Missing markets for storage and their implications for spatial water markets

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Abstract

A great deal of attention has been given in recent years to the question of externalities associated with water entitlements and how third parties can be protected without restricting opportunities for water trade. Yet one market failure that has received no attention at all is the missing market for storage that arises from the current specification of water entitlements, particularly in Victoria where all storage decisions are made at the centralized - common property level. Whilst it has been recognized that there are reliability issues associated with broadening the spatial scope of water markets because water entitlements are specified differently between states, proposed solutions, such as ‘tagging’ and ‘exchange rates’ do no adequately deal with the missing market for storage problem.

The economic significance of the missing market for storage is demonstrated using an empirical model that represents the spatial-temporal pattern of irrigation water demand in the Goulburn Valley and decisions regarding inter-year storage of water in Lake Eildon. It is shown that, because irrigators have no incentive to trade of the benefit of current use (or sale) with the value of water storage, there is an erosion of reliability when opportunities for trade are broadened. The empirical results demonstrate that the loss in economic value associated with reduced reliability are as large as the gains from trade, so there is no net benefit from trade. These empirical results represent the scenario that would arise with the proposed ‘tagging’ arrangements for inter state trade. On the other hand, the introduction of clearly specified (private) rights to storage would allow for the optimal allocation of water over time and space, allowing the potential benefits of trade to be realized.

Keywords: Water markets; storage; drought

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1. Introduction

Policy makers in Australia are continuing to drive reform in water markets, and in the Murray Darling Basin the emphasis is on expanding the spatial scope of trade in permanent water entitlements. At the same time there is a commitment to providing more secure water entitlements, hence concern about the potential for third party impacts of trade has been the source of some contention and a stumbling block to reform. Aside from the 'stranded assets' argument put forward by some irrigation companies and communities, which is more about structural adjustment than about economic efficiency[1], one of the main impediments to expanding trade is the fact that water entitlements are defined quite differently in the different states. In particular, the services provided to holders of water entitlements with respect to water storage and reliability are very different. Whilst other potential externality issues associated with expanding trade have been widely discussed in the literature (Brennan and Scoccimarro 1999, Beare and Heaney 2002, Heaney *et al.* 2006), there has been little discussion of the storage services provided to water entitlement holders and what will happen to them as the spatial pattern of water use changes with expanded trade.

On the matter of providing consistency in the 'entitlement' to be traded, two main strategies have been suggested. One option is to develop a system of 'exchange rates' that provide a means of converting an entitlement in one location into an equivalent volume of water in another system. This was the approach used in the pilot interstate water trading project dealing with relatively homogenous high reliability water; but the scope for expanding the method to any class of reliability has been the subject of scientific investigation (eg. Etchells *et al*. 2003, Etchells *et al.* 2004). Whilst that approach has been popular because of its apparent simplicity, it has been criticized because of its potential for creating third party reliability impacts (Price Waterhouse Coopers 2006). The alternative method which appears to be more acceptable to current policy makers is the 'tagging' method, where any water traded between states continues to be 'tagged' according to its point of origin, so that it can continue to be managed in the same way. For example, a Victorian farmer buying a New South Wales right would receive a seasonal allocation announced by the relevant NSW authority, determined according to the rules governing entitlement holders in the source region.

Economists have had little to say on the matter. Whilst there has been a great deal of discussion surrounding the unbundling of water entitlements into access rights, use rights, delivery capacity rights as so forth (Marsden 2002, Young and McColl 2003, Goesch and Beare 2004), most discussion seems to take the bundling of inflows and storage services as a given. Heaney *et al.* (2006) reinforce the pro-tagging argument with a claim that changes in the spatial pattern of trade on the seasonal market have no third party impacts. On the question of reliability of water deliveries across seasons, most of the discussion has focused on whether the proportional rights system used in Australia (where irrigation share the available water) should be abandoned in favour of a priority system resembling the Western United States (e.g. Freebairn 2003, Young and McColl 2003, Freebairn and Quiggin 2006). Empirical studies

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[1] Any economic efficiency issues relate to the pricing of capital and therefore can be solved through market mechanisms

focusing on risk and dynamic issues in water resources management have generally taken the current dam release pattern as given (eg. Adamson *et al.* 2006). Apart from early work by Dudley (Dudley 1988, Dudley 1992, Dudley and Hearn 1993, Dudley and Musgrave 1988) in northern New South Wales, there has been little empirical work done on the question of optimal water storage for irrigation. The exception is a study by Beare et al. (1998) which only considered marginal private modifications to storage according to current New South Wales carryover rules.

The aim of this paper is to provide an analysis on the underlying storage services embedded in current water entitlements, using a case study of the Goulburn Valley where storage services are substantial and relatively simple (there are no private carryover provisions). It is argued and then demonstrated empirically that there is a missing market (for storage) problem in the current property rights arrangements and this can lead to efficiency costs if spatial markets are broadened without addressing this underlying market failure.

The paper is organized in five additional sections. In the next section, a graphical presentation of the economics of water storage and the missing market associated with current entitlement structure is presented. Section 3 describes the empirical model used to derive the results presented in Section 4. The final section contains a discussion of the implications of these results for policy formulation, and the future research needs in this area.

2. A graphical presentation of the missing markets problem

The principles of the competitive storage market are represented here using graphical analysis and extended to show the impact of broadening spatial markets on the 'missing market' problem.

The basic decision making problem for storage and release of water in a particular irrigation season *t* is shown in figure 1. Water available in the current period depends upon the quantity of inflows into the dam since the last irrigation season, and the amount of water carried forward from the last irrigation season as storage (storage in t). These two sources define current availability which can either be allocated for use in the current season or carried out into the next season.

