Managing water resource reliability through water storage markets

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Abstract

The specification of irrigation property rights has undergone significant reform in Australia in recent years, which has allowed for the development of an active water market for allocating available water between irrigators in any given irrigation season. In contrast, decisions regarding the allocation of water across time are typically based on engineering rules of thumb, with little or no opportunity offered to irrigators to manage risk by physically transferring their allocated water between years. An empirical examination of the economics of water storage is presented using a case study of the Goulburn Valley, a major irrigation region in the state of Victoria. It is shown that the storage policy embedded in existing irrigation entitlements is significantly different from what would be provided by an efficient storage market. A storage market would store more water on average, but would also allocate more water in periods of low rainfall. The substantial costs associated with a recent prolonged drought were $100m more than they would have been if water storage decisions were left to the market, and prices were three times higher.

Key words: water market, storage, irrigation, stochastic dynamic programming, reservoir management.

1. Introduction

The allocation of irrigation water in Australia has become substantially market oriented in the past decade as a result of significant reforms to irrigation property rights. In the lower Murray-Darling river system, where an extensive river and channel conveyance network connects around 20,000 irrigation farms across three state boundaries using around 6,000 GL per annum in total, trade in water on a seasonal basis has become a standard practice for many farmers. In some irrigation districts, up to 15 percent of all water used is bought on the seasonal market. Yet despite the introduction of broad spatial markets to reallocate water with a given irrigation season according to seasonal scarcity, decisions about inter-year storage continue to be made according to engineering decision rules. As a result, the highly variable Australian climate delivers significant variation in the amount of irrigation water available in any given irrigation season and water prices vary substantially between seasons.

A similar absence of water storage markets is evident in other parts of the world where spatial markets for irrigation water have been emerging. For example, in California, water 'banks' perform the same function as Australian seasonal markets, allocating water between users (including competing sectors) in a given season. In Idaho, true water banks have been developed for inter-year aquifer storage of water there but price signals and storage decisions are not consistent with a competitive storage market (Miller 1996).

There is very little economic literature on the management of surface water storage in the context of inter-seasonal risk. Alaouze (1991) demonstrated in principle the importance of inter-temporal transfers in the context of Australian drought, but provided no empirical analysis. Dudley (1998a, 1998b) and Dudley and Hearn (1993) report on an empirical study of irrigation reservoir management for the Australian cotton industry, which focused jointly on intra-seasonal and inter-seasonal risk, on both the supply and the demand side. Supply risk was determined by stochastic inflows and was managed by storage decisions. Demand risk was driven by rainfall conditions. They highlighted the information coordination problems associated with centralized dam management, demonstrating that if storage property rights were defined to allow autonomous decision making by farmers, higher economic surplus could be obtained because farmers had better information than the central dam manager regarding the condition of the crop and the value of irrigation water as the season progressed. Their analysis had little to say about the value of inter-year storage, but this result might be attributable to the computational problems that they encountered. Their empirical emphasis on the intra-seasonal allocation of water involved modeling complex multiple decision stages, which meant that simultaneous solution of the inter-year storage problem posed a dimensionality problem. In order to solve this problem they used an approximation to the inter-year storage rule, by assuming that the potential value of placing water into storage in the current season could only be realized in the subsequent two seasons. This myopic approximating rule had been applied previously to commodity storage problems (e.g. Gilalson 1960). However, recent advances in mathematical techniques have allowed more precise solutions to the storage problem and the inaccuracy of the myopic approach has been demonstrated (Williams and Wright 1991).

Beare *et al*. (1998) examined storage release decisions for irrigators in the Murrumbidgee Valley using the polynomial approximation technique proposed by Williams and Wright (1991), and demonstrated that market based storage releases would improve expected agricultural returns by five percent. However, they focused on a monthly storage release decision which did not account for the dramatically different nature of stochastic inflows during and between irrigation seasons, and therefore may have underestimated the value of inter year storage. The returns to storage between seasons may be substantially higher than the returns to storing water from one month to the next during the irrigation season, because in Australia, the majority of dam inflows occur outside the main irrigation season. Moreover, it is difficult to justify an emphasis on intra season risk because it can be managed by trading on the seasonal water market and deferring uptake of the purchased water until later in the season (Brennan 2006). These two characteristics combine to drive current seasonal water market prices where, as shown in figure 1, there is substantially greater variation in prices between years than during irrigation seasons.

The aim of this paper is to present an empirical analysis of the potential for a water storage market to improve the inter-temporal allocation of irrigation water held in a reservoir, using a case study from the Goulburn Valley, the largest irrigation region in the Australian state of Victoria. This is achieved by presenting an analysis of the economic returns generated by the current centrally-based storage policy and comparing them to the return that could be derived if inter-temporal arbitrage opportunities were fully exploited using a storage market. Unlike previous studies on irrigation water demand, which have used economic-engineering approaches to approximating water values (e.g. Dudley and Hearn 1993; Booker and Young 1994; Knapp and Olsen 1995; Beare *et al.* 1998; Howitt *et al.* 2001), the seasonal demand curve for water used in this study is drawn from values revealed in the last decade of trade on the seasonal market.

The paper is organized in four additional sections. In the next section, a brief introduction to the nature of irrigation property rights and status of market reforms in the case study region is provided to set the context for the analysis. Section 3 sets out the nature of the inter-year storage problem and the inter-temporal arbitrage conditions that would drive an efficient water storage market. The detail of the empirical model used to determine the market demand for storage, and to simulate the dynamic pattern of water use and prices associated with alternative dam release rules is described in section 4. In section 5, the characteristics of market-based dam release policies are compared with the current release policy. The final section contains a discussion of the implications of these results for policy formulation and for future research.

