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State-contingent modelling of the Murray Darling Basin: implications for the design of property rights

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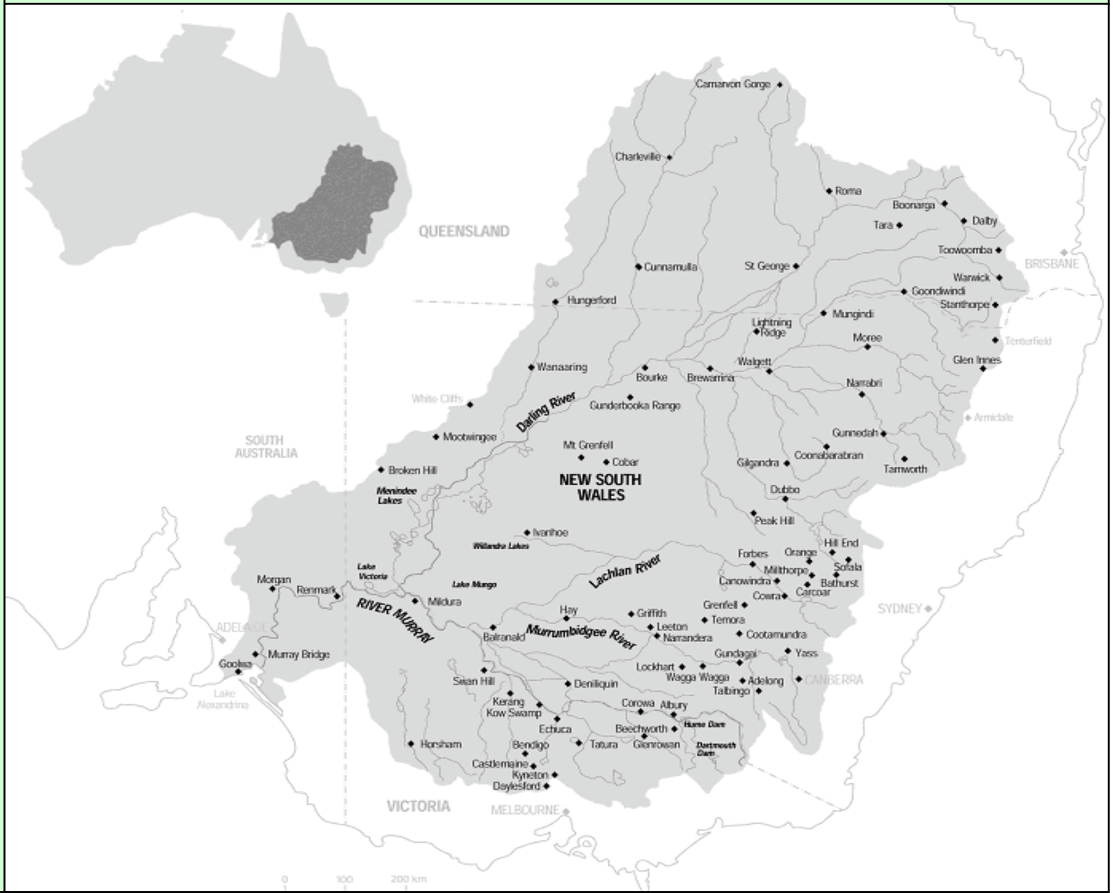

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Abstract

Questions relating to the allocation and management of risk have played a central role in the development of the National Water Initiative, particularly as it has applied to the Murray-Darling Basin. The central issues of efficiency and equity in allocations are best understood by considering water licenses as bundles of state-contingent claims. The interaction of property rights and uncertainty regarding water flows, production and output prices is modelled using a state-contingent representation of production under uncertainty. The role of technology and investment in the determination of efficient adaptation strategies to manage risks is explored using an illustrative example.

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The management of the Murray Darling Basin plays a central role in environmental policy in Australia. The economic and social importance of the Basin and the complex and often intractable nature of the problems arising from past patterns of land and water use have made it a symbol of the success or failure with which Australians have managed the natural environment in the period since European settlement.

In a more practical sense, policy initatives adopted in response to the problems of the Murray-Darling Basin have influenced the design of policies to respond to other large-scale environmental problems, such as those of the Great Artesian Basin (Tan and Quiggin 2004). More generally, the market-based approach adopted in relation to the Murray-Darling Basin has been employed more widely to deal with issues such as climate change. This suggests the desirability of considering in more detail the strengths and weaknesses of such approaches, and the issues of detailed implementation raised by the management of the the Murray-Darling Basin.