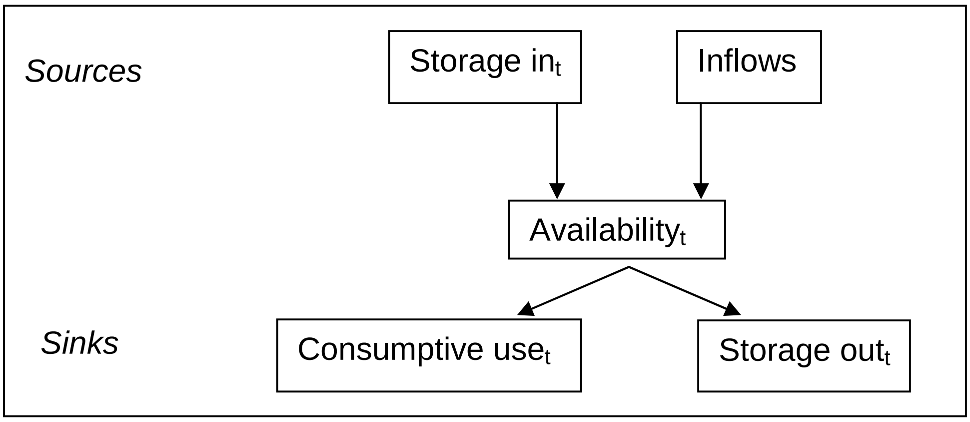

Figure 1. The decision making problem

2.1 Optimal storage

The economically efficient method of allocating available water between current and future use is determined by equating the marginal benefit of current season use and the expected marginal benefit of storage. The marginal value of storage is the expected value of water for consumption in the subsequent period(s), which is downward sloping: the more that is stored, the more likely that the marginal unit will have to be sold onto the market in the subsequent period at a lower price. By expressing this marginal benefit of storage net of the costs of storage (in this case losses, rent on physical infrastructure, and interest costs), the inter-temporal equilibrium can be shown diagrammatically. In figure 2, the horizontal axis shows the total amount of water available which has to be allocated either to consumption or to storage. The marginal benefit associated with allocating to current use is a declining function of use. The opportunity cost of using the water in the current period is the foregone marginal value of storage, which is increasing with water use as it is decreasing with quantity stored. The optimal allocation between water use and storage is the intersection of these two marginal benefit curves.

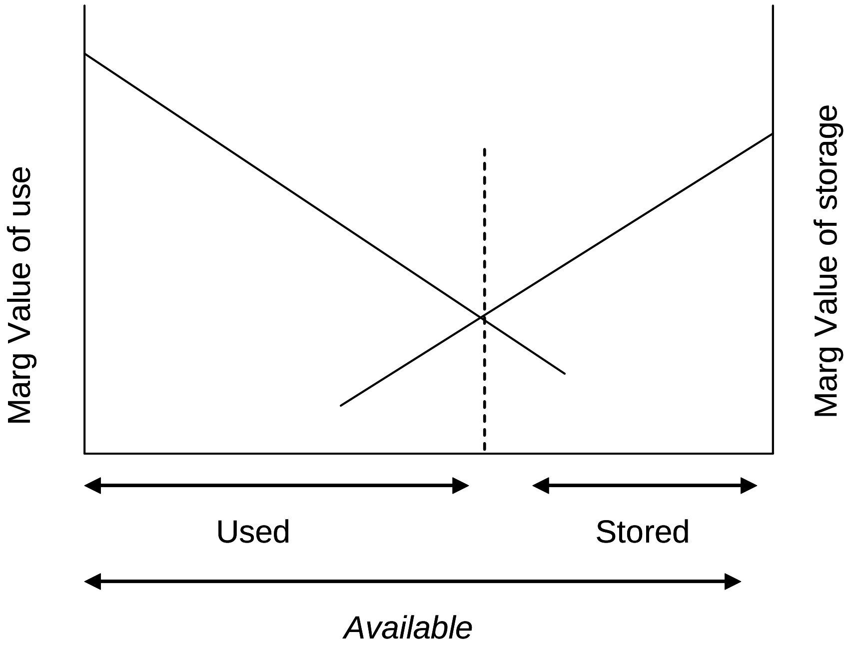

Figure 2: The efficient storage equilibrium

The marginal value of storage is the expected value associated with the use of the water in the future, and as long as the system is stationary (no demand growth or contraction, risk profile of future inflows is unchanging) then this expected value curve is also constant. In contrast, the opportunity cost of water in the current season varies according to the prevailing seasonal conditions. In particular, irrigation season rainfall has been shown to be a significant driver of current season opportunity cost (Brennan 2006). The marginal value of use will shift upward under low rainfall conditions, resulting in relatively more use and less storage at a given level of availability, as shown in figure 3a. Similarly, under high rainfall conditions current season demand is reduced and a greater quantity should be stored. When there is relatively more water available, either as a result of storage decisions made last period or high winter inflows, additional water is likely to be allocated to both storage and use, depending on the relative positions of the marginal benefit curves as shown in figure 3b.