2. The Goulburn Valley water market

The Goulburn River is the largest Victorian tributary of the lower Murray system and has one major dam in the upper catchment that provides most of the inter-year storage for the irrigation industry in the Goulburn Valley. The irrigation industry is highly dependent on water storage to manage seasonal climatic risk because 80 percent of the rainfall and runoff occurs outside the main irrigation season, and because annual inflows to the dam are highly stochastic, with a standard deviation of inflows equal to about half the mean value. Dam releases are determined using a fixed decision rule which is relatively conservative compared to the way dams are managed in other parts of the country, and is aimed at providing reliable volume of water each year, called the “water entitlement”. This entitlement provides the farmer with a right to receive a seasonal water allocation, which varies according to seasonal availability, and is shared between irrigators in direct proportion to the quantity of entitlements they hold. The dam release rule is designed to ensure that the seasonal allocation is at least 100 percent of the volume specified in an ‘entitlement’ most of the time. 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. 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. The dam release policy and associated entitlement system achieves an allocation greater than or equal to the full water entitlement in 95 percent of years, and allocations exceed the full entitlement in around 75 percent of years. The relatively high reliability has allowed for the development of high valued irrigation industries including horticulture and dairy which have relatively inelastic demands for water. In addition, there is substantial use of water by mixed cereal-livestock enterprises that are able to make use of water opportunistically when there is high seasonal availability (Dwyer *et al.* 2004; Brennan 2006).

Irrigation entitlements are ‘open ended’ in their definition, in that seasonal water allocations define the maximum quantity of water that can be used in the season, but farmers do not necessarily take up these rights, particularly when allocations are high. The historical dam release rule, and the pattern of uptake of seasonal water allocations, is illustrated in figure 2. The low marginal uptake at high allocations is likely to be the result of rational long term decisions regarding 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).

Water allocations are announced at the beginning of each irrigation season, but can be revised throughout the season as spring inflows can yield an increase in dam reserves. At any time in the irrigation season, irrigators are permitted to trade their seasonal allocation, and can do so by private treaty or through the public water exchange which operates a weekly market throughout the season. The traded good is the right to use the water in the current season, and that right can be drawn on at any point over the season. Thus the seasonal market acts as a forward market for managing intra-seasonal risk. For example, farmers making decisions about planting annual crops or buying livestock which may require more water if rainfall turns out to be relatively poor or if seasonal allocations are not increased, can hedge these decisions by buying extra seasonal water rights on the market.

In contrast to this flexibility in managing intra seasonal risk, irrigators in the Goulburn valley are not permitted to ‘carryover’ their water allocation into the subsequent irrigation season. Any unused seasonal allocation is returned to the common property dam reserves and is reallocated according to dam release rules and the irrigator's entitlement share in the subsequent season. This inability to carryover water means that private value of storing water is zero, whereas the irrigator has a private incentive to use or sell water on the current season market at a value equal to the current market price. Consequently, the level of water use in the current season is likely to be higher than it would be if rights to carry water forward into the next season were well defined[1].

3. Nature of the inter-year storage problem

The role of the central dam manger in the current water entitlement system is not unlike the role of the public stockholder in the commodity price stabilization schemes that were popular in agricultural policy prior to the 1990s. There was a vast amount of scholarly literature that debated the merits of public intervention in commodity storage using comparative static analysis (e.g. Waugh 1944, Oi 1961, Massell 1969, Samuelson 1972, Turnovsky 1976). However, it has since been shown that the proposed benefits of 'public intervention' in commodity storage were actually the benefits of storage itself, which might be provided just as well if the private sector were permitted to exploit opportunities for inter-temporal arbitrage. Indeed, unless there is some underlying market failure problem in the storage sector, the pareto optimal level of storage is the amount that would be provided by a competitive storage market. It has been shown that public intervention in storage crowds out the private sector and distorts the inter-temporal equilibrium causing deadweight losses (Wright and Williams 1998, Williams and Wright, 1991).

The water storage problem is very similar to the commodity storage problem. Vagaries of the weather lead to a variable pattern of inflows from one year to the next, and the decision making problem is to choose between allocating water for use in the current irrigation season, and placing it storage for use in subsequent seasons. The nature of demand for water in irrigation industries is such that the marginal economic value of water is substantially higher in years of scarcity than in years of abundance. At the extreme, water shortages can lead to losses in perennial plantings which have an economic cost that is substantially higher than the value of foregone current season production. In contrast, at high levels of water consumption the marginal value is relatively low as opportunities to use the water are tied to longer-term irrigation specific investments, and the short run marginal productivity of water is fairly flat. Brennan (2006) reports on an empirical analysis of the seasonal water market in the Goulburn and Murray valleys where she found evidence of strong curvature in the irrigation demand curve, as well as substantial shifting of the curve depending on irrigation season rainfall. In the two major drought seasons since the commencement of water trading, seasonal prices traded on the public water exchange were five to seven times higher than the mean value of water traded in the three preceding years.

The nature of the seasonal demand for irrigation implies that there is an economic value associated with inter-season water storage, and indeed water institutions

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[1] In fact, recent changes to legislation in the state of New South Wales have resulted in some level of carryover being permitted. However, these rights are still poorly defined, for example rights to stored water were revoked in the 2006/7 irrigation season.

throughout the world operate dam release rules designed to stabilize the consumption of water between seasons. As in the case of public intervention in commodity storage markets, it is unlikely that centralized storage decisions will provide a better outcome than what would be achieved by a market. However, the main difference between a commodity market and an irrigation water market is that it is generally physically possible for the private sector to operate at the margin of public stockholding activities in the case of commodity markets, which may provide some benefit unless central storage is so high that the private sector is completely crowded out. In contrast, property rights to stored water are often ill defined and therefore there is little potential for private corrections to central decisions regarding inter-temporal storage.