The central difficulties revolve around risk and uncertainty, and are exacerbated by the vagueness and imprecision that commonly surrounds discussion of these concepts. The most satisfactory analytical framework for the discussion of these issues that has been developed thus far is based on the concept of random variables as vectors of state-contingent outcomes, and the associated Bayesian decision theory.

Central elements of this theory were developed by Savage (1954) in the context of decision theory, and Arrow (1953, 1954) and Debreu (1952, 1959) in the context of general equilibrium theory. Despite these early advances, little use has been made until recently of state-contingent representations of uncertainty in applied economic analysis (important exceptions are Hirshleifer (1966) and Hirshleifer and Riley 1992). Chambers and Quiggin (2000) develop a detailed state-contingent analysis of production under uncertainty and conclude that the state-contingent approach provides the best way to think about all problems in the economics of uncertainty, including problems of consumer choice, the theory of the firm, and principal agent relationships.

The aim of this paper is to show how the state-contingent model may be used in a simulation context to model production under uncertainty. The analysis is applied to compare alternative specifications of water-entitlements contingent on available flows of water.

The paper is organised as follows. General information on the Murray-Darling Basin and the National Water Initiative is presented in Section 1. The state-contingent approach to modelling production under uncertainty and the state-contingent specification of property rights is described in Section 2.

1. Background

The Murray-Darling Basin encompasses a substantial proportion of the agricultural area of Eastern Australia, including parts of four states and the ACT. In addition, it is an actual or potential water source for Adelaide, Canberra, and Melbourne. The Snowy Mountains scheme, diverting water from the Snowy river to the Basin, supplies both additional water for irrigation and hydro-electric power. There also exist technical possibilities for supplying Sydney through a diversion of water from the Murrumbidgee River to the Wollondilly River in the catchment of Warragamba Dam, though the economic feasibility of this option has not been investigated in detail. Hence, the management of the resources of the Murray-Darling Basin is the single most important issue in Australian water policy.

Quiggin (2001) gives a summary of the development of irrigation and water policy in the Murray-Darling Basin during the 20th century. Rapid expansion of irrigated agriculture contributed to the development of a range of environmental problems including salinity, land degradation, and loss of biodiversity, leading to the imposition, in 1994, of a cap on diversions of water for irrigation. Major environmental issues are summarised by the Murray–Darling

Basin Commission (2006).

The most important developments since 2000 have been the Living Murray Initiative (Murray--Darling Basin Commission 2003) and the National Water Initiative. The Council of Australian Governments (COAG) has taken central role in the design and implementation of these initiatives.

The National Water Initiative

The National Water Initiative (NWI) emerged from the 2003 COAG meeting (ref), and has been developed further through the COAG process. Questions relating to the allocation and management of risk have played a central role.

Two major principles were announced at the 2003 COAG meeting. The first was that, in future, water allocations should be stated as shares of available water, rather than as specific volumes. This approach deals with fluctuations in water availability by allocating the total amount available among users in proportion to their shares.

The second principle concerned an approach to the allocation of risk arising from changes in the aggregate availability of water. Under this principle, the risk of changes in water availability due to new knowledge about the hydrological capacity of the system will be borne by users. The risk of reductions in water availability arising from changes in public policy, such as changes in environmental policy, will be borne by the public, and water users will receive compensation for such reductions.

The principles of the National Water Initiative were elaborated in more detail in a statement issued by the 2004 COAG meeting (Council of Australian Governments 2004). The Communique specified a framework that assigns the risk of future reductions in water availability as follows:

- reductions arising from natural events such as climate change, drought or bushfire to be borne by water users;
- reductions arising from bona fide improvements in knowledge about water systems' capacity to sustain particular extraction levels to be borne by water

users up to 2014. After 2014, water users to bear this risk for the first three per cent reduction in water allocation, State/Territory and the Australian Government would share (one-third and two-third shares respectively) the risk of reductions of between three per cent and six per cent; State/Territory and the Australian Government would share equally the risk of reductions above six per cent;

- reductions arising from changes in government policy not previously provided for would be borne by governments, and
- where there is voluntary agreement between relevant State or Territory Governments and key stakeholders, a different risk assignment model to the above may be implemented.

The state-contingent approach

To analyze the implications of the risk allocation procedure proposed in the National Water Initiative, it is necessary to model production under uncertainty. A number of modelling approaches have been proposed and used, including mean-variance analysis (Just and Pope 1978), stochastic production functions (Newbery and Stiglitz 1979), parametrised distribution functions (Grossman and Hart 1983) and the state-contingent approach (Chambers and Quiggin 2000, Quiggin and Chambers 2006).