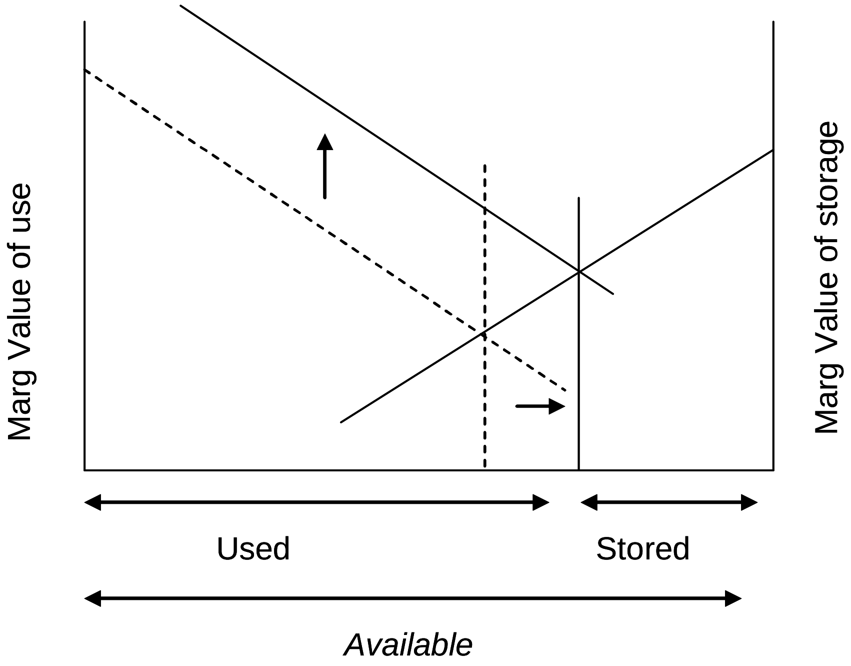

Figure 3a: Impact of current season demand on use and storage

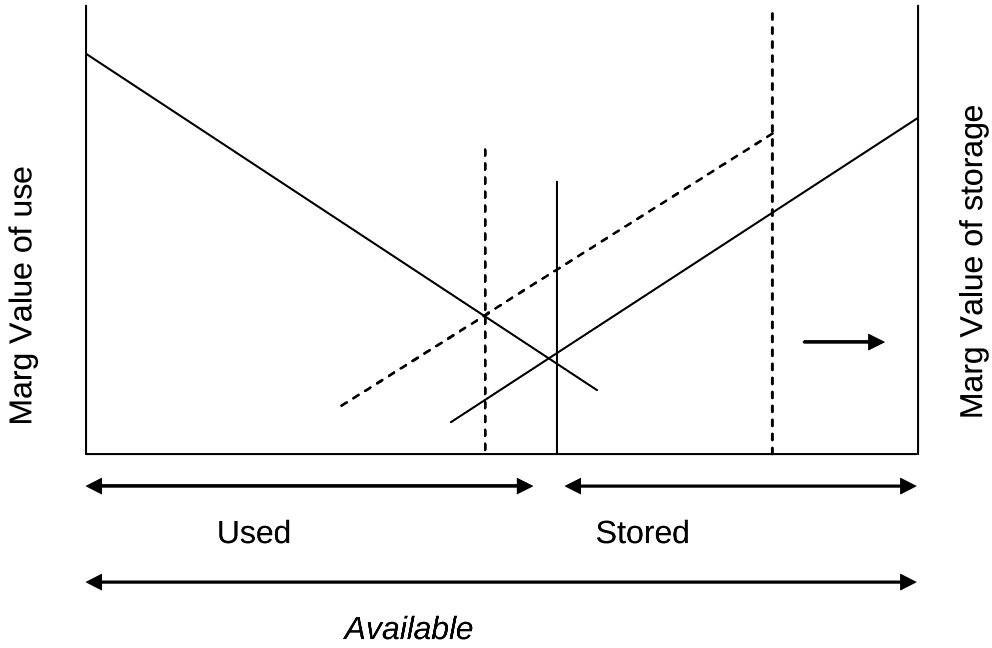

Figure 3b: Impact of current season availability on use and storage

2.2 Water storage in the current entitlements system

In Victoria, fixed decision rules govern the allocation of available water between current use and storage. Storage carried out of an irrigation season is the sum of a deliberate (and compared to New South Wales very conservative) reserve policy, plus a residual amount made up of unused seasonal water allocations. The water allocation decision and its converse, the water storage policy, is shown in figure 4. Specifically, the dam release rule requires that if available dam reserves exceed the aggregate entitlement volume, then this extra water is set aside as a reserve for next year's supply up until the point where water stored is equal to 100% of entitlement. If available reserves exceed twice the entitlement, then additional water can be allocated to irrigators in the current season. The maximum allocation is 200% of entitlement. If available dam reserves are less than the entitlement volume, then all available water is allocated to the irrigation industry in the current year and entitlements are not fully met.

Whilst allocations can be up to 200%, at high water allocations the actual level of water use is substantially less than allocations. The low marginal uptake at high allocations is likely to be the result of rational long term decisions regarding expected utilization under seasonal risk. For example, it would not be efficient to invest in additional channel delivery capacity, or additional irrigation specific capital, to use additional quantities of water that might only be available infrequently (Brennan 2006). By default, this unused water is placed into storage. The storage rule is shown in figure 4b.

