Working Paper

Institutional Arrangements and the Efficiency of Environmental Water Demand Management

Dr Stephen Beare

July 2013

1. INTRODUCTION

The objective of the project is to examine how the way in which the Commonwealth Environmental Water Holder (CEWH) manages and delivers its environmental water holdings could influence on-farm productivity.

The specific aim of this research project is examine how the institutional arrangements under which environmental water demands are managed may affect the availability and security of water supplies, water prices and investment options on farm. The types of factors affected by these arrangements would include:

- Foregone agricultural returns;
- Increased risk and consequent impediments to on farm investment; and
- The need to restructure farm enterprises.

The specific objectives of the project are to:

- Quantify the relationships between how changes in the management of environmental allocations and demands impact on water market prices and the volumes of water available for agricultural production;
- Derive from the water prices and volumes available to agriculture an implicit, but nevertheless equivalent, yield and expected value of an agricultural water entitlement; and
- Undertake this analysis for high and general security entitlements, given the allocation rules in place.

1.1.1. Institutional Arrangements

The two key institutional arrangements that will influence the overall economic efficiency with which environmental demands can be managed are the capacity of the CEWH to:

- Trade in the allocation or physical water market, including any restrictions placed on trade; and

- Carryover unused water allocations to subsequent seasons.

The Murray Darling Basin Authorities' (MBDA) revised draft of the Murray Daring Basin Plan (MDBAa, 2012) does not go into substantive detail regarding the institutional arrangements under which the CEWH should or will operate. The plan makes three specific references to arrangements that apply to the CEWH. First (11.07):

> *"A person may trade a water access right free of any condition as to the person being, or not being, a member of a particular class of persons.*

Note 1: An example of a class of persons is 'environmental water user'"

MDBA 2012a, page 105.

Second (11.12):

> *"(1) A person may participate in a carryover arrangement in relation to a water access right free of any restriction arising from the fact that the person acquired the water access right by way of trade.*
>
> *(2) Despite subsection (1), if:*

a) the trade of a water access right results in a change of the water resource to which the right relates; and

b) the carryover arrangement for the destination water resource is different from that of the origin water resource;

> *the carryover arrangement for the destination water resource may be applied to the water access right."*

MDBA 2012a, page 108.

Third, it the States determine carryover arrangements, but must report these arrangements to the MDBA (MBDAa, 2012, page 119).

In addition, the plan makes the following provisions for extreme events (9.51):

> *"A water resource plan must describe how the water resources of the water resource plan area will be managed during the following types of events:*
>
> 1. an extreme dry period;
> 2. a water quality event of an intensity, magnitude and duration that is sufficient to render water acutely toxic or unusable for established local uses and values;
> 3. any type of event that has resulted in the suspension of a statutory regional water plan in the past 50 years (including a transitional water resource plan or interim water resource plan)."

MDBA 2012a, page 89.

It therefore seems appropriate to examine the question of instructional arrangements that govern the CEWH access to trade in the allocations market and carryover provisions across a broad range of potential options.

1.1.2. Alternative arrangements considered

Five general environmental water management scenarios are considered in this research project. Each scenario corresponds to a different set of institutional arrangements governing trade and carryover:

1. The environmental manager operates without access to the allocation market or carryover provisions.
2. The environmental manager operates without access to the allocation market but has access to carryover provisions.
3. The environmental manager operates with unrestricted access to the allocation market but without access to carryover provisions.

4. The environmental manager operates with unrestricted access to the allocation market but has access to carryover provisions.
5. The environmental manager operates with restricted access to the allocation market but has access to carryover provisions.

1.2. ANALYTICAL APPROACH

The analysis presented in this report draws on two models that have been constructed to examine water issues within the Southern Murray Darling Basin.

The Environmental Flow Model (EFM), developed jointly by ANALYTECON and DPI, takes the perspective of an environmental water manager seeking to meet a set of flow objectives at least cost, given the uncertainty associated with future climatic conditions. The EFM is described in Section 2 and detailed results are presented in Section 0.

The Risk Management Model (RMM) is cast at an enterprise level for the purpose of examining water market risks and the value of permanent entitlements as a hedge against that risk. A capital asset pricing model (CAPM) is using to evaluate the risks faced by a horticultural producer exposed to the allocation market and to estimate the value of general or high security water entitlements. The value of the hedge is a premium over the purely productive value of the entitlement and provides a comparative measure of changes in the level of risk in allocation market under the different environmental water management scenarios. The RMM and results are set out in Section 4.

2. ENVIRONMENTAL WATER DEMAND AND THE ENVIRONMENTAL FLOW MODEL

The application of the EFM is described in this section. The model is reported in full in Heaney, Beare and Brenan 2012. Environmental water demands are derived from a dynamic optimisation models that seeks to minimise the costs of meeting environmental flow objectives under uncertain climatic conditions. The model is based on the Goulburn River below Eildon dam and has five components:

1. A set of flow targets and associated levels of desired reliability in meeting those targets. Taken together these are the flow objectives.

2. A hydrological accounting model that takes as inputs the inflows into and releases from Eildon dam to generate water allocations and storage levels.

3. An allocation water market that balances available water supplies with agricultural and environmental water demands. Agricultural returns are derived from the agricultural water demand relationship.