All of these approaches have advantages and disadvantages. However, the state-contingent approach provides the most natural approach to the problem of designing property rights and other market-based instruments for the management of irrigation systems in the Murray-Darling Basin. In particular, the allocation of risk proposed under the National Water Initiative is most naturally understood in terms of the concept of state-contingent commodities, introduced by Arrow and Debreu.

A crucial feature of the state-contingent approach is the distinction between exogenous states of nature, such as those associated with climatic variation, and the endogenous actions of decision-makers. By contrast, in the parametrised distribution function approach, states of nature are considered to be endogenous, in that the probability with which particular states occur is determined by the actions of decision-makers. The mean–variance and stochastic production function approaches make no explicit reference to states of nature, and therefore provide no natural way of representing the distinction between changes in the state of nature, changes in knowledge and changes in public policy.

State-contingent specification of water rights

An illustration of the way in which the state-contingent approach may be applied to the design and analysis of property rights is provided by Freebairn and Quiggin (2005). Freebairn and Quiggin compare three systems of property rights in a model with two states of nature, corresponding to normal and drought (low-flow) conditions. The model may be generalised to allow for more than two states of nature, but the two-state case captures many of the essential issues.

The first systems of property right, considered primarily as a benchmark for welfare analysis is a system of contingent state claims, each of which consists of an entitlement to water in a specific state of nature. The second is the system of proportional allocations proposed under the NWI, in which a right entitles the holder to a given volume of water in normal conditions and a reduced volume in low-flow conditions. The third is a combination of high-security rights, which provide an entitlement to a given volume of water in all states and low-security rights which provide an entitlement to water only in normal states.

Production in the state-contingent approach

The state-contingent approach captures important features of production under uncertainty that are excluded from consideration in alternative frameworks such as the stochastic production function, which is effectively equivalent to a fixed-output-proportions technology (Chambers and Quiggin 2000). In particular, in the state-contingent framework it is possible to represent production decisions that have the effect of increasing output in some states of nature and reducing it in others.

This flexibility is crucial to the modelling of issues relating to irrigation and water management. One of the central goals of irrigation is to manage the risk associated with variable supplies of water by storing water in wet years (favourable states of nature) and using it in dry years (unfavourable states of nature). The allocation of effort to irrigation produces an increase in output in unfavourable states of nature at the expense of a loss of output in favourable states of nature. Irrigation is beneficial if the increase in the (risk-adjusted) value of output in unfavourable states is greater than the corresponding loss in favourable states.

The model

The model is a development of that described by Adamson, Quiggin and Mallawaarachchi (2005). A programming approach is used to model the allocation of land and water resources within a river system, designed to simulate the Murray-Darling Basin. The river system is divided into regions $m = 1...K$. The system is modelled as a directed network, as in Hall et al. 1993.

Agricultural land and water use in each region is modelled by a representative farmer with agricultural land area L_k. There are S possible states of nature corresponding to different levels of rainfall/snowmelt and other climatic conditions. The status of the river in each region and state of nature is measured by a flow variable and a salinity variable (salinity is taken as a proxy for other measures of water quality, since most such measures are reduced by excessive extractions. The $2 \times K \times S$ vector of status variables is determined endogenously by water use decisions.

There are M distinct agricultural commodities, and therefore $M \times S$ different state-contingent commodities. In addition to water, where the usage level is determined after the state of nature is known, there are N inputs, committed before the state of nature is known. Each commodity may be produced using one or more activities. In particular, we consider alternative production technologies involving higher and lower, or fixed and flexible, levels of water use. The total number of activities is given by J. Each activity requires a state-independent choice of N inputs. Urban water use in Adelaide is modelled separately and an environmental value is imputed to residual flows to the sea.

Solution concepts

A number of solution concepts may be considered for the model. The first is global optimization of returns from the system as a whole, included the expected profit of agricultural enterprises and the value of water in urban and environmental uses. Thus, it is the solution that would be adopted by a social planner whose objective is to maximising social returns. Adamson, Quiggin and Mallawaarachchi (2005) discuss this solution, which is primarily used as a benchmark for the assessment of alternative policy options.

In practice, water usage is not determined centrally, but by the actions of individual water users, constrained by a system of rights and licenses. This outcome can be modelled using a sequential solution concept. Sequential solution concepts involves optimisation within each region, with allowable water use being determined by an allocation of water rights. Since the quantity and quality of water in any given region is determined by upstream usage, the model must be solved sequentially, beginning with upstream regions.

The simplest case of the sequential solution, analyzed in Adamson, Quiggin and Mallawaarachchi (2005) is that of riparian rights, where users in each region can extract as much water as they wish, subject to the constraint that extractions cannot exceed the volume of water flowing through the region. For most regions, this constraint is not binding, since limits on the area of land suitable for irrigated cropping provide a binding constraint.