The inter-temporal arbitrage conditions that would be associated with a competitive market for water storage can be demonstrated formally by setting up the decision making problem as an infinite stage stochastic dynamic programming problem. Given a current season demand for water defined as $P_t(Q_t, R_t)$ where Q_t is total water consumed in the current period, and R_t is rainfall, the value function is:

Maximize with respect to S_t (water kept in reserve in period *t)*:

$$V_t(A_t, R_t) = \int_0^{A_t - S_t} P_t(q, R_t)dq - cS_t + \frac{1}{1+r} E_t[V^{*}_{t+1}(S_t + \tilde{\theta}_{t+1} - \psi_t(S_t, K, \tilde{\theta}_{t+1}), \tilde{R}_{t+1})] \quad (1)$$

Given the state transition equation:

$$A_t = S_{t-1} + \tilde{\theta}_t - \psi_t(S_{t-1}) \quad (2)$$

And the constraint on dam capacity:

$$A_{t+1} = S_t + \tilde{\theta}_t - \tilde{\psi}_t(S_t) \le K$$

And the non- negativity constraint:

$$S_t \ge 0$$

Where:

A_t is the availability in the dam in the current irrigation season
S_t is storage set aside in year *t*
c is the marginal cost of storage
ϑ_t is inflows into the dam in the current period, which occurs after storage decisions are made in the previous period and before storage decisions are made in the current period (in the non-irrigation season)
$\psi_t(S_t)$ is water spilled from the dam occurring in the inflow (non –irrigation) period which occurs if storage capacity is reached.
K is the storage capacity of the dam.

The first order conditions to this problem are the inter-temporal arbitrage conditions.

$$P_t + c - \frac{1}{1+r} E_t[\frac{\partial V_{t+1}}{\partial S_t}] \geq 0 \, , S_t \geq 0 \, , \; (P_t + c - \frac{1}{1+r} E_t[\frac{\partial V_{t+1}}{\partial S_t}]).S_t = 0 \qquad (3)$$

Where $E_t[\frac{\partial}{\partial S_t} V_{t+1}(S_t, K)]$ is the expected marginal value of storage which is influenced by the total volume stored S_t which affects the potential benefit that can be derived from water available for sale in the subsequent period; and together with storage capacity K determines the expected value of spillage (ψ).This value function is estimated empirically using the parameter iteration method (Williams and Wright 1991), and described further below. The first order conditions imply that a competitive market for inter-year storage would ensure that prices in the current period were in equilibrium with expected prices in the subsequent period, except for where stock outs (S_t=0) occur, when prices would be higher than the expected future value of the stored water.

4. The empirical model

4.1 Hydrological balance

Because the Goulburn Valley is an upstream tributary of the Murray River system and has a single dam responsible for most water storage, the hydrology of the system is relatively simple. The hydrological balance equation is shown in equation 4, where the left hand side is the state transition equation defining current period availability in the dam, which is disposed of through storage S_t or consumption D_t. For simplicity, delivery losses are subsumed into consumption D_t, which is therefore defined as availability less storage (A_t-S_t):

$$S_{t-1} + \tilde{\theta}_t - \psi_t(S_{t-1}) = D_t + S_t \qquad (4)$$

This hydrological balance equation was used to track availability of water in the dam based on an historical time series of inflows 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 take account of dam spillage associated with variable monthly inflows that might not be captured in an annual time step model. The 113 year time series of physical data provides a sound basis for developing probability distributions of inflows, climatic conditions and for simulating the economic responses that might occur if the industry, at is current stage of development, were to experience any of the sequence of weather conditions on the historical record.

One of the main assumptions required for the materials balance equation is the uptake of seasonal allocations by irrigators, D_t, which can be less than or equal to the seasonal water allocation, as was illustrated in figure 2. The simulation model draws on key relationships in the Victorian government's REALM model of the Goulburn

River (James et al 1993), including the uptake of seasonal allocations which was used to derive the use curve shown in figure 1 A reduced form equation of the more complex relationships described in the James *et al.* (1993) model was developed for this exercise which describes seasonal irrigation diversions D_t as a function of irrigation season rainfall and seasonal allocations. The simulated probability distribution of water allocations for the base case, which uses the current dam release rule to determine seasonal water use, correlates well to the probability distribution of water allocations simulated from the REALM model, as shown in figure 3.

Insert figure 1 -3 about here

4.2 The current season value of water

The current season value of water was based on Brennan (2006) who found that current season water prices were exponentially related to 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 5. Economic values of water use reported in section 4 represent the area under this demand curve.

$$P_t = \exp(8.100 - 6.92 \text{ x } 10^{-3} R_t - 2.33 \text{ x } 10^{-6} Q_t) \tag{5}$$

Where:

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

4.2 Estimating the marginal value of storage associated with the optimal storage rule

Stochastic dynamic programming techniques were used to estimate the marginal value of storage shown in (3), $E[\frac{\partial}{\partial S_t} V^*_{t+1}(S_t)]$, using the polynomial approximation technique developed by Williams and Wright (1991). The technique involves the development of a discrete probability matrix describing the joint distribution of inflows and rainfall with M possible combinations with a probability ϕ_i, where $\sum_i^M \phi_i = 1$. This matrix was constructed from the historical inflow records from 1881 to 2004, and rainfall from the Tatura meteorological station (Bureau of Meteorology, 2006). The solution described below was solved in a spreadsheet using a looping macro that calls the Excel solver.