4. A cost function that determines the direct costs of environmental water releases and the opportunity cost of foregone agricultural returns.

5. A set of decision rules that are optimised to minimise the costs of meeting the flow objectives. The rules govern purchases of entitlements and environmental releases.

As it has been applied in this report, the EFM solves for a least cost strategy for the CEWH given unrestricted or restricted access to the following instruments:

- The volume of permanent water entitlements held;

- Purchases and sales in the allocation market; and

- The extent of carryover from one period to the next.

The least cost strategy gives rise to an environmental water demand from which it is possible to derive:

- The costs of attempting to meet the flow objectives including the direct costs in terms of public expenditures and the costs of foregone agricultural returns;

- The reliability with which flow targets can be achieved;
- Expected water prices in the allocation market and their distribution;
- Expected volumes of environmental water use, agricultural use and trade, along with their associated distribution; and
- Expected agricultural returns and their distribution.

2.1. ENVIRONMENTAL FLOW TARGETS – GOULBURN RIVER FLOOD PLAIN

The development of environmental flow targets has and remains an ongoing process. Initially, targets were identified in terms of the average frequency of flow events defined in terms of volume and duration at a specified gauging point. Environmental flow objectives for the lower Goulburn River floodplain were identified by the MDBA (MDBA, 2010 2010a, 2010b, 2010c). The environmental outcomes and targets for the lower Goulburn River floodplain are presented in Table 1. Two flow regime frequencies were identified by the MDBA to accommodate the scientific uncertainty associated with defining environmental objectives. These environmental objectives are taken to be ordinal; for example, a 60,000 Ml flow for seven days (outcome 5) would meet the objectives for outcomes 1, 2 and 4.

Table 1. Environmental flow objectives for the lower Goulburn River floodplain

Environmental outcome	Flow requirement[A] (Ml/day)	Duration (Days)	Seasonality	Probability (%)			
				Target		Development	
				Low	High	Pre	Post
1. Improve wetland condition	25,000	7[B]	Winter Spring	60	50	72	36
2. Improve wetland condition	30,000	7	Winter Spring	50	40	65	32
3. Improve red gum condition	30,000	14	Winter Spring[D]	40	33	50	23
4. Improve red gum condition	45,000	7	Winter Spring[D]	35	25	44	13

5. Improve red gum condition	60,000	7	Winter Spring[D]	20	15	26	6
6. Bird breeding event	30,000	30	Winter Spring	30	30	35	11

A. Refers to river flow at McCoys Bridge gauging station. It should be noted that these flow requirements are part of a broader flow regime and that multiple flow rules will contribute to meeting environmental objectives.

B. Days are the total for the period, not consecutive. The minimum duration for any flow event is a full day.

C. Low and high are based on the level of scientific uncertainty.

D. "Preferred" rather than required period due to the high flow requirements.

Source: MDBA 2010c.

More recently targets have taken the maximum time between events into account as this is seen as being closely tied to resource condition. For example, watering events to support bird breeding must occur within a timeframe that is compatible with the birds' lifecycle. While these targets have yet to be developed for the lower Goulburn River floodplain, they have been specified for the Goulburn River at Shepparton (MDBAa, 2012). These targets are presented in **Error! Not a valid bookmark self-reference.**.

Table 2. Flow indicators for the Lower Goulburn River in-channel and floodplain used during in-valley SDL modelling, including target Low and High Uncertainty frequencies expressed as a proportion of years

Event	Flow requirement Ml/day	Duration (Days)	Low Uncertainty Frequency (% Years)	High Uncertainty Frequency (% Years)	Max Time Between Events (% Years)
Event 1	2,500	8 (Dec-Apr)	48	36	NA
Event 2	5,000	14 (Oct _Nov)	66	49	NA
Event 3	25,000	5 (Jun-Nov)	80	70	3
Event 4	40,000	4 (Jun-Nov)	60	40	4

Source: MDBAb, 2012.

2.2. ENVIRONMENTAL FLOW OBJECTIVES

To place the environmental flow objective into a workable format, the required frequency of events is specified as the threshold inter-arrival time between events. The threshold time should characterise the most relevant parts of the inter-arrival time distribution. The level of reliability is specified as an acceptable probability that the threshold inter-arrival time will be exceeded. Taken together, the objective is to shape the frequency distribution of threshold inter-arrival times at specific percentiles. For example, given a threshold inter-arrival time of, say, five years:

- A 50 per cent exceedence probability targets the median or 50th percentile; and
- A 10 per cent exceedence probability targets the 90th percentile.

Another way to consider the above is:

- The objective is to create an event every five years with an acceptable level of reliability of 50 per cent; and
- The objective is to create an event every five years with an acceptable level of reliability of 90 per cent.

The cost of meeting a flow objective is a direct function of the frequency of the event and the prevailing conditions when the environmental manager creates the event by releasing water from the storage. The cost minimisation problem is therefore largely about the timing of the event. The environmental manager needs to consider the benefits and costs or meeting flow target is advance when required when conditions are favourable as well a delaying a release when conditions are adverse. Going early essentially buys time while delays are constrained by how tight the reliability requirements are. Lower level of reliability allow greater flexibility to avoid needing to make large releases when water availability is limited.