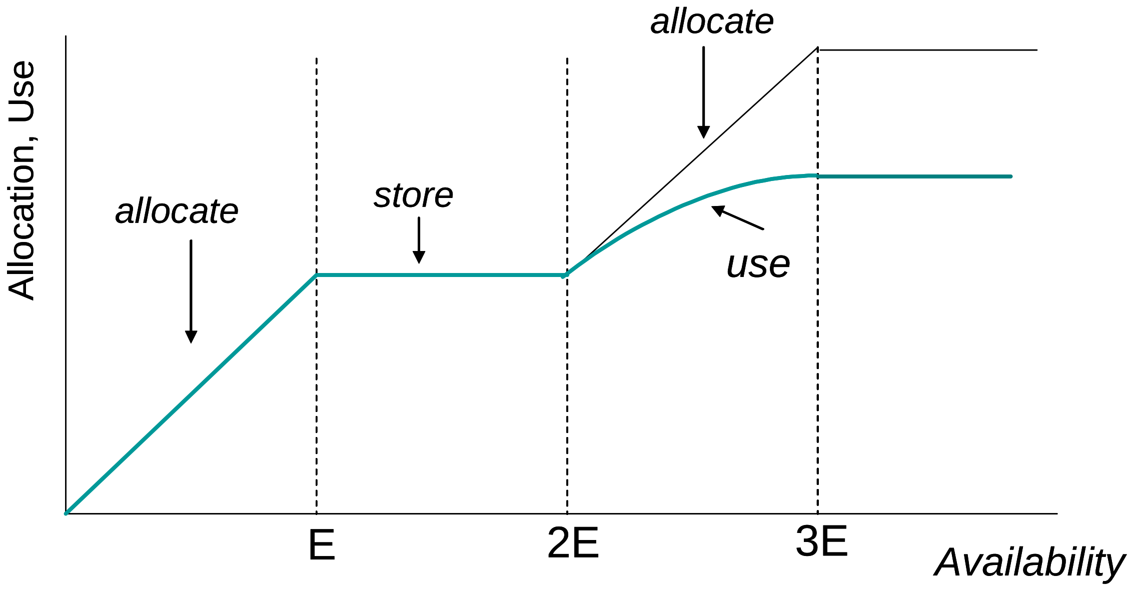

Figure 4a. The seasonal allocation rule

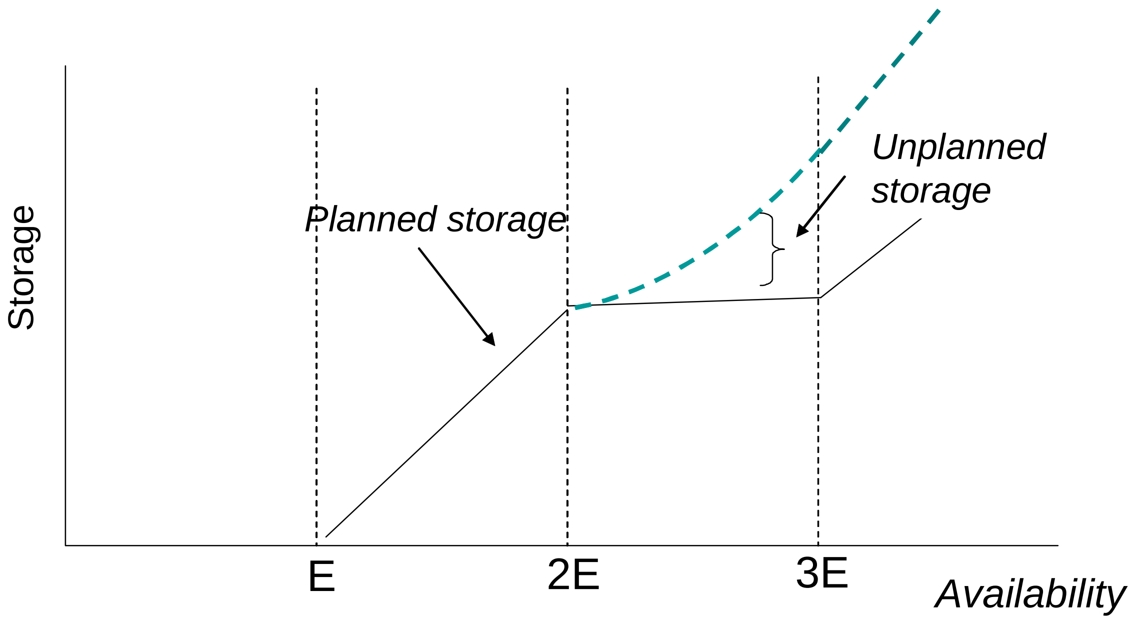

Figure 4b. Storage under current arrangements

Under this entitlement structure, some of the risk associated with variable inflows is removed by the engineered storage policy, but there is no capacity for farmers to modify the quantity stored to satisfy their own reliability requirements, because the unused water is returned to a common pool at the end of the irrigation season. Even if the irrigator has a private value associated with storage as shown in the dashed line in figure 5, in the absence of clearly defined property rights over that storage the irrigator will use (or sell) seasonal allocations in the current period until all the current season rents are dissipated.

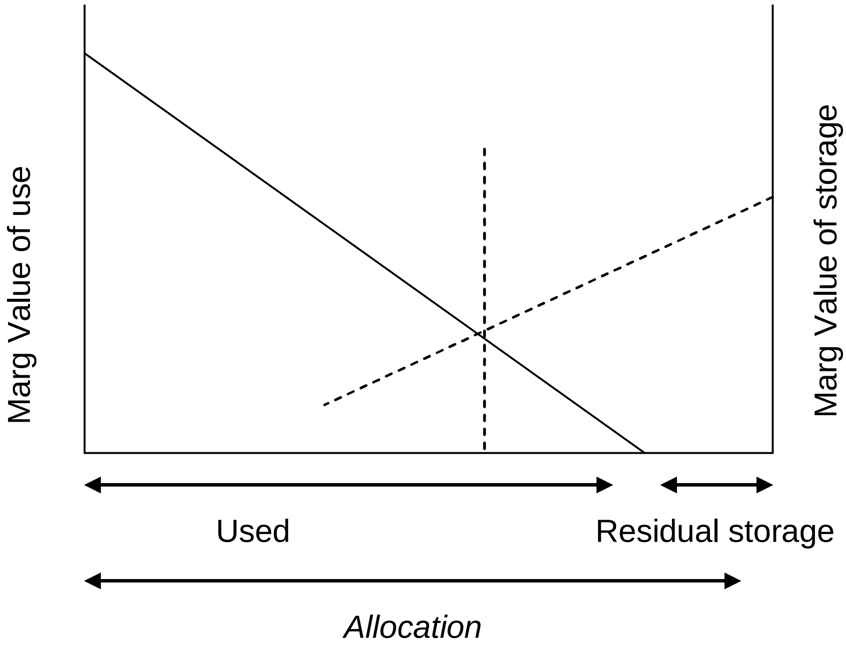

Figure 5: Residual storage occurs by default

The problem with broadening spatial markets is that it increases the opportunity for current season use and therefore reduces the ‘residual storage’ that occurs with the current entitlement structure, as illustrated in figure 6. As long as there exists some opportunity for using water in another location under circumstances where current use opportunities in the original location are low, there will be an increase in current period use and a reduction in residual storage, hence an erosion of reliability.

