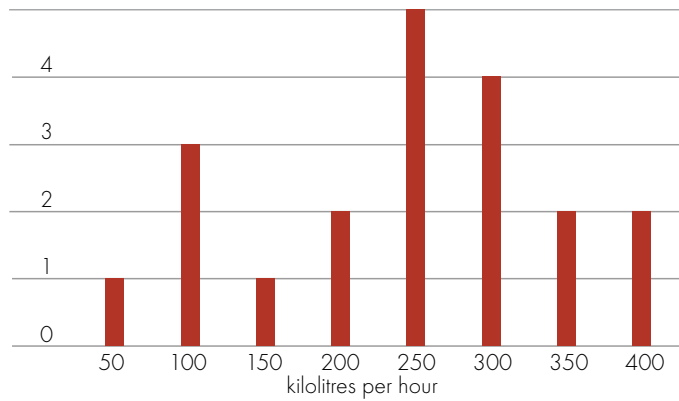
table 4 **summary statistics on land and water use, by the sample farms in the Dumaresq River Valley area in 2003-04**

	total area planted	SW use	GW use	total water use	average water use	average yield
	ha	ML	ML	ML	ML/ha	t/ha
crop						
other fruits	10	9	10	19	1.90	8.00
vegetables	45	52	65	117	2.60	7.78
pumpkins	2.5	15	0	15	6.00	4.00
wheat	0	0	0	0	0.00	0.00
barley	405	465	500	965	2.38	4.93
soybean	132	140	230	370	2.80	3.30
maize	240	204	965	1 169	4.87	8.68
cotton	189	903	294	1 197	6.33	1.22
peanuts	40	200	0	200	5.00	3.50
pasture	493	206	891	1 097	2.23	0.00
forage sorghum	10	0	80	80	8.00	25.00
fodder crops	65	250	0	250	3.85	56.62
chickpeas	20	0	21	21	1.05	2.00
navy beans	30	0	75	75	2.50	2.00
oats for hay		0	0	0	0.00	0.00
barley for hay	235	0	245	245	1.04	2.28
lucerne hay	656	1 235	2 478	3 713	5.66	16.59
navy beans for hay	50	20	40	60	1.20	0.60
oats for silage		0	0	0	0.00	0.00
barley for silage		0	0	0	0.00	0.00
other field crops for silage	183	0	1 464	1 464	8.00	30.60
all crops	2 806	3 699	7 358	11 057		

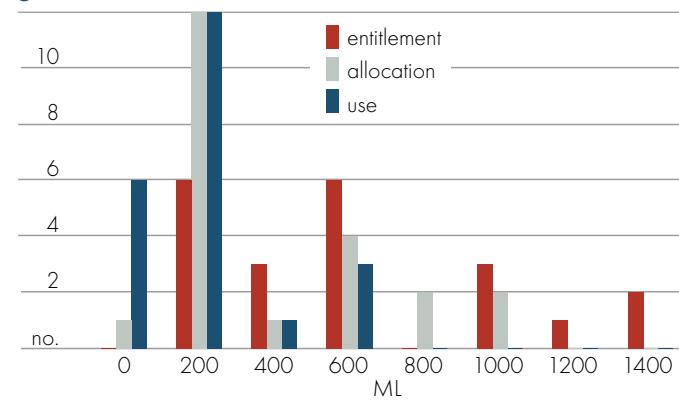
The survey also contained a number of questions on factors that influence land and water management decisions and constraints to effectively managing land and water resources. The responses obtained for these questions are summarised in tables 5-13. The importance of the reliability of surface water availability, including rainfall, in land and water management decisions on-farm was highlighted in the responses to these questions. For example, key crop irrigation decisions are mainly based on soil moisture content and uncertainty about surface irrigation water availability has been cited as one of the main reasons preventing an increase in cropping area. The lack of financial resources was also an important constraint to increasing the area cropped.



I groundwater pumping capacity
number of survey farms reporting



J surface water entitlement, allocation and use
number of survey farms reporting



K groundwater allocation and use
number of survey farms reporting

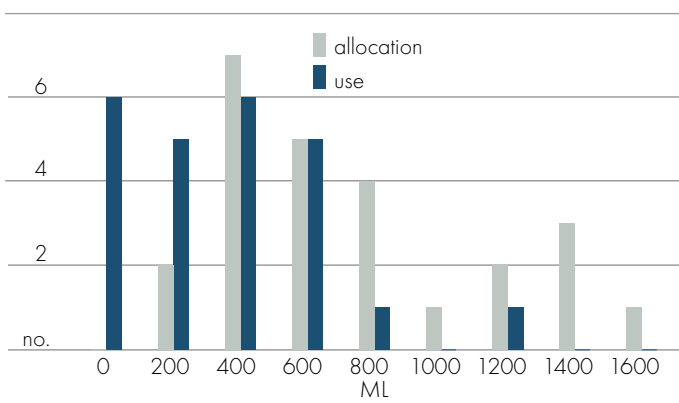


table 5 on what do you base your irrigation decision?

	when to start irrigating	when and how frequently to irrigate	how much water to apply
number of respondents reporting	no.	no.	no.
soil moisture level	14	14	14
irrigation scheduling devices	1	1	1
surface water delivery schedule	0	0	0
water watch	0	0	0
water budgets	0	0	0
calendar	0	0	0
soil conditions	22	19	18
crop conditions	4	21	20
weather forecast	0	9	13
farmer's observations/knowledge	23	24	23
agro notes/agronomist advice	3	2	2
based on evapotranspiration	0	0	0

table 6 what constraints do you face in expanding the area cropped?