The optimal storage rule is found by iterating over a range of possible incoming storage levels and an initial guess at $E[\frac{\partial}{\partial S_t} V^*_{t+1}(S_t)]$ which is assumed to be approximated by a third order polynomial. The inter-temporal arbitrage condition (3) is solved for every possible inflow and rainfall outcome defined in the discrete probability distribution. For any particular incoming storage level S_t, the probability weighted sum of realized seasonal water prices ($\sum_i^M P_{it}(S_t).\phi_i$) that would be derived if the storage rule were followed, is calculated. At high levels of carry-in storage, some realized inflows result in spillage occurring, and in these cases the marginal value associated with incoming storage is zero. In one complete iteration, a range of storage levels are evaluated and the realized subsequent period prices are recorded, then these data are used to update the marginal value of storage function, and the process is repeated until the realized values generated over the range of levels of S_t (S_t, $\sum_i^M P_{it}(S_t).\phi_i$) converge with the approximating polynomial function $E[\frac{\partial}{\partial S_t} V^*_{t+1}(S_t)]$.

The estimated marginal value of storage function is shown in figure 4 where it is represented in current period terms (net of storage costs) and can be compared directly the current opportunity cost of water. Examples of current period demand curves are shown for three different seasonal conditions. The intersection of the demand for storage curve with the demand for irrigation shows the point of water availability at which storage will be a competitive water use in the current period. For example, if availability in the dam exceeds 500 GL, then the marginal value of putting water into storage is higher than the value of additional use in the current season under high rainfall conditions. In contrast, availability would have to exceed 1700 GL before it would be optimal to put water in reserve for the subsequent year, if low rainfall conditions were being experienced in the current period.

Insert figure 4 about here

5. A comparison of optimal and current release rules

From the estimated marginal demand for storage curve, physical dam release rules for the market case were derived using (3), and are compared with the current dam release rule in figure 5. The market based release rule is similar to the current rule where current season rainfall is low and opportunity cost is high, although the optimal availability-release relationship is smoother. Relatively less water is released when dam reserves are less than entitlement, and more water released when dam reserves are moderately higher than entitlements. Under higher rainfall conditions, when the opportunity cost of current season used is relatively low, the optimal release rules lie below the current release rule, implying that relatively more water would be stored by a market than is stored currently.

Insert figure 5 about here

The historical time series of inflows and rainfall were used to generate cumulative probability distributions for storage and water use. The cumulative probability distribution for the quantity of water stored is illustrated in figure 6. The market based storage rule lies to the right of the current storage rule, reflecting the rules shown in figure 5 which indicated that the central planners are generally not storing enough water. The probability distribution of current season irrigation use is shown in figure 7. Under the current storage rule, there is a small probability that use is below the nominal value of entitlements, and a high probability that seasonal water use will be just equal to the nominal value of entitlements. In contrast, the seasonal water use under the optimal storage rule is much smoother, and there is a greater probability that use will be lower than the nominal value of entitlements. However, the presence of low water consumption periods does not imply system failure in this case, but is instead the result of less water being used and more being stored when current market conditions are weak due to high seasonal rainfall. Under the storage market, there is a greater chance that use will occur in the range of 100% to 115% of nominal entitlements, compared to the current release rule. Beyond that level of use, there is a greater chance of high releases under the current rule – this is because when availability is high under the optimal release rule, there is a greater likelihood that water will be stored for future use.

Insert figures 6 and 7and 8 about here

Insert table 1 about here

The relatively greater level of storage under the market based rule results in more stable prices, as demonstrated in the cumulative probability distribution of seasonal market prices in figure 8. Prices are more likely to be lower, and higher, under the current storage policy. Summary data on prices is also shown in table 1. There is a greater incidence of events where seasonal prices exceed $120, $150, and $250 per ML under the current storage policy, compared to the market based policy. There is only one event when the price of water exceeds $250 per ML in the market based policy, this was in the drought of 1914-5, when a sequence of low inflow years preceded one of the lowest winter inflows on record and was followed by a low rainfall summer. However, the impact of that drought was lower for the market based storage policy, than for the current storage policy. There were a total of 17 events (15% of total periods) when the price exceeded $120 per ML with the current storage policy.

The economic benefit associated with greater price stability provided by the market based storage rule is demonstrated in table 2. The market based policy results in a higher mean level of storage (around 25 percent higher than the current storage policy), and as a result the average amount of water available in the dams is larger. The average level of irrigation water use is reduced slightly under the optimal release policy, and this is due to the increased quantity of water spilled when inflows are high. However, even though average use is reduced, mean prices are also lower due to the reduced frequency of high prices. Comparing the economic values generated under the two dam release policies, the expected annual benefit associated with the storage market is $2.7 m. This is of a similar magnitude to value of trade generated on the seasonal market in 'normal' years, which has been estimated to be about $3.5m[2].