In Australian water management, the riparian concept derived from the very different conditions prevailing in Britain has been replaced by a system under which all water is publicly owned, and water use is determined by allocations of rights. Realistic modelling requires that these rights should be incorporated into the constraints of the model.

By definition, the globally optimal solution must yield an aggregate return at least as high as that of any sequential solution. The gap between the two is an indication of the social loss arising from an inefficient allocation of property rights.

Modelling the design of property rights

The constrained-optimal sequential solution is derived for the case when the only restriction on water use is an aggregate constraint for each region, consisting of a state-contingent allocation of water. Thus, water rights (as opposed to aggregate availability of water) do not introduce relevant constraints on land allocation. This is the solution that would arise in the presence of complete markets for state-contingent water rights (Freebairn and Quiggin 2006). The constrained-optimal sequential solution also arises when there is unrestricted, and costless, temporary water trade within regions.

A more realistic specification involves the creation of two classes of water rights, one giving high security and the other giving low security. Since the number of classes of rights is less than the number of states in the model, the resulting assets do not span the state space and markets are incomplete.

The two-class rights structure may be modelled by imposing a constraint for each technology in any region requiring that its allocation of rights be sufficient to meet the water requirements in each state of nature. The aggregate allocation of rights is determined by creating high-security rights equal to the aggregate allocation of water in the worst state of nature (the drought state) and low security rights equal to the difference between the aggregate allocation in the normal state and the aggregate allocation in the drought state.

Proportional water rights work by scaling down the water available in proportion to the aggregate availability for the region in question. This may be modelled by assuming that there is a single water input, namely a proportional water right. For each technology, the water input requirement generates three constraints, one for each state of nature

Given proportional water rights for technologies he constraint associated with the drought state will be binding, with an inflexible demand for water, but for technologies that switch to dryland agriculture in the drought state, the constraint associated with the normal state will be binding.

Results

Results of simulations for three sequential solution concepts are presented in Tables 1-4. Table 1 shows the sequential solution with no restrictions other than those associated with the CAP. This is the solution that would arise with costless and unrestricted water trade within regions. Table 2 shows the sequential solution with high security and low security water rights and no trade. Table 3 shows the sequential solution with proportional water rights and no trade. Tables 1a-3a show state-contingent values of water use, salinity and value added for the three solutions in turn, while Tables 1b-3b show land allocations for the same solutions. Table 4 is a comparative summary of expected returns for the three simulations.

Consider first, the summary results presented in Table 4. The highest expected value arises for the sequential solution with unrestricted intra-regional trade. This is unsurprising, since it would normally be expected that the removal of constraints will allow a higher value of the objective function. However, since this is a second-best solution, with no account being taken of externalities between upstream and downstream users, such an outcome is not guaranteed.

This point may be illustrated by consideration of the regional results. The unrestricted solution gives the highest values of the objective function for upstream regions (those with no preceding region in the network). However, it gives lower values for some downstream regions than the solution with high security and low security rights and lower values for Adelaide than the solution with proportional property rights.

The results for the solution with high security and low security rights are fairly similar to those with unrestricted trade. This reflects the observation of Freebairn and Quiggin (2006) that the availability of water rights with high and low security will reduce the need for trade. Although two water rights are insufficient to span the state space with three states of nature, the deviation from complete spanning is modest.

It is possible that this result would change if a more realistic model, with a large number of states of nature, were used. However, experience has suggested that, in most cases, modelling more than three states of nature (or using fourth and higher-order moments in a moment-based representation of uncertainty) has little effect on results, and may introduce additional error due to the need to make distributional assumptions on the basis of limited evidence.

The solution with proportional water rights and no trade produces a signficant reduction in the value of the objective function and more variable water use. However, because water use varies positively with flows, the variability of salinity is reduced in this solution, as is the maximum level of salinity, occurring in the drought state.

Simulations of land allocation are presented in Tables 1b-3b. As noted above, differences between the unrestricted-trade sequential solution (Table 1b) and the solution with high-priority and low-priority rights (Table 2b) are relatively modest. The solution with proportional rights shows more substantial differences

First, there is a substantial decline in the area planted to citrus, and stone fruits are eliminated altogether. These high-value crops depend on a reliable supply of water, and thus require a large purchase of rights to guarantee an adequate supply of water in drought years. In the absence of a capacity to sell excess water in normal years, the activities are unprofitable. Thus, the result may be interpreted as implying that, with proportional water rights, the viability of stone fruit and citrus activities will depend on the presence of smoothly functioning markets.