number of respondents reporting	no.
no suitable land available	3
not viable (low returns, marketing issues etc)	8
lack of financial resources	13
lack of time	4
inadequate irrigation water	10
uncertainty of water allocations	12
others	5

table 7 how do you decide which crop to irrigate when water is short?

number of respondents reporting	no.
abandon low value crops	8
irrigate best crop first	19
deficit irrigation	2
scheduling devices	1
others	1

table 8 **of the area you did irrigate do any of the following constraints limit your ability to irrigate effectively and profitably?**

number of respondents reporting	no.
fixed surface water delivery schedule	3
difficult soil conditions	7
poor water quality	2
insufficient surface water quantity	14
insufficient ground water quantity	3
poorly graded/prepared paddocks	0
irrigation system capacity limitations	4
irrigation system design limitations	5
others	2

table 9 **if during 2003-04 you did not irrigate the total area available to irrigate please list three main reasons why?**

number of respondents reporting	no.
inadequate surface water available	7
additional surface water received	
too late in the season	0
prefer to carry surface water over to next year	0
sold surface irrigation water	2
sold groundwater	0
crop rotation reasons	4
doubt about likely success	3
lack of financial resources	8
wet seasonal conditions	0
limited bore capacity	6
unable to purchase additional surface water	0
unable to purchase additional groundwater	2
others	4

table10 **have you noticed fluctuations in the groundwater table at different times of the year over the last 5 years?**

number of respondents reporting	high	average	low
	no.	no.	no.
Spring	0	14	2
Summer	0	3	13
Autumn	0	13	3
Winter	2	12	2

table 11 **what do you normally do in the event of below average weather conditions (eg low rainfall)?**

rank in order of importance with 1 being the most important

	1	2	3	4	5	6	7
number of respondents reporting	no.	no.	no.	no.	no.	no.	no.
improve system efficiency	10	1	0	0	0	0	0
change cropping plans (reduce area)	12	4	3	0	0	0	0
deficit irrigation	0	2	0	1	0	0	0
purchase surface water from others	0	1	3	0	0	0	0
purchase groundwater from others	0	2	0	1	0	0	0
abandon cropping	3	6	2	0	0	0	0
others	1	0	0	0	0	0	0

table 12 **if after a prolonged drought your average surface irrigation water availability declined, what changes would you try to make?**

rank in order of importance with 1 being the most important

	1	2	3	4	5	6	7
number of respondents reporting	no.	no.	no.	no.	no.	no.	no.
change enterprise mix (eg less crops)	7	4	1	0	0	0	0
buy additional irrigation water	3	0	1	1	0	0	0
install additional on-farm water storage capacity	4	2	1	0	0	0	0
install additional groundwater pumping	7	2	0	0	0	0	0
install additional water reuse system	0	2	0	0	0	0	0
change method of water application	0	2	2	0	0	0	0
sell irrigation water and cease irrigation	0	0	1	1	0	2	0
sell land	2	1	0	1	0	0	0
others	1	1	1	0	1	0	0

table13 how concerned are you with the following?

	very concerned	concerned	not concerned
number of respondents reporting	no.	no.	no.
surface water quality	2	6	17
groundwater quality	5	5	15
falling groundwater level	4	10	11
increased salinity of groundwater	3	8	14
unrestricted access to groundwater	10	6	8
interference on the groundwater table by others' pumping	5	4	16
excessive use of groundwater impacting on river flows	5	5	15
increasing demand for water resources in the future	8	13	3
relationship between increased irrigation and the environment	10	14	0

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RESEARCH FUNDING ABARE relies on financial support from external organisations to complete its research program. As at the date of this publication, the following organisations had provided financial support for ABARE's research program in 2005-06 and 2006-07. We gratefully acknowledge this assistance.

Agricultural Production Systems Research Unit	Independent Pricing and Regulatory Tribunal
Asia Pacific Economic Cooperation Secretariat	International Food Policy Research Institute
AusAid	Land and Water Australia
Australian Centre for International Agricultural Research	Meat and Livestock Australia
Australian Greenhouse Office	Minerals Council of Australia
Australian Government Department of the Environment and Heritage	Ministry for the Environment, New Zealand
Australian Government Department of Industry, Tourism and Resources	National Australia Bank
Australian Government Department of Prime Minister and Cabinet	Newcastle Port Corporation
Australian Government Department of Transport and Regional Services	NSW Sugar
Australian Wool Innovation Limited	Rio Tinto
CRC - Plant Biosecurity	Rural Industries Research and Development Corporation
CSIRO (Commonwealth Scientific and Industrial Research Organisation)	Snowy Mountains Engineering Corporation
Dairy Australia	University of Queensland
Department of Business, Economic and Regional Development, Northern Territory	US Environmental Protection Agency
Department of Premier and Cabinet, Western Australia	Wheat Export Authority
Department of Primary Industries, New South Wales	Woolmark Company
Department of Primary Industries, Victoria	
East Gippsland Horticultural Group	
Fisheries Research and Development Corporation	
Fisheries Resources Research Fund	
Forest and Wood Products Research and Development Corporation	
Grains Research and Development Corporation	
Grape and Wine Research and Development Corporation	
GHD Services	