Insert table 2 about here

The economic value generated by allowing the private sector to exploit inter-temporal arbitrate opportunities in the 'market based' scenario are further illustrated in figure 9, where the net difference in the value of consumption for the two scenarios is shown over the historical time sequence. On the y axis, the economic value of irrigation generated under the market based storage rule in a particular year *minus* the economic value of irrigation that would have been achieved under the current storage policy is shown. As would be expected, there are many periods when the irrigation industry is temporarily worse off under the market based storage policy, because water is taken off the market and placed in storage, resulting in foregone consumption. However, the opportunity cost of this foregone consumption is outweighed by the benefits of greater water use in periods of water scarcity. For example, the market policy could have reduced the current season impacts of the 2002-3 drought by $100 million. By way of comparison, the total economic surplus generated by opportunities to trade on the seasonal water market in that drought was only around $14 million. Simulated prices for that season were $347 per ML for the current policy, and only $117 per ML for the market based policy.

Insert figure 9 about here

6. Discussion and policy implications

The analysis demonstrates that a market-based water storage policy could produce significant benefits over the current storage policy. Even though the current storage policy is associated with substantial storage of water (setting aside one year's supply in 75 percent of years), it was shown that the market would store significantly more on average, and would be more flexible in responding to current seasonal conditions and opportunity cost. The most significant gains would be realized in periods of extreme scarcity. On average, the magnitude of the benefits compare favorably with the seasonal (spatial) water market currently operating in the case study region, and suggest that it is worth investigating the mechanisms and transactions costs associated with introducing a storage market.

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[2] Calculated by the author, based on the area between the buyer and sellers bid schedules submitted to the public exchange and accounting for the volume of sales occurring outside the market. The value of water trade in the 2002-3 drought ($14 million) was estimated in the same manner.

The mechanism for introducing such a market was not considered here, but there are number of possible institutional arrangements that could ensure the competitive storage equilibrium. These include for example, privatizing the dam and subjecting the owner to third party access provisions like those used in other contestable infrastructure markets, where the dam space could be rented to specialized storage entrepreneurs. Another option would be to assign explicit rights to dam capacity to individual irrigators. The current property rights regime does not allow for the development of a storage market because rights are defined beyond the dam wall, with the temporal pattern of water allocations generated by the current storage being an implicit part of the water entitlement. The characteristics of these rights (rights to a share of dam inflows and rights to dam space) would need to be unbundled in order for the market for storage to develop.

The desirability of alternative property rights regimes for water storage is an open question. Given that irrigators currently own implicit rights to dam capacity and inflows, the transactions costs of rearranging rights might be lower by simply assigning a capacity share to each irrigator in proportion to current entitlements, avoiding the need to partition the current entitlement value between rights to inflows and rights to dam space, which would be required if the dam space were sold to a third party. However, these factors would need to be considered alongside the possible economies of information associated with a more concentrated ownership structure. Successful development of an inter-year storage market would require that market participants were well informed about the probability profile of inflows, had up-to-date information about the status of their stocks and any system constraints that may affect their participation in any of the associated markets (such as system delivery constraints). Such information would require a well calibrated system model that could be provided by a government agency or as a private sector information provider, as well as proper accounting systems.

Only the short term benefits associated with inter-temporal consumption smoothing were demonstrated in this exercise, based on the market demand curve associated with the current level of irrigation development, and assuming a stable climate pattern. However, the most important benefit of a storage market over the current release rule may be the dynamic efficiency implications on longer term investment decisions and in managing risks associated with potential climate change. As Brennan (2006) demonstrates, the inter-temporal pattern of prices on the seasonal water market is an artifact of longer term investment decisions, which is in turn dependent on the reliability profile of water entitlements. Increased investment in capital intensive industries would shift the inelastic component of demand to the right, the prospect of higher prices in times of shortage would induce greater storage and thus provide the required improvement in reliability. Thus a water storage market could jointly guide irrigation investment decisions and allow for the management of risk associated with these investments.

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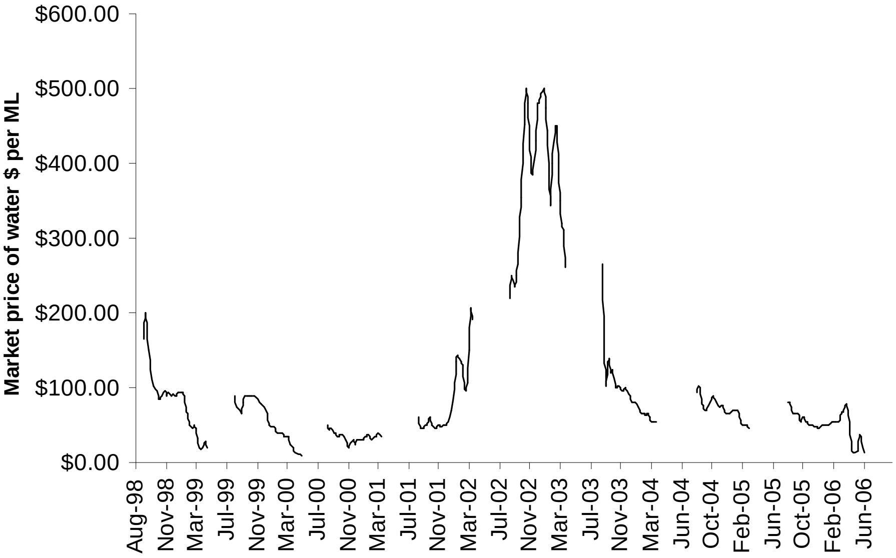

Source: Watermove, www.watermove.com.au

Figure 1. Price of water traded on public water exchange in the Goulburn Valley, 1998-2006.