Second, rice is grown in the Murrumbidgee region, whereas in the other two solutions rice is displaced by a mixture of cotton and irrigated wheat. This apparently reflects model assumptions about crop rotation, under which the proportional water allocation is well suited to the rice activity.

Finally, under the proportional solution, salinity levels at Adelaide are generally lower, reflecting reduced upstream water use. Water use in Adelaide and the social value of water are correspondingly higher.

Discussion

The results presented above illustrate a number of important issues in the policy debate. First, the state-contingent specification of water rights can make a substantial difference to resource allocation and environmental outcomes. Proportional rights allocations have both advantages and disadvantages, as do systems of high security and low security rights.

In the past, New South Wales has favoured a mixture of high security and low security rights while Victoria has favoured proportional rights. One of the issues under discussion in the development of the National Water Initiative

An important implication of the model results presented above is that farmers adapt their production plans to the state-contingent structure of property rights. This adaptation will, in general, involved capital investment decisions. Unanticipated changes in the structure of property rights will therefore, in general, reduce the value of existing investments.

This does not mean that existing policies should remain unchanged or that existing investments should be protected by 'grandfather clauses' and similar devices from any possibility of loss due to policy change. On the other hand, administrative neatness is not a sufficient justification for policy change. Similarly, given the limited development of markets for trade between catchments within states, it seems premature to require standardisation of property rights in the hope that this will promote interstate trade.

A second implication, previously derived in a theoretical model by Freebairn and Quiggin (2005) is that a system of rights based on proportional shares in a state-contingent aggregate allocation is likely to require substantial temporary trade if it is to function effectively. This in turn may generate significant transactions costs.

Modelling

Some points regarding modelling are also worthy of discussion. The issue of representing uncertainty in simulation models based on a programming approach has been debated for many years and a variety of solutions have been proposed. Most of these solutions involve a two-stage procedure, either adding stochastic uncertainty to the results of a deterministic model or deriving an uncertain probability distribution from many runs of a deterministic model.

By contrast, the state-contingent approach allows uncertainty to be incorporated within the standard linear programming framework. The main cost is an expansion of the dimensionality of the model to allow production activities to generate a vector of state-contingent outputs rather than one or more deterministic outputs. As computing power increases, this cost becomes less significant.

An important advantage arising from the consistency of the state contingent approach with standard linear programming is that outputs such as shadow prices and sensitivity analyses, routinely generated by linear programming packages, can be obtained. Furthermore, as observed by Chambers and Quiggin (2000), the duality relationships of modern production theory are entirely applicable to state-contingent production. Hence, the dual variables derived from a linear programming analysis can be interpreted in the usual way.

A second important advantage is illustrated in the present study. Policy problems involving uncertainty and contingent policy responses commonly generate a natural state-contingent representation as in the present case. It is rare, by contrast, for policy proposals to be framed in terms of probability distributions and correlations, as is required in common stochastic approaches.

Risk aversion

The model solutions presented here maximize an expected return, and therefore imply risk neutrality. However, risk-averse behavior can easily be incorporated in the model using the idea of risk-neutral probabilities. These are the betting odds for state-contingent claims that would be accepted by risk-averse investors given their state-contingent distribution of wealth.

Risk-neutral probabilities can be determined iteratively in the state-contingent framework. The simplest procedure is to derive a risk-neutral solution given the objective probabilities, compute the risk-neutral probabilities for the resulting wealth distribution, then proceed iteratively.

As Pannell (2004) points out, the optimal allocation of resources is, in general, not highly sensitive to risk aversion in cases of this kind. Hence, a couple of iterations will probably be sufficient to yield a reasonably accurate solution.

Concluding comments

As the role of market-based instruments in environmental management continues to grow, the specification of property rights will become increasingly important. Since property rights are typically specified as bundles of contingent claims and obligations, formal modelling of the specification of property rights is most naturally undertaken in a state-contingent framework. This approach allows for a seamless integration of the description of property rights and the modelling of production responses under uncertainty.

In the case of the Murray-Darling Basin, the analysis here suggests that alternative choices for the specification of property rights may have significant implications for resource allocation and environmental outcomes. Thus far, it does not appear that these implications have been given adequate consideration in the policy debate.