The targets in Table 1 are recast as the desired frequency of flow events over a finite number of years. The case study focuses on the subset of environmental objectives 2, 3 and 6 (shaded in table 1). The flow requirements and representative reliability targets are presented in Table 3.[1]

Table 3. Environmental objectives: Inter-arrival times for the lower Goulburn River floodplain

Event	Environmental outcome	Flow requirement Ml/day	Duration (Days)	Threshold inter-arrival time (Years)	
				Median	90th percentile
Event 1	Improve wetland condition	30,000	7	2	4
Event 2	Improve red gum condition	30,000	14	3	6
Event 3	Bird breeding event	30,000	21	5	10

The flow objective can then be stated in terms of median inter-arrival time, the 90th percentile or both. The 90th per centile was selected for the purpose of evaluating alternative environmental flow management regimes. Other potential objectives are examined in Heaney, Beare and Breen 2012.

2.3. THE ALLOCATION MARKET

Brennan (2010) constructed a spatial equilibrium model of the southern connected Murray River catchments including the major irrigation districts on the Murrumbidgee, Murray and Goulburn rivers, as well as private diverters. The purpose of the model is to simulate market prices making it necessary to include water market trading rules, such as those associated with the Barmah Choke, and financial transactions costs imposed by irrigation authorities. The model is used to assess the impact of physical trading constraints, the spatial pattern of water entitlement holdings on the market price of water

[1] Note that the duration of Event 3 has been reduced from 30 to 21 days. The longer duration was analysed in Heany, Beare and Brennan and found to generate extremely high costs. The total flow requirement was 900 Gl which is around ** per cent of total entitlements in the Goulburn River system

under historic climate and climate change scenarios, and the Commonwealth entitlement buyback program.

2.3.1. Estimating the demand function for consumptive water

Prices in seasonal markets in each irrigation district are affected by supply (local as well as that imported from other regions) and demand in the same market. Demand depends on local demand and also on the demand of those bidding from outside the district. As buy and sell decisions made by irrigators will depend on the opportunity cost of water, water will be delivered into the irrigation district as long as the value of consumptive use does not exceed the opportunity cost of that water. This enables the estimation of a district level water demand curve by regressing the market price against the quantity of water delivered to the *j*th district at time *t*. Annual time series of irrigation diversions and weighted average seasonal prices were used to estimate a multiplicative semi log demand function in price dependent form:

$$P_{jt} = \exp\left(\gamma_0 + \gamma_1 D_{jt} + \gamma_2 R_{jt} \varepsilon\right)$$

Where:

P is the average seasonal price in period t for the trading region in $ per megalitre (ML)

D is diversions in the irrigation district in ML

Rt represents useful rainfall

γ_i is a coefficient to be estimated

ε is an error term

For the Goulburn Broken Catchment the estimates were:

- γ_0 = 9.1944, representing the average seasonal price (in $/ML) in a particular time period and trading region, excluding the effects of diversions and useful rainfall;

- γ_1 = -.00000319, so that the average seasonal price falls as diversions increase; and
- γ_2 = -0.007, so that the average seasonal price also falls as a result of useful rainfall.

Some caveats with the modelling approach should be noted. The demand curve for consumptive use in any season is a short-run concept; the curve is derived from current decisions about water use given current prices. In reality, the value derived from consumptive use is the result of investment decisions made in previous years. For example, horticultural producers require water to protect perennial plantings as assets, as well as to maximise productive yield. Decisions about annual crops are more opportunistic and producers of annual crops will most likely have more flexibility in their water use decisions. Over the longer term, the underlying asset base can change as new investments are made and old investments are abandoned. This may change the demand characteristics of an irrigation region over time if, for example, permanent entitlements are sold and producers rely more on the temporary market to manage water availability requirements for opportunistic crops.

2.3.2. Incorporating environmental demands

The price of water is taken to be a multiplicative function of the current total water allocation less the net purchases made by the environmental manager, shown without regional subscripts as:

$$P_t = \exp\left[\gamma_0 + \gamma_1\left(A_t - ER_t - \Delta C_t\right) + \gamma_2 R_t \varepsilon\right]$$

Where:

A is the total allocation

ER is the environmental release

Δc is the net change in carryover.

Net agricultural returns (NAR) are derived as consumer surplus from the allocation market demand equation as:

$$NAR_t = \lambda \frac{P_t - P(0)}{\gamma_1}\left(A_t - ER_t - \Delta C_t\right)$$

Where:

P(0) is the price corresponding to a market volume of zero and is dependent on rainfall

λ is an adjustment factor

The area under the water market demand curve is the 'gross surplus', which is comparable to the gross value of irrigated agricultural production as reported by the Australian Bureau of Statistics (ABS). It therefore includes returns to other factors, including land and variable inputs. The value of λ is intended to scale gross returns to net return to water. It is however, a subjective choice. In the results presented in this report λ is set to one.

2.4. A CONSISTENT COST ACCOUNTING FRAMEWORK

Within the modelling framework adopted here, the objective of the environmental manager is to minimise the total economic costs of meeting environmental flow objectives. These costs need to be accounted for in a consistent manner. There are two issues to consider. The first relates to the treatment of virtual spilling of water when carryover limits are reached and physical spills when dam storage capacity is exceeded; the second relates to how the entitlements held by the CEWH should be valued.