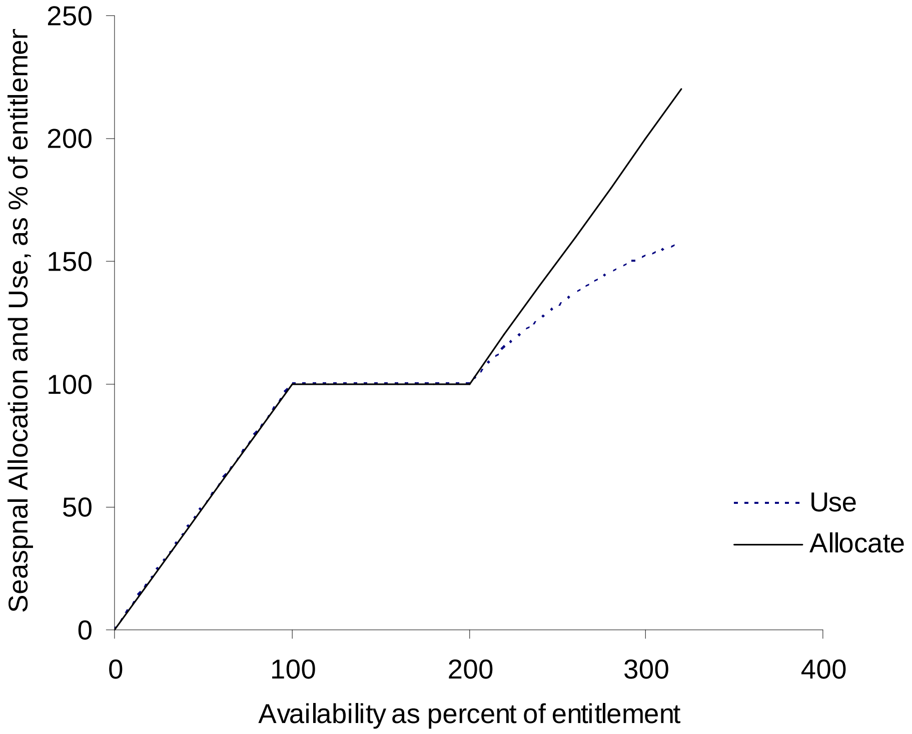

Figure 2. Current dam release rule: Seasonal allocations and uptake

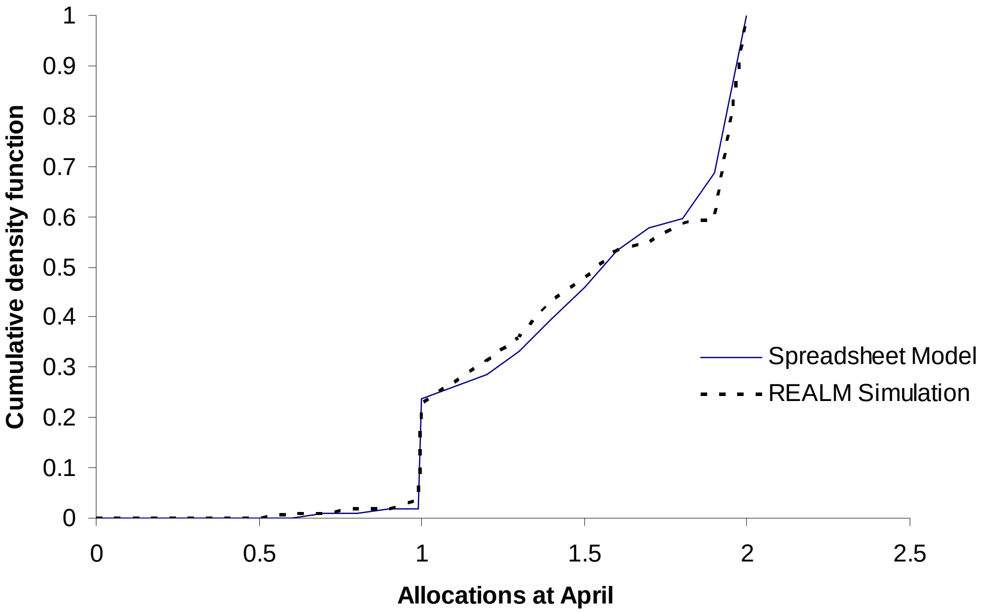

Figure 3. Comparison of simulated allocations under spreadsheet model

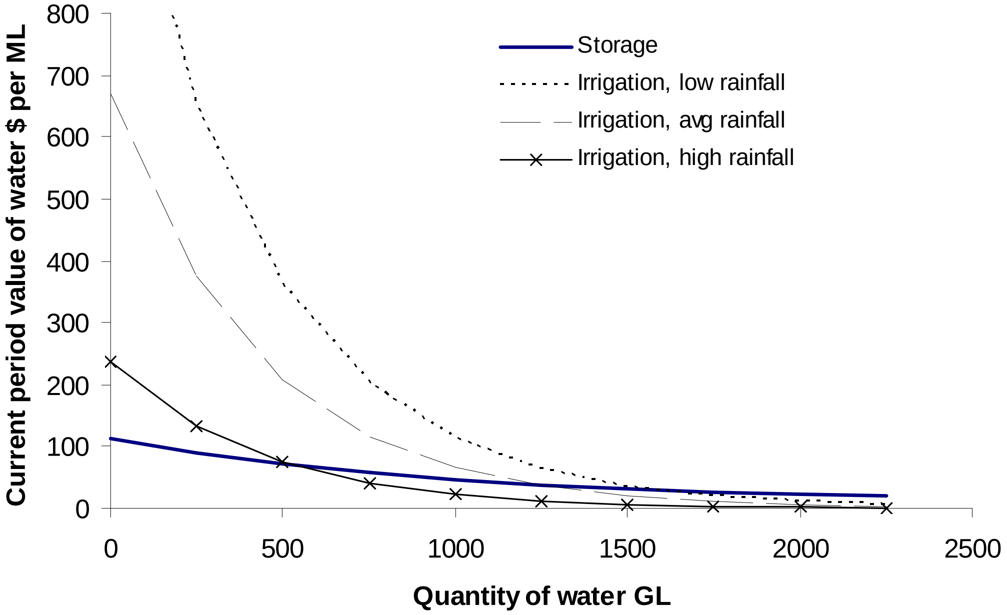

Figure 4: Comparison of demand for storage with demand for current period irrigation