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Table 1a: Values of state-contingent solution variables: Sequential solution with spanning

	Water Use (GL)			Salinity (mg/L)			Return ($m)			
Catchment	**Normal**	**Drought**	**Wet**	**Normal**	**Drought**	**Wet**	**Normal**	**Drought**	**Wet**	**Average**
Condamine	123.0	73.8	123.0	29.1	48.9	24.4	99.9	58.7	141.6	104.2
Border Rivers(Q)	89.0	53.4	89.0	74.0	124.4	62.2	99.2	58.3	148.3	105.8
Warrego-Paroo	3.5	3.5	3.5	94.3	163.7	81.8	1.8	1.8	2.8	2.1
Namoi	527.0	316.2	527.0	154.1	259.2	129.6	101.0	63.7	150.6	108.4
Central West	482.0	289.2	482.0	124.3	211.5	105.7	142.7	75.3	239.0	158.1
Maranoa-Balonne	24.1	24.1	24.1	41.5	65.8	34.2	12.3	12.5	19.4	14.5
Border Rivers(N)	531.0	318.6	531.0	110.9	183.7	92.1	112.4	68.3	171.3	121.3
Western	110.2	110.2	110.2	228.6	369.6	182.6	18.6	18.6	36.4	23.9
Lachlan	375.0	225.0	375.0	353.6	594.1	297.1	93.6	45.2	169.6	106.7
Murrumbidgee	1,498.6	1,204.2	1,498.6	24.0	40.4	20.2	376.4	233.6	655.2	431.5
North East	97.5	98.3	98.3	38.9	65.7	32.8	101.9	47.7	191.8	118.0
Goulburn-Broken	1,047.0	628.2	1,052.7	134.1	225.5	112.7	340.1	157.4	638.9	393.2
Wimmera	103.0	61.8	103.6	530.1	1089.0	544.5	11.2	3.7	24.9	13.8
North Central	82.0	49.2	82.3	319.2	587.8	291.1	43.4	22.5	74.8	48.6
Murray	903.0	541.8	903.0	226.3	381.7	189.2	103.4	70.4	174.4	118.1
Mallee	53.0	31.8	53.0	442.3	743.5	365.6	37.5	13.5	71.3	42.8
Lower Murray Darling	87.0	52.2	87.0	410.3	697.1	333.3	35.1	-9.9	99.0	45.3
SA MDB	302.2	302.2	302.2	548.0	927.0	444.8	185.6	0.2	462.5	231.6
Adelaide	123.6	123.6	123.6	577.8	977.4	467.8	63.0	63.0	63.0	63.0
TOTAL	**6,561.6**	**4,507.2**	**6,569.0**				**1,979.2**	**1,004.3**	**3,534.9**	**2,251.0**
Note: Flows to Sea	14,562.3	8,149.4	18,010.6	603.8	1015.4	488.3				

Table 1b: Land allocations ('000 ha): Sequential solution with spanning

Catchment	Citrus H	Citrus-L	Grapes	Stone H	Stone L	Veg	Cotton	Rice	Wheat	Dairy - H	Dairy - L	Adelaide water	Return	Salinity
Condamine			3.4				21.2						104.2	31.66
Border Rivers (Q)		5.3					17.3						105.8	80.56
Warrego-Paroo							0.7						2.1	104.45
Namoi			0.5				74.9						108.4	167.77
Central West			8.1				57.3						158.1	136.19
Maranoa-Balonne							4.8						14.5	44.16
Border Rivers (N)		0.0	1.8				74.6						121.3	119.83
Western							15.7						23.9	242.98
Lachlan		10.1					37.8						106.7	384.73
Murrumbidgee		30.5							337.4				431.5	26.10
North East				5.2						12.8			118.0	42.45
Goulburn-Broken				14.7					108.9	107.5			393.2	146.00
Wimmera			1.2						10.7	11.2			13.8	646.19
North Central			4.0						8.5	5.5			48.6	364.49
Murray		5.8							222.6				118.1	246.24
Mallee			5.8						5.4				42.8	479.56
Lower MD			10.4						8.9				45.3	444.57
SA MDB			55.0										231.6	592.82
Adelaide												123.6	63.0	624.75
TOTAL		**51.7**	**90.2**	**19.9**			**304.4**		**702.4**	**137.0**		**123.6**	**2,251.0**	

Table 2a: Values of state-contingent solution variables: Priority rights solution