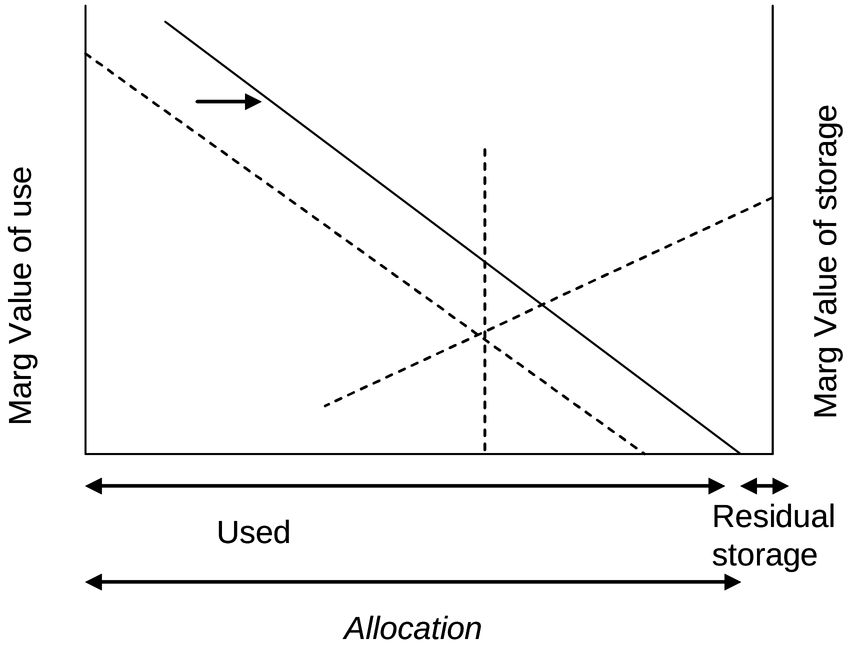

Figure 6. The impact of trade on current period demand and residual storage

3. Modeling the impact of market expansion on storage and gains from trade

The dissipation of rents from trade under the current entitlement system is demonstrated using a case study of the Goulburn Valley, where the opportunity to trade with irrigators in the NSW Murray is simulated. The model is applied by examining the potential for trade in water on seasonal markets, where decisions are made in the current period regarding whether to use or sell or store water. The model can also represent a permanent ‘tagged’ transaction between a Goulburn and NSW irrigator, where the NSW irrigator only used the water in NSW if the expected value of use was greater than that value that could be obtained by making it available for sale on the Goulburn seasonal market[2].

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[2] Since the water originates in Goulburn such trade would be physical feasible.

3.1 Estimating the marginal benefit of storage for the ‘optimal storage’ case

A stochastic dynamic programming model was developed to estimate the expected marginal value of storage demonstrated in figure 2 for the base case, and for the case where opportunities for trade with NSW are possible. (Because this trade opportunity changes the current season opportunity cost it also changes the expected marginal value of storage.) The expected value function was estimated using the parameter iteration method (Williams and Wright 1990), where the expected value function is estimated as a polynomial function of the quantity stored. A detailed description of the solution method is provided in Brennan (2007). The process involves estimating, for a range of incoming storage levels, the expected price that would be realized if the approximation equation for the value of storage were used to allocate between current season and the future use, over the range of possible climatic outcomes represented by a discrete probability distribution. The model is solved repeatedly until the estimated value curve converges with the realized value of storage.

3.2 Representing the hydrological system

The decision making components of the model are represented on an annual time step, that is, the decision regarding storage and use is made once in the irrigation season with irrigation season inflows and current rainfall known. In reality the information is obtained over the course of the irrigation season and storage and use decisions are modified in response. However, since the key driver of risk in the model is the winter-spring inflows most of which occur before the main irrigation season, the important components of the fundamental decision making problem are captured. The hydrological system is modeled in a spreadsheet using the historical series on inflows into Lake Eildon from 1881 to 2004, using a time step of one month during the May to October period when 80 percent of inflows occur, in order to better account of dam spillage associated with variable monthly inflows that might not be captured in an annual time step model. The distribution of currently available water between ‘seasonal allocations’ and ‘deliberate storage’ was based on the decision rule is illustrated in figure 4a. One of the main difficulties in modeling the current entitlement system is modeling the uptake of those seasonal allocations (hence residual storage). Because of the existence of constraints on delivery, and the option value of holding water during the irrigation season in the event of a dry finish, there is no reason to expect that water will be used up to the point where the realized market price is zero. Instead, the simulation model draws on key relationships in the Victorian government’s REALM model of the Goulburn River (James *et al.* 1993) which uses a set of equations to represent the uptake of current season allocations according to irrigation season rainfall and the volume allocated. The simulated probability distribution of water allocations in the base case (current policy), which uses the dam release rule to determine seasonal allocations, correlates well to the probability distribution of water allocations simulated from the REALM model, as shown in figure 7.