First, there are indirect benefits associated with virtual spills of allocations that are insufficient or unneeded for an environmental release and that cannot be carried over when there is space available in storage. These spill occur most often when there are no carryover provisions, but can still occur within a capacity sharing system. Virtual spills are reallocated in the following season according to the entitlements held by all water users. In is necessary to consider the distribution of the benefits costs that arise from this redistribution. From the perspective of the taxpayer that is paying the cost incurred by the CEWH, the costs of virtual spills are fully internalised as the sum of the value of the entitlements held and the net value of trade, that is, purchases less sales. The proportion of a virtual allocation reallocated to the environmental manager is fully captured, essentially as additional carryover. From an agricultural perspective the benefits of virtual spill are fully captured in returns to agriculture or agricultural surplus.

In contrast, actual physical spills may or may not impose costs. This depends on whether:

- The spill comprises part of the volume required to meet an environmental flow target; or
- The spill its either too small or in excess of what is required to meet an environmental flow target.

Again, these costs are internalised as part of the cost incurred by the CEWH. Therefore, the costs und the different management scenarios can be compared in a consistent manner as the difference in the sum of:

- Direct costs to taxpayers; and
- Agricultural surplus.

The second issue is how the entitlements held by the CEWH should be valued. One approach to valuing these entitlements would be to determine the (historical) cost of acquiring the right. However, historical valuations provide little information about the price of water entitlements today. The alternative valuation approach, which has been adopted in this report is therefore to apply the opportunity cost of not returning the water back for consumptive use; that is, the market value of the water that is ultimately released for environmental purposes.[2] This approach is preferable because an entitlement is an asset that is purchased given an expectation of the forward value of the water allocations that will be derived from it. The realised value of the entitlement then depends on actual allocations made under prevailing market conditions.

2.5. THE DECISION RULES

The benefits that arise from the ability of the environmental manager to access trade and carryover are modelled by assuming that the manager applies a set of decision rules that govern the manager's actions as a function of external circumstances. The parameters of the decision rules are the control variables that are chosen to minimise costs. These parameters are the result of an optimisation applied to historical data described below. The decision rules in turn take the form of 'primary' rules related to the release of water and 'ancillary' rules related to the management of carryover.

The primary decision rules are discrete: to make a release that is sufficient to achieve any one of the three environmental flow objectives or to make no release. The required rule structure fits a multinomial choice problem. There is a score, *s*, which is a function of the 'state of the world' (such as the current price of water entitlements or elapsed time since a

[2] This was the approach used in Heaney, Beare and Brennan (2012).

flow event) and a set of parameters to be optimised. The maximum scores determine the release strategy at each point in time as a function of the state of the world. The scores are relative so the event scores can be compared to an arbitrary constant k_1 that corresponds to no release. The structure of the rules are shown below.

$$
\begin{aligned}
&s_0 = k_1 \\
&s_{it} = \beta_{01} + \beta_{1i} p_t + \beta_{2i} v_{it} + \beta_3 d_{it} \qquad i = 1,3 \\
&S_{it} = \begin{cases} 1 & \text{if } s_{it} = \max(s_t) \\ 0 & \text{otherwise} \end{cases} \\
&\textit{where} \\
&\begin{cases} S_0 = 0 \ \Rightarrow & \text{no release} \\ S_1 = 1 \ \Rightarrow & \text{meet requirement one} \\ S_2 = 1 \ \Rightarrow & \text{meet requirement two} \\ S_3 = 1 \ \Rightarrow & \text{meet requirement three} \end{cases}
\end{aligned}
$$

Where:

p is the price of water in the temporary or physical market

v is the proportion of the ith downstream flow requirements that is met by natural inflows and dam spills

d_i is the elapsed time since the ith flow event.

The release rules are optimised through the choice of the β parameters. These parameters represent the weights that are attached to variables such as price or downstream flow requirement. λ, the choice of how much entitlement to hold, as a percentage of the total entitlement available, is a continuous but bounded parameter:

$$0 \le \lambda \le 1$$

An ancillary rule is used to manage any water allocations that have not been used in the current period by the environmental manager to deliver an environmental objective. This is a choice between:

- Carrying water over to the next period up to the maximum allowed and selling the balance on the temporary market in the current period; or
- Selling all of the water available on the temporary market in the current period, given the environmental manager has access to the water market.

The ancillary decision rule is constructed as a price threshold:

$$if \begin{cases} p_t^* - \alpha > 0 \Rightarrow W = 1 & \text{(carry over)} \\ else \qquad W = 0 & \text{(sell)} \end{cases}$$

The price, p*, is the market price given the chosen release strategy. The optimisation is to minimise cost over the choice of the parameters α, β and λ, subject to the environmental objectives being met.

2.6. SOLVING FOR THE DECISION RULES

Solving the model for optimal rules requires an appropriate data set and search algorithm.

The data set needs to cover a sufficiently long sequence of seasons to ensure the rules are able to meet the flow targets at the required reliability. For example, to meet a 90th percentile requirement for Event 3, the target must be met nine times out of ten over a 100-year time span. At the same time, is desirable to maintain the tendency for dryer and wetter than average years to occur in sequence as this increases the likelihood that in some instances, targets well need to be met under adverse conditions.