	Water Use (GL)			Salinity (mg/L)			Return ($m)			
Catchment	**Normal**	**Drought**	**Wet**	**Normal**	**Drought**	**Wet**	**Normal**	**Drought**	**Wet**	**Average**
Condamine	123.0	61.5	123.0	29.1	48.9	24.4	99.0	54.3	137.1	101.5
Border Rivers(Q)	89.0	44.5	89.0	74.0	124.4	62.2	99.3	54.0	145.6	104.1
Warrego-Paroo	3.5	3.5	3.5	94.3	163.7	81.8	1.8	1.8	2.8	2.1
Namoi	527.0	263.5	527.0	154.1	259.2	129.6	101.0	55.1	140.7	103.7
Central West	482.0	241.0	482.0	124.3	211.5	105.7	142.9	68.8	230.7	154.4
Maranoa-Balonne	24.1	24.1	24.1	41.5	64.2	34.2	12.3	12.5	19.4	14.5
Border Rivers(N)	531.0	265.5	531.0	110.9	182.2	92.1	112.4	59.6	161.4	116.6
Western	110.2	110.2	110.2	228.6	343.7	182.6	18.6	18.6	36.4	23.9
Lachlan	375.0	187.5	375.0	353.6	594.1	297.1	93.6	42.1	164.1	104.5
Murrumbidgee	1,498.6	1,003.5	1,498.6	24.0	40.4	20.2	370.0	223.4	627.5	418.0
North East	97.5	98.3	98.3	38.9	65.7	32.8	101.9	47.7	191.8	118.0
Goulburn-Broken	649.0	628.2	655.0	134.1	225.5	112.7	327.8	152.2	619.8	380.3
Wimmera	63.9	61.8	64.4	530.1	1089.0	544.5	10.0	3.2	23.0	12.5
North Central	51.0	49.2	51.3	303.7	587.8	277.9	39.0	3.8	91.9	47.8
Murray	903.0	451.5	903.0	216.0	381.7	181.7	100.5	65.8	161.9	112.0
Mallee	34.0	31.8	34.0	421.0	733.6	350.2	40.2	10.5	69.6	43.1
Lower Murray Darling	43.5	43.5	43.5	396.3	664.5	323.3	31.7	-5.1	86.7	40.8
SA MDB	280.5	280.5	280.5	528.1	881.8	430.7	200.8	23.1	466.4	244.9
Adelaide	123.6	123.6	123.6	554.5	924.3	451.2	62.1	62.1	62.5	62.2
TOTAL	**6,009.2**	**3,973.1**	**6,016.9**				**1,965.0**	**953.5**	**3,439.4**	**2,205.0**
Note: Flows to Sea	14,949.0	8,523.3	18,397.1	577.8	956.9	469.6				

Table 2b: Land allocations ('000 ha): Sequential solution with priority rights

Catchment	**Citrus H**	**Citrus-L**	**Grapes**	**Stone H**	**Stone L**	**Veg**	**Cotton**	**Rice**	**Wheat**	**Dairy - H**	**Dairy - L**	**Adelaide water**	**Return ($m)**	**Salinity**
Condamine		3.4					24.3						101.5	31.66
Border Rivers (Q)		5.3					17.3						104.1	80.56
Warrego-Paroo							0.7						2.1	104.45
Namoi			0.5				74.9						103.7	167.77
Central West			8.1				57.3						154.4	136.19
Maranoa-Balonne							4.8						14.5	43.83
Border Rivers (N)		0.0	1.8				74.6						116.6	119.54
Western							15.7						23.9	237.78
Lachlan		10.1					37.8						104.5	384.73
Murrumbidgee		30.5							337.4				418.0	26.10
North East				5.2						12.8			118.0	42.45
Goulburn-Broken				14.7						113.0			380.3	146.00
Wimmera			1.2							11.8			12.5	646.19
North Central				4.0						4.8			47.8	352.78
Murray		5.8							222.6				112.0	238.84
Mallee			6.2										43.1	462.27
Lower MD			8.7										40.8	428.02
SA MDB			51.0										244.9	569.59
Adelaide												123.6	62.2	597.47
TOTAL		**55.0**	**77.5**	**23.9**			**307.4**		**560.0**	**142.3**		**123.6**	**2,205.0**	

Table 3a: Values of state-contingent solution variables: Proportional rights solution