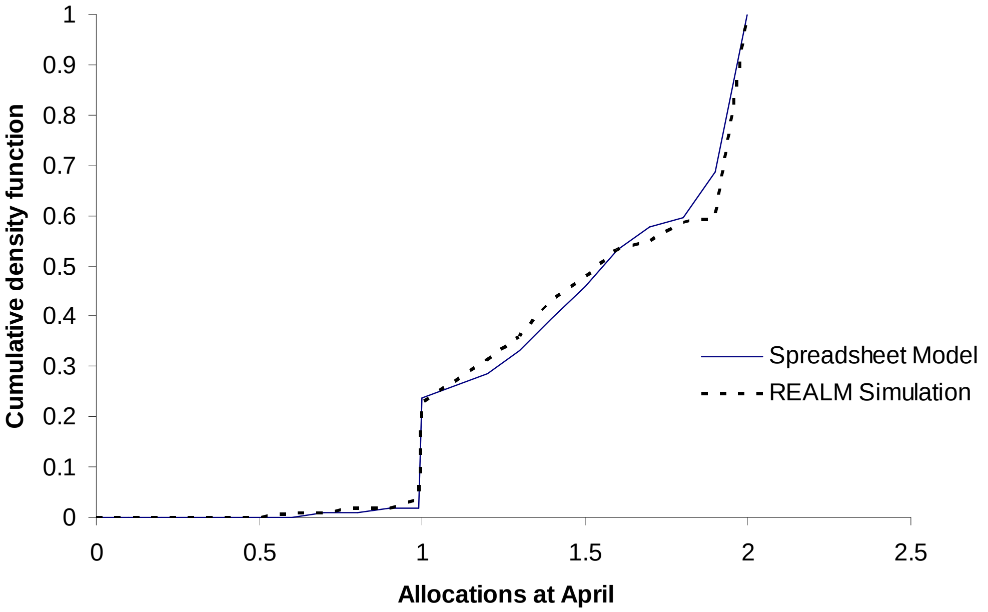

Figure 7: Comparison of spreadsheet model with official REALM model for probability profile of allocations

3.3 Current season water values

The current season value of water for the Goulburn system was derived from results reported in Brennan (2006) which describe current season water prices as a function of irrigation season rainfall and seasonal allocations. This equation was combined with the empirical relationship between allocations and diversions described in the previous section to define an irrigation demand equation, as shown in equation 1. Results in section 4 represent the area under this demand curve.

$$P_t = \exp(8.100 - 6.92 \text{ x } 10^{-3} R_t - 2.33 \text{ x } 10^{-6} Q_t) \qquad (1)$$

Where:

P_t is price of irrigation water in season *t*
Q_t is quantity consumed by irrigators (diversions - delivery losses), ML
R_t irrigation seasonal rainfall in mm

To represent the potential demand for water from the NSW Murray, a similar model was estimated using data reported on the Murray exchange[3]. An historical time series of NSW Murray allocations, together with rainfall at Deniliquin, were then used to generate the marginal (pre trade) price in New South Wales. The slope of the trade demand function was derived by adjusting the coefficient for allocation in equation 2, to represent volume rather than percent.

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[3] Available at URL:http://www.murrayirrigation.com.au/watexch/

$$P_t = \exp(6.52 - 5.398 \text{ x } 10^{-3} R_t - 2.439 \text{ x } 10^{-4} A_t) \qquad (2)$$

Where: A_t is allocation in the current year as a proportion of entitlement.

In the simulations where trade with NSW is allowed, it is assumed to only occur in one direction (from Goulburn to NSW) reflecting current trading rules associated with system delivery constraints. The quantity of trade was determined by the solution to the spatial equilibrium. In the case of the optimal storage simulations the spatial and temporal equilibria were solved simultaneously.

4. Results

The expected annual value of water (the area under the water demand curve) was estimated for the baseline (current storage rule, no trade with NSW Murray), and for two trade scenarios. The first trade scenario assumes that the current entitlement system and associated storage rules are used. The second trade scenario examines the case where an efficient storage market is able to determine the spatial-temporal equilibrium. The change in economic surplus, relative to the baseline, is shown for two trade scenarios in table 1. Using the current storage regime, there is an expected annual loss in value of $5.32m in the Goulburn region, and a gain for the importing region of $5.04m. The net effect of introducing trade is slightly negative. In contrast, there are positive gains from trade when storage is based on market conditions - the change in the value of water use in the Goulburn region is minimal whilst the water is used to produce $4.86 million in the importing region. Note that the same total quantity of water is in the system in both cases, the measured economic differences are due to the market mechanism allocating water to the right time and right place.

Table 1. Change in expected annual value of consumptive water use for two trade scenarios (difference from baseline), $m

	Change in value of water used from Goulburn system, $m		
Water used in:	Goulburn	Importing region	Total
Current storage	-5.32	5.04	-0.28
Market-based storage	-0.45	4.86	4.42

The distributional impacts of these scenarios are shown in table 2. Under the current water entitlement/storage system, the irrigators in the Goulburn valley are made worse off by the trading regime. Revenue earned from trade in periods when it is profitable to do so are undermined by a loss in reliability that leads to a loss in the value of production in the region. This contrary result – that the net gains from trade are negative – is the result of the 'missing markets' problem. In contrast, the Goulburn Valley irrigators are beneficiaries of the trading regime because they gain from selling water when values in NSW are high, but their trading behaviour is curtailed due to the opportunity cost of storage, and this allows them to maintain most of the existing value of water use in their own irrigation region.

Table 2. Change in expected annual income associated with introducing trade, by region, $m.

	Change in producer surplus, Goulburn	Change in revenue earned from trade, Goulburn	Change in total income in Goulburn	Change in producer surplus, Importing region
Current storage	-5.32	4.10	-1.22	0.94
Market-based storage	-0.45	3.89	3.45	0.97

Results presented in the tables only show the mean annual effect. They can be compared with the mean annual value of rents earned on the temporary water market in the Goulburn of around $3m in ‘normal years’ (Brennan 2007) and the mean annual rental value of water entitlements simulated in the baseline model run of $67m. To gauge the relative importance of these results therefore, it can be said that the loss in the economic value of water use in the Goulburn is of a larger magnitude than the economic rents currently generated on the spatial market, and is equivalent to around 8% of the rental value on current water entitlements. However, the net loss in income for farmers in the region is only 2% of the value of water entitlements after then revenue from exports is accounted for.