Inflows to Eildon Dam and tributary inflows downstream of the dam and above the gauging station at McCoys Bridge were obtained from the Victorian Department of Sustainability and Environment from a simulation of the Resource Allocation Model (REALM) from 1891 to 2004 (Victorian Department of Sustainability and Environment 2005). The data was randomly sampled to obtain a set of candidate release rules from the optimisation model.

The data were sampled in random sized blocks ranging from one to seven years to preserve the correlation structure between years. The starting point for each sequence was selected at random. If the sequence extends beyond the historical data series, the starting point was adjusted so that the sequence terminated with the last historical observation. The same data sequence was used for each environmental management option.

The search is over decisions that are continuous and discrete, which requires the use of direct as opposed to directional search methods. A genetic algorithm proved to be the most robust method. The following strategy was adopted to initiate the search and to limit the susceptibility of the algorithm to local minima: An initial feasible string was provided by calibrating the rule parameters for the time since the last release to the threshold times. The balance of two sub-populations of 100 strings was generated randomly about the feasible string. The algorithm migrated the sub-population every 20 iterations.

3. RESULTS FROM THE ENVIRONMENTAL FLOW MODEL

The modelling results from the environmental flow model are discussed in this section. A total of six alternative environmental water management scenarios are evaluated. Each scenario corresponds to a different set of instructional arrangements governing trade and carryover:

- NTNC: The environmental manager operates without access to the allocation market or carryover provisions. This is taken to be the reference case.
- NTC: The environmental manager operates without access to the allocation market but has access to carryover provisions. The carryover arrangements operate in a capacity sharing format with storage limited to the level of the nominal entitlement.
- TNC: The environmental manager operates with unrestricted access to the allocation market but without access to carryover provisions.
- TC: The environmental manager operates with unrestricted access to the allocation market and has access to carryover provisions. The carryover arrangements operate in a capacity sharing format with storage limited to the level of the nominal entitlement.
- TRA: The environmental manager operates with unrestricted access to the allocation market and has access to carryover provisions. The environmental manger is excluded from making purchases in the market if water allocations are below the 20th percentile of historical allocations. The carryover arrangements operate in a capacity sharing format with storage limited to the level of the nominal entitlement.
- TRV: The environmental manager operates with unrestricted access to the allocation market and has access to carryover provisions. Purchases in the allocation market are limited to 20 per cent of the current allocation.

3.1. RELIABILITY AND COST OUTCOMES

The level of reliability achieved and the costs associated with each scenario are shown in Table 4. The reliability requirements for the flow targets are met. In most cases reliabilities are close to specified limits. They are not met exactly as the rules provide an approximate solution to the cost minimisation that at least meets the constraints. Costs will be higher, the more the reliability requirements are exceeded.

The entitlement value is calculated as the net present value of the allocations received by the environmental manager at prevailing market prices, and does not reflect what has been paid to date by the CEWH. The optimal value of the entitlement held by the environmental manager varies over the scenarios.

Table 4. Achieved levels of reliability and the costs under the six flow management scenarios

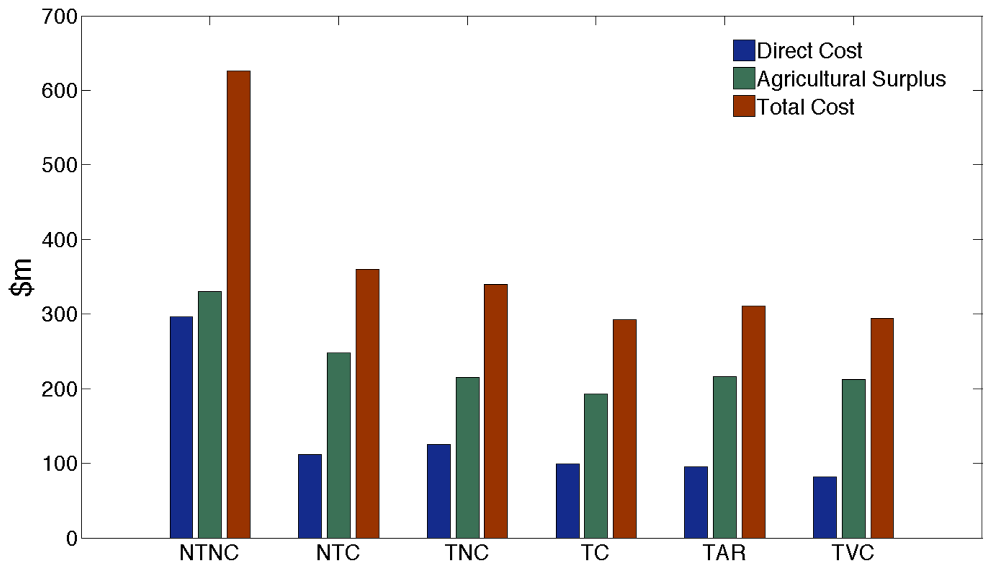
	Reliability (%)			Cost $m				
	Event 1	Event 2	Event 3	Entitle-ments	Trade	Direct	Surplus	Total
NTNC	90.2	90.5	90.7	296	0.0	296	330	626
NTC	96.4	94.4	91.9	112	0.0	112	248	360
TNC	90.7	91.7	91.9	12	113.	125	215	340
TC	90.0	91.3	91.4	425	-326	99	193	292
TRA	91.6	90.8	90.3	122	-27	95	216	311
TRV	90.8	94.1	95.6	230	-148	82	212	294

Notes: The market value of entitlements and the net surplus from trade make up the direct cost to the taxpayer. The sum of the direct cost to the taxpayer and the cost of the foregone agricultural surplus makes up the total cost.