	Water Use (GL)			Salinity (mg/L)			Return ($m)			
Catchment	**Normal**	**Drought**	**Wet**	**Normal**	**Drought**	**Wet**	**Normal**	**Drought**	**Wet**	**Average**
Condamine	123.0	10.1	126.4	29.1	48.9	24.2	99.6	16.6	117.9	88.5
Border Rivers(Q)	89.0	21.2	94.3	74.0	124.4	61.6	86.1	35.7	110.4	83.3
Warrego-Paroo	3.5	0.0	3.5	94.3	163.7	77.8	1.8	-0.3	1.8	1.4
Namoi	527.0	1.6	527.5	154.1	259.2	128.1	101.0	-78.2	103.7	66.0
Central West	482.0	24.3	490.1	124.3	211.5	103.1	142.0	-36.8	186.1	119.5
Maranoa-Balonne	24.1	0.0	24.1	41.5	57.7	34.3	12.3	-2.5	12.5	9.4
Border Rivers(N)	531.0	5.6	532.9	110.9	178.6	92.1	112.4	-71.9	121.8	78.4
Western	94.0	0.0	94.0	228.6	252.2	179.7	17.4	-16.1	22.2	12.1
Lachlan	375.0	0.0	373.7	353.6	594.1	294.0	84.9	-150.5	209.8	75.3
Murrumbidgee	2,007.0	1,204.2	2,403.9	24.0	40.4	19.9	352.8	194.5	572.6	387.1
North East	90.4	66.9	108.2	38.9	65.7	32.4	72.5	35.0	106.5	75.2
Goulburn-Broken	1,047.0	628.2	1,254.7	134.1	225.5	111.5	270.3	32.3	442.2	274.3
Wimmera	78.6	61.8	94.0	530.1	1089.0	421.9	11.3	-34.5	28.9	7.4
North Central	82.0	49.2	98.3	309.4	587.8	252.3	45.7	-9.5	78.3	44.5
Murray	903.0	541.8	1,079.1	225.4	379.9	188.1	87.1	-90.6	193.4	83.4
Mallee	53.0	31.8	63.6	440.7	739.7	368.5	61.7	-41.6	123.5	59.6
Lower Murray Darling	86.9	36.8	104.4	420.8	611.6	347.1	37.1	-69.7	119.4	40.4
SA MDB	302.2	181.3	362.7	563.0	809.8	465.4	162.3	-324.1	524.2	173.6
Adelaide	0.0	0.0	0.0	595.4	836.2	494.4	94.8	94.8	94.8	94.8
TOTAL	**6,898.6**	**2,864.8**	**7,835.1**				**1,853.3**	**-517.5**	**3,170.0**	**1,774.1**
Note: Flows to Sea	14,326.4	9,299.1	17,596.3	619.4	851.6	516.6				

Table 3b: Land allocations ('000 ha): Sequential solution with proportional rights

Catchment	**Citrus H**	**Citrus-L**	**Grapes**	**Stone H**	**Stone L**	**Veg**	**Cotton**	**Rice**	**Wheat**	**Dairy - H**	**Dairy - L**	**Adelaide water**	**Return ($m)**	**Salinity**
Condamine			3.4				21.2						88.5	31.6
Border Rivers (Q)		5.3					12.5						83.3	80.4
Warrego-Paroo							0.7						1.4	103.2
Namoi			0.5				74.9						66.0	167.3
Central West			8.1				57.3						119.5	135.4
Maranoa-Balonne							4.8						9.4	42.6
Border Rivers (N)	0.1		1.7				74.5						78.4	118.8
Western						0.4	13.1						12.1	218.6
Lachlan						10.1	32.0						75.3	383.8
Murrumbidgee		30.5						246.0	19.8				387.1	26.0
North East			5.2							12.8			75.2	42.3
Goulburn-Broken			14.7						62.9	148.6			274.3	145.6
Wimmera			1.2							14.8			7.4	609.4
North Central			4.0						3.9	9.2			44.5	347.9
Murray		5.8							59.7	142.8			83.4	245.1
Mallee			9.6										59.6	478.9
Lower MD			12.3						6.5				40.4	436.8
SA MDB			55.0										173.6	583.1
Adelaide												206.0	94.8	613.2
TOTAL	**0.1**	**41.6**	**115.7**			**10.4**	**291.1**	**246.0**	**152.9**	**328.2**		**206.0**	**1,774.1**	

Table 4: Comparative values of objective function values

Expected return ($m) for solutions

Catchment	Spanning	Priority rights	Proportional
Condamine	104.2	101.5	88.5
Border Rivers(Q)	105.8	104.1	83.3
Warrego-Paroo	2.1	2.1	1.4
Namoi	108.4	103.7	66.0
Central West	158.1	154.4	119.5
Maranoa-Balonne	14.5	14.5	9.4
Border Rivers(N)	121.3	116.6	78.4
Western	23.9	23.9	12.1
Lachlan	106.7	104.5	75.3
Murrumbidgee	431.5	418.0	387.1
North East	118.0	118.0	75.2
Goulburn-Broken	393.2	380.3	274.3
Wimmera	13.8	12.5	7.4
North Central	48.6	47.8	44.5
Murray	118.1	112.0	83.4
Mallee	42.8	43.1	59.6
Lower Murray Darling	45.3	40.8	40.4
SA MDB	231.6	244.9	173.6
Adelaide	63.0	62.2	94.8
TOTAL	**2,251.0**	**2,205.0**	**1,774.1**

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