The reporting of mean annual effects masks the impact of the trading regimes on water reliability. Increased frequency of seasons with low water availability will not only lead to hardship for the farmers but for tax payers as well, given the Australian governments tendency for drought relief payments. The following figures demonstrate the impact of the alternative trading regimes on reliability.

First, the reliability of the current water entitlement (as measured by allocations announced as a proportion of water entitlement) is shown in figure 8. The introduction of trading shifts the reliability curve to the left, implying a greater probability of low water allocations. This is the result of a reduction in ‘residual storage’. The probably that full entitlements will not be received is doubled, and there is a lower chance of receiving higher allocations.

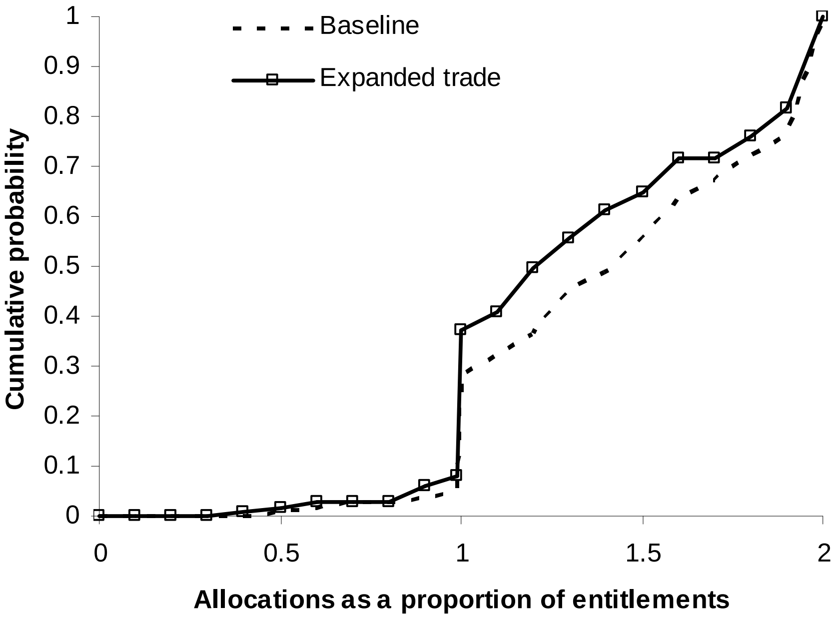

Figure 8: Impact of trade on reliability of entitlement under existing storage regime

The impact of the trading regimes on water use in the irrigation season is shown in figure 9. In the case of the ‘current storage’ regimes, these values differ from the underlying entitlements reliability shown in figure 8, because they include the modeled uptake of allocations. In the case of the ‘optimal storage’ regime, the water use is the optimal level, given both trade and storage opportunities. Compared to the baseline, the expanded trade scenario with the current storage regime leads to a greater likelihood of high water use, reflecting greater uptake of allocations via trade, which in turn undermines reliability. The ‘optimal’ storage scenario shows a lower tendency toward higher utilization but also an increased tendency for low utilization. The reason for this is that in periods of relatively high rainfall when water values are low, it is optimal to put relatively more water into storage in those years. That is, low water use in the ‘optimal case’ is generally a matter of choice, rather than a ‘scarcity induced’ low level of use.

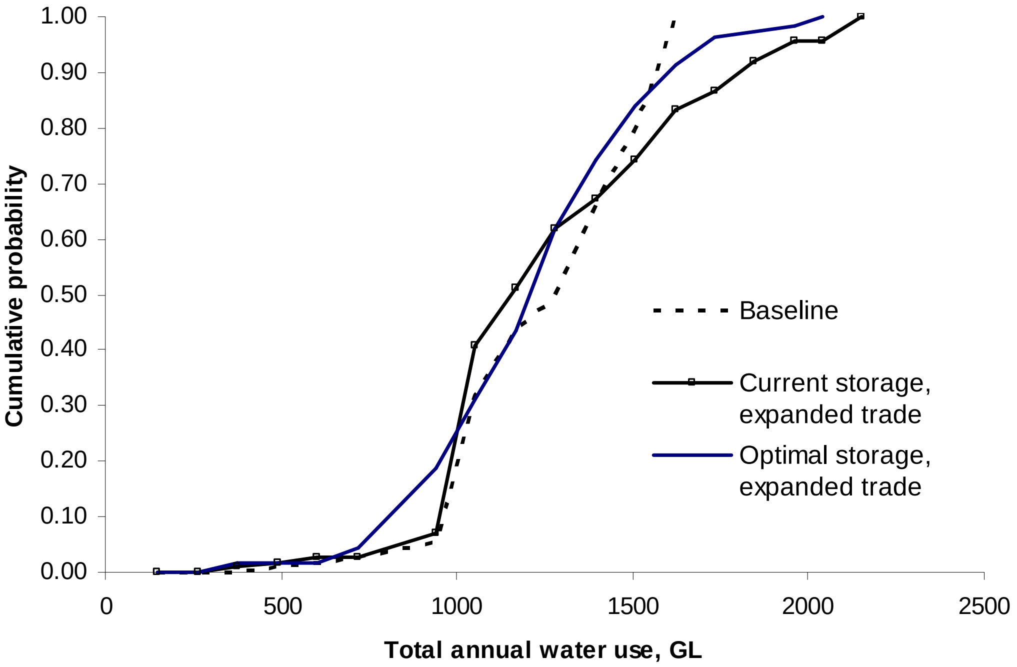

Figure 9: Impact of trade on probability distribution of current season use, baseline and trade scenarios

That low water use coincides with low opportunity cost in the “optimal storage’ case can be demonstrated by examining the probability of high prices in table 3. Under the baseline scenario, market prices exceeded $120 per ML in 17 years out of 113 in the simulation; and exceeded $150 per ML in six years and twice exceeded $250 per ML. With expanded trade and using the same storage policy, the frequency of high prices increased to 25 ($120 per ML) and 12 years ($150 per ML). In contrast, the introduction of a storage market at the same time as broadening trade actually reduces the likelihood of very high prices. Only in the drought of 1914, which was a year of extremely low irrigation season rainfall and low winter inflows, did the simulated price exceed $250 ML in the ‘optimal storage’ case, just as it did under the ‘current regime’ storage rules.