Table 4 shows that without access to trade or carryover (NTNC), the manager needs to hold a large entitlement to meet environmental objectives. As a consequence, the direct costs incurred by the CEWH and the costs of foregone agricultural returns in this scenario are much higher than in any other management scenario. Costs are reduced substantially with access to carryover due to the smaller entitlement needed to meet the environmental objectives. Table 4 also shows that while the majority of the benefits from flexible trading or carryover arrangements are captured by the CEWH, the increased efficiency with which environmental demands can be met does benefit agriculture and society more generally through increased agricultural production.

Figure 1 compares the cost outcomes for the six flow management scenarios. The patterns of costs are similar for the NTC and TNC scenarios in which the environmental manager is either able to trade but has no access to carryover (TNC) or where the manager may not trade but has access to carryover provisions (NTC) . A relatively small entitlement is held with unrestricted trade without carryover provisions and the environmental manager can work effectively in the allocation market. Trade is essentially a perfect substitute for holding an entitlement. With trade the gains are more equally shared between agriculture and the CEWH, although the CEWH remains the largest beneficiary. Trade with carryover reduces costs further, but the additional gains are relatively small. The additional gains are shared almost equally between agriculture and the CEWH. With carryover the environmental manager's optimal entitlement holding is much higher.

Figure 1. Costs under the six flow management scenarios



3.2. MARKET OUTCOMES

Summary statistics for market prices and trade volume are shown for each management scenario in Table 5. Average prices and the level of price variability are greatest when the environmental manager is constrained to operate without access to trade or carryover arrangements. Access to carryover provisions substantially reduces the average market price and the level of price variability. However, access to trade clearly has the most significant impact on prices levels and variability. Prices in the TNC scenario where the manager may trade but has no access to carryover are around 50 per cent lower relative to the NTC scenario where trading is not permitted but there is access to carryover arrangements. Combining access to the allocation market with carryover provisions does not substantially alter the price outcomes. This suggests that in a market context, carryover adds relatively little additional flexibility in managing environmental demands.

Table 5. Summary of market prices and trade volume under the six flow management scenarios

	Prices			Traded Volumes GL		
	Median	Mean	Standard Deviation	Median	Mean	Standard Deviation
NTNC	241.57	316.14	291.85			
NTC	127.72	198.32	241.88			
TNC	63.38	129.39	193.31	0	128	199
TC	62.72	129.36	195.04	-218	-188	148
TRA	63.49	128.13	191.16	0	17	138
TRV	63.59	132.88	190.69	-66	-37	131

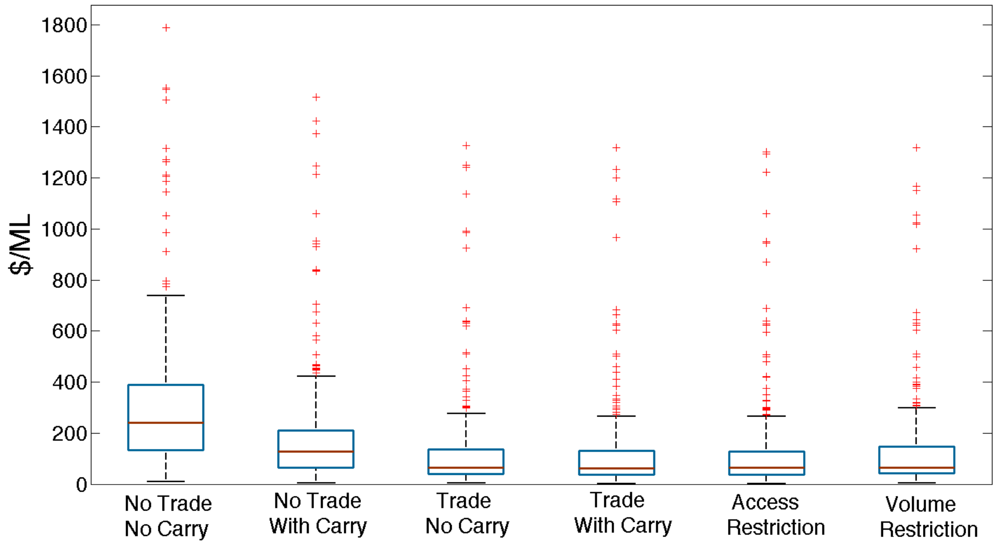
The impact of trade is evident in Figure 2 in which the distributions of market prices are presented as box and whisker plots. In the box and whisker plots shown in Figure 2:

- The box represents the interquartile range, while the lower and upper edges represent the 25th and 75th per centiles, respectively, so that 50 per cent of all prices lie within the lower and upper bounds of the box;
- The median is represented by the line within the box;
- The whiskers (the dotted lines ending in a horizontal bar) are 1.5 time the interquartile range and are intended to represent the extent of the distribution; and
- A cross marks statistical outliers or extreme events.