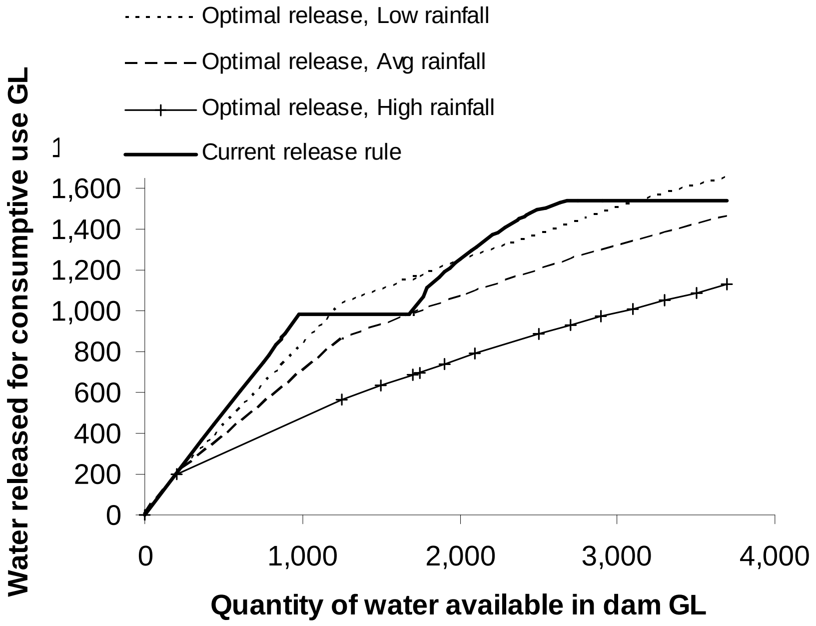

Figure 5. Dam release rules according to availability and seasonal rainfall conditions