Table 3: Impact of trade on mean water prices and the frequency of very high prices

		With expanded trade	
	Baseline	Current storage	Optimal
Mean prices:	$67.2/ML	$79.6/ML	$68.9/ML
Number times price exceeds			
$120/ML	17	25	7
$150/ML	6	12	4
$250/ML	2	2	1

5. Conclusions

This analysis demonstrates the nature of the missing markets problem. There are third party effects from broadening the spatial scope of trade when the entitlement system is based on centrally planned storage decisions, rather than a storage market. Existing entitlement holders are currently the beneficiary of 'residual storage', which underwrites the reliability of entitlements. The introduction of broader spatial trade exacerbates the problem of the missing market because it creates greater opportunity for current season use. In contrast, the introduction of clearly defined property rights to storage would allow for the development of a storage market which would then allow for the gains from trade – in both spatial and temporal dimensions – to be achieved.

The mechanism by which expanded seasonal water trading is shown to impact on the reliability of water entitlements is the same mechanism by which permanent trades with 'water tagging' will affect reliability. Current demand patterns are the basis of long term investment decisions and local rainfall patterns, and changes to the spatial pattern of drawdown of water from a particular dam will affect the temporal pattern of demand for water, because the economic and climatic conditions driving demand differ by location. Most importantly, high valued water uses are associated with higher investments in irrigation specific capital that are usually made on the basis of a high level of reliability, and changes in reliability erode the returns on these investments.

References

Adamson, D., Mallawaarachchi, T. and J. Quiggin (2005) Modelling basin level allocation of water in the Murray Darling Basin in a world of uncertainty, Working Paper M05_1, 8/2/2005, School of Economics, University of Queensland, Available at URL [http://www.uq.edu.au/economics/rsmg/WP/WPM05_1.pdf]

Brennan, D. (2006) Water policy reform in Australia, lessons from the Victorian seasonal water market, Australian Journal of Agricultural and Resource Economics, 50: p403-424.

Brennan, D. (2007) Managing water resource reliability through water storage markets, working paper, available from the author.

Brennan, D. and M. Scoccimarro (1999), Issues in defining property rights to improve Australian water markets, Australian Journal of Agricultural and Resource Economics, 43: 69-89.

Beare, S. and A. Heaney (2002). Water trade and the externalities of water use in Australia, ABARE report prepared for the Natural Resource Management Unit, Department of Agriculture, Fisheries and Forestry, Canberra, ACT.

Beare, S. Bell, R. and B. Fisher (1998) Determining the value of water: The role of risk, infrastructure constraints, and ownership. *American Journal of Agricultural Economics*, 80(5): 916-940.

Dudley, N.J. (1988a) A single decision maker approach to irrigation reservoir and farm management decision making, Water Resources Research, 24(5):633-640.

Dudley, N. and B. Hearn (1993) Systems modeling to integrate river valley water supply and irrigation decision making under uncertainty, Agricultural Systems, 42:3-23

Dudley, N. 1992, Water allocation by markets, common property and capacity sharing: Companions or competitors? Natural Resources Journal, 32(4), 757-778.

Dudley, N. 1988b, Volume sharing of reservoir water, Water Resources Research, 24(5): 641-648.

Dudley, N. and W Musgrave (1988) Capacity sharing of water reservoirs, Water Resources Research, 24(5):649-658.

Etchells, T., Malano, H. and T. McMahon (2003). Developing a methodology to calculate water trading exchange rates, *Australian Journal of Water Resources*, 7:41-48.

Etchells, T., Malano, H. and T. McMahon (2004). Calculating exchange rates for water trading in the Murray Darling Basin, Australia, *Water Resources Research*, 40, W12505, doi:10.1029/2004WR003332.

Freebairn, J. (2003). Principles for the allocation of scarce water, Australian Economic Review, 36, 203-12.

Freebairn, J. and J. Quiggin (2006). Water rights for variable supplies, *Australian Journal of Agricultural and Resource Economics*, 50(3):295-312.

Goesch T. and S. Beare (2004). Water rights and trade: meeting the water reform agenda, Australian Commodities, 11, 180-189.

Heaney, A., Dwyer, G., Beare, S., Peterson, D. and L. Pechey (2006) Third-party effects of water trading and potential policy responses, *Australian Journal of Agricultural and Resource Economics*, 50(3):277-294.

James, B., Erlanger, P.D. and W.R. Hansen (1993), Modelling a Complex Irrigation Restriction Policy Using a General Simulation Package Hydrology and Water Resources Symposium, Newcastle, June 30 - July 2 1993

Marsden, J. (2002). Water entitlements and property rights: an economic perspective, Chapter 3 (p43-54), *in* Property: Rights and responsibilities, Current Australian Thinking, Land and Water Australia, available at URL: [http://www.lwa.gov.au/downloads/publications_pdf/PR020440.pdf]

Price Waterhouse Coopers (2006). National Water Initiative Water Trading Study, Final Report to the Department of Prime Minister and Cabinet, July 2006. Available at URL [www.dpmc.gov.au/water_reform/docs/nwi_wts_full_report.pdf]

Williams, J. C. and B. D. Wright (1991) *Storage and Commodity Markets,* Cambridge University Press, Cambridge.

Young and McColl (2003) Robust Reform: The case for a new water entitlement system, Australian Economic Review, 36(2):225-234.