Trade compresses the distribution of prices as indicated by the height of the box and the whiskers. Trade also eliminates a few extreme price events, but the majority of the extreme price events are due to seasonal conditions. The trade access and volume restrictions do not have much of an impact on the trade price distributions, as trade is sufficiently countercyclical to preclude purchases in the allocation market when water availability is low. The countercyclical nature of trade is a direct reflection of the overall objective of the optimisation of minimising total economic costs, including foregone agricultural returns.

The variability in traded volumes is largely a reflection of the size of the entitlement held and the volume of water needed to meet the environmental flow targets.

Figure 2. The distribution of market prices under the six flow management scenarios



3.3. AGRICULTURAL WATER USE AND NET RETURNS

Summary statistics for annual agricultural water use and agricultural returns (surplus) are shown for each management scenario in Table 6. The distributions are presented as box and whisker plots in Figure 3 and Figure 4.

Agricultural water use and returns are lowest when the environmental manager operates without access to trade or carryover provisions. The introduction of carryover arrangements has quite a large positive impact on the level of water use and on agricultural returns. Relative to the NTNC scenario, access to carryover (NTC) increases water use by around 28 per cent and net returns by around 22 per cent. Trade has a greater positive effect on water use and returns; water use increases by more than 40 per cent and net returns increase by 32 per cent. Again, access carryover does not appear to add much flexibility over what can be achieved through trade.

Table 6. Summary of water use net returns in agriculture under the six flow management scenarios

	Water USE GL			Net Returns $m		
	Median	Mean	Standard Deviation	Median	Mean	Standard Deviation
NTNC	734	669	153	367	433	274
NTC	941	862	210	447	518	322
TNC	1044	1014	280	485	576	369
TC	1037	1027	275	480	576	363
TRA	1083	1034	276	480	576	360
TRV	1032	1012	248	488	570	349

In contrast, trade and carryover increase the variability in the annual volumes of water use and returns. In the case of carryover, this is due to different shares of entitlements held by the agricultural sector and by the environmental manager. The greater the share held in agriculture, the greater the variation in the volume of allocations due to seasonal conditions. In the case of trade there is again an effect associated with the share of entitlements but also a countercyclical impact. With trade, a larger share of entitlements is held by agriculture that more than offsets the countercyclical impact of trade.

Figure 3. The distribution of agricultural water use under the six flow management scenarios

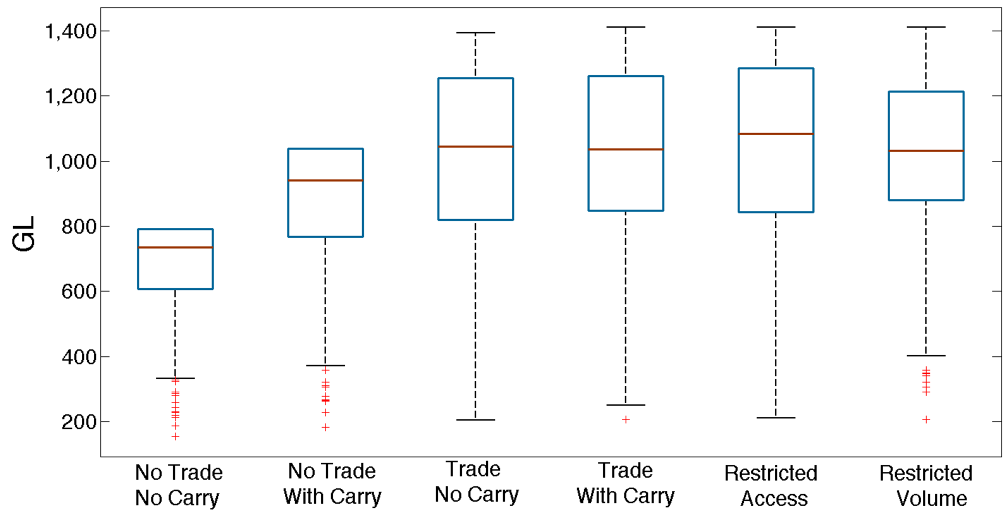
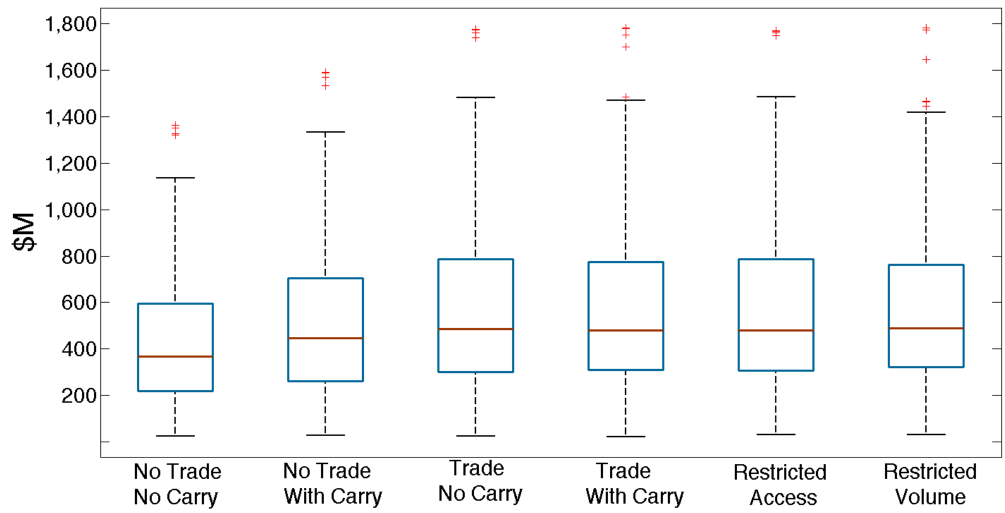


Figure 4. The distribution of gross agricultural returns and agricultural surplus under the six flow management scenarios



4. THE RISK MANAGEMENT MODEL

The modelling results described in Section 3 highlight that institutional arrangements affect the cost at which the environmental manager can deliver environmental objectives and that the types of arrangements that are in place also have a material impact on water prices and the volatility of these prices. The RMM described in this section is cast at an enterprise level for the purpose of examining the water market risks associated with different rules regarding the operation of the environmental manager.

The analysis is framed in terms of the valuation of a permanent water entitlement, which can be viewed as a 'hedge' against high price outcomes in water allocation markets. The value of the hedge is a premium over the purely productive value of the entitlement and provides a comparative measure of changes in the level of risk in the allocation market under the different environmental water management scenarios.

4.1. ECONOMIC IMPLICATIONS OF PERMANENT WATER ENTITLEMENTS

Access to permanent water entitlements is an important risk management tool for irrigators and other water users who have significant fixed investments. Irrigated horticulture, which relies on fixed investments in tree crops and vines, irrigation systems and delivery infrastructure, is the specific example considered here. However, the issues discussed extend to any water user with large investments in fixed infrastructure or with responsibility for the ongoing management of environmental assets.

A permanent water entitlement can be used as a hedge against adverse price movements in water allocation markets due to reduced water availability and increased water demand. Limiting financial exposures arising from variable water availability with a hedge has a number of benefits:

- Individuals will tend to prefer a more certain income stream over a more variable stream, as long as the risks are symmetric. Given an investment with the same expected return they will generally be willing to pay a premium to obtain greater certainty (analogous to an insurance premium).
- Individuals will tend to prefer a reduced probability of very low returns for a given average return. That is, they will prefer a greater probability of a slightly below average return if there is a reduction in the risk of a large loss. This can:
  - Increase the probability of being able to meet loan and other fixed payments; and
  - Reduce the probability of business failure.

One way of creating a hedge is by acquiring financial or real asset with a value that is positively correlated to the cost of an input (such as water) into a business enterprise. A rise in the cost of the input is then offset by an increase in the value of the asset held as a hedge, while a decline in the input price will be offset by a fall in the price of the asset. The overall result of such a hedging arrangement is that costs are less variable. A permanent water entitlement can act as a hedge if:

- The value of the allocation derived from the entitlement increases as seasonal market price increases; and
- The value of the allocation derived from the entitlement falls as seasonal market price falls.

The importance of being able to hedge against an increase in the price of water in the allocation market is related directly to the fixed assets that in turn shape the business enterprise's demand or willingness to pay for water. The value of being able to hedge the risks associated with purchasing water are greater when water users have limited opportunity to adjust their level of demand; that is, when demand is inelastic. There are three key points.

- Within a season, the willingness to pay for water is constrained by the need for revenue to cover at least the variable costs of production. That is, a business is still better off earning a low rate of return on its fixed assets rather than no return.
- A business may choose to incur costs that are greater than revenue if fixed assets, such as orchards and vines, will incur an irreversible loss in value, as for example, through reduced yields into the future.
- The size or capacity of the fixed assets is likely to constrain maximum water demand. The willingness to pay for additional water may approach zero as this level is reached.

Each of these points implies that the demand for water at the enterprise level can be highly inelastic or non-responsive to price changes within a season and, importantly, over the life of the fixed assets. As a consequence, the potential value and effectiveness of a hedge based on a permanent water entitlement may be quite high.

The effectiveness of a permanent entitlement hedge depends on the extent to which price risks are the result of changes in the level of demand for irrigation water or the level of water availability. Prices in physical markets for water allocations may change in response to short-term factors such as drier and hotter growing conditions and longer-term factors such as an increase in government purchases of water for the environment. In this case, a permanent entitlement is a perfect hedge. As there is no change in the yield of the entitlement, the value of the entitlement in a given season changes in the same proportion as the price in the allocation market due to a shift in demand.

Prices in physical markets for water allocations may also change in response to changes in the level of available resources, due for example to reduced inflows into upstream storages or changes to the administrative rules that govern the share of available resource made available for use by entitlement holders. In this case, the hedge is unlikely to be perfect as entitlement yields are changing as well as price. As yields fall, prices will tend to increase and as yield increases prices will tend to fall. The value of the entitlement is the