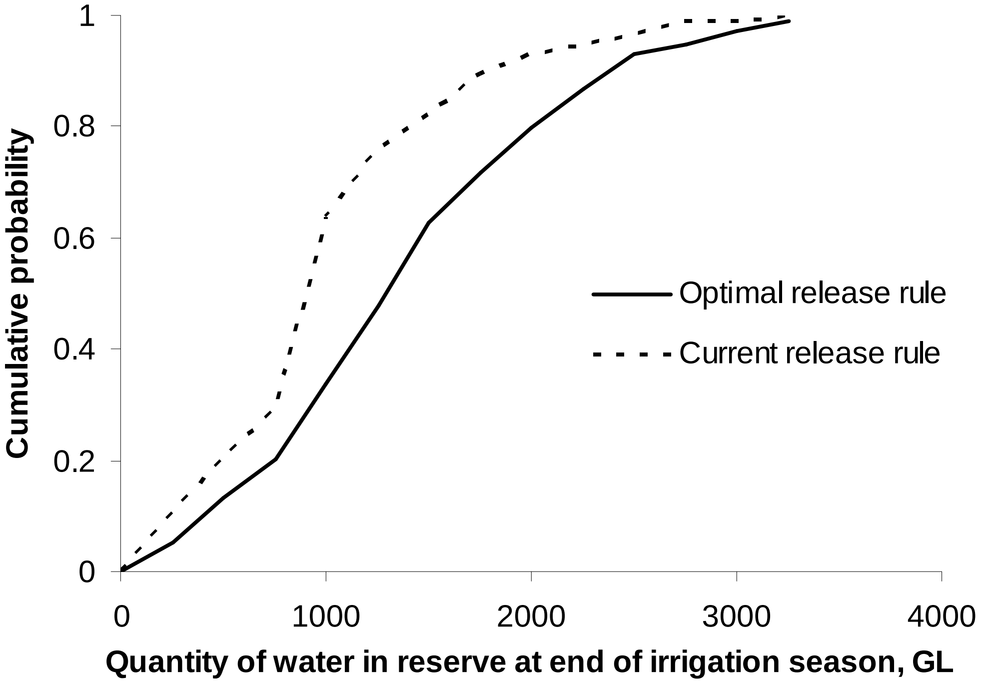

Figure 6. Probability distribution of end of season carryover

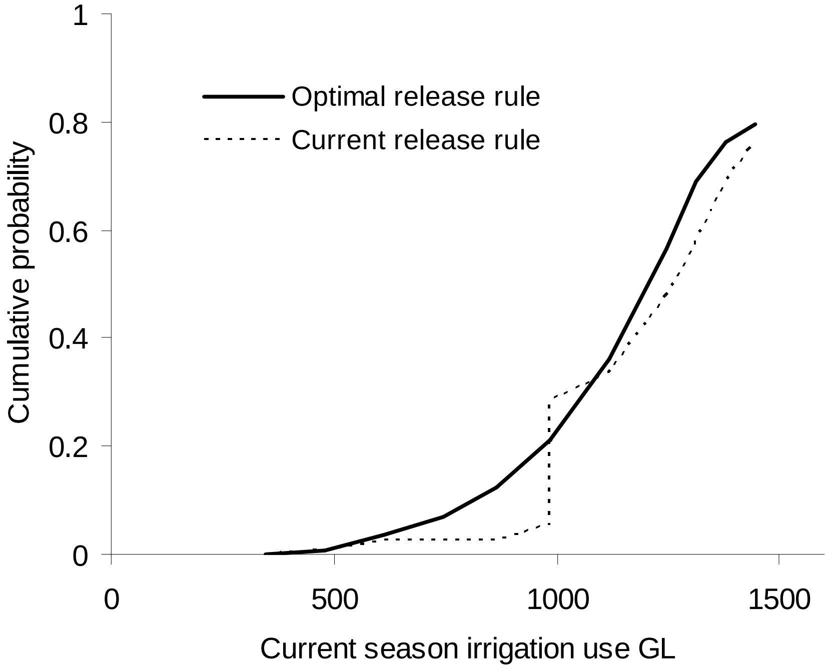

Figure 7. Probability distribution of irrigation use, current and optimal release rules.

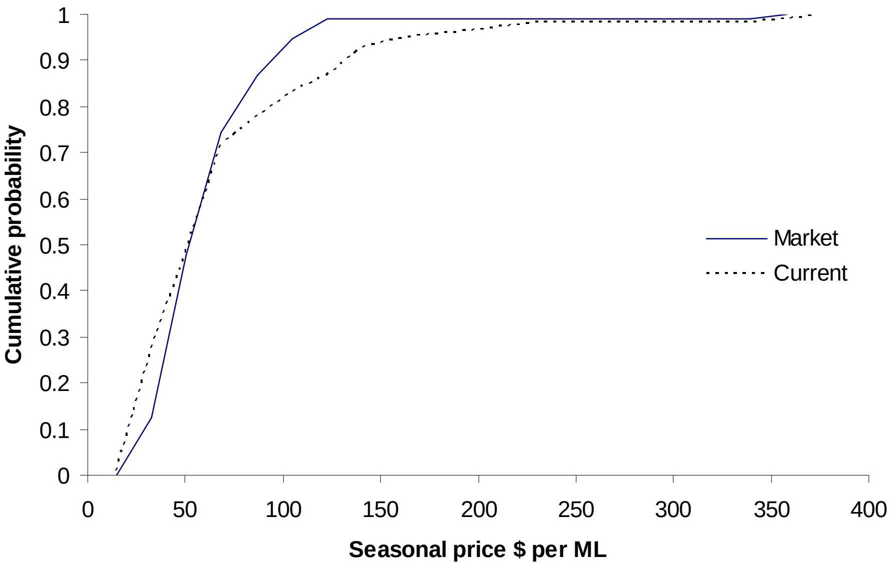

Figure 8. Probability distribution of seasonal market prices, current and optimal release rules.

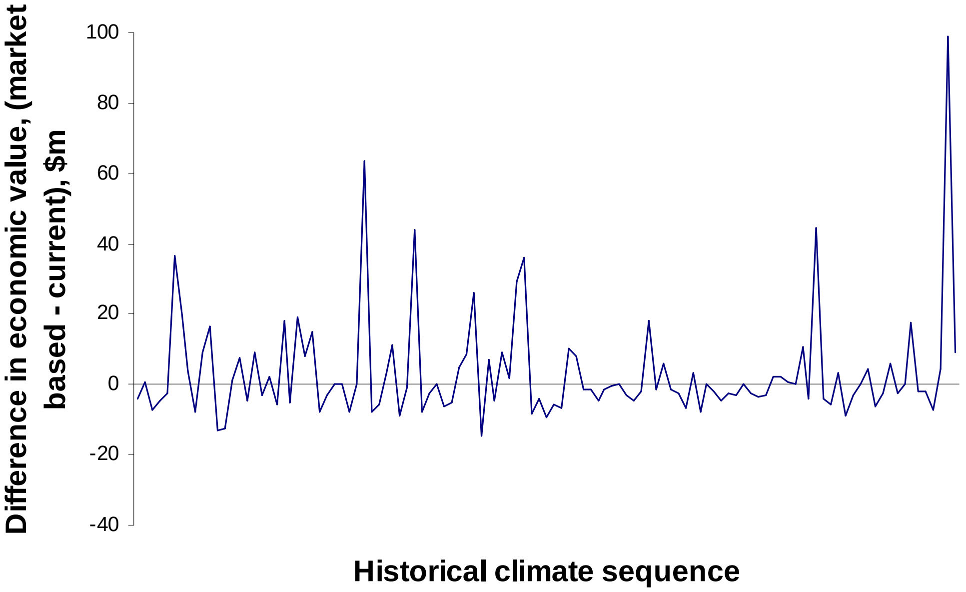

Figure 9. Difference between current period surplus from irrigation for market based and current release policy

Table 1. Frequency of high prices under alternative storage policies

	Current	Market based
Mean prices:	$67.2/ML	$60/ML
$120/ML	17	1
$150/ML	6	1
$250/ML	2	1

Table 2. Comparison of outcomes of alternative storage policies

	Storage strategy		
	Current rule	Market based	Difference
Mean availability of water in dam GL	2,272	2,596	227.4
Mean water storage at end of irrigation season GL	991	1,359	368
Expected annual use in irrigation, GL	1,226	1,178	-47.9
Expected price irrigation water $/ML	66.1	59.6	-6.5
Expected annual economic value of irrigation water use, $m	308.5	311.29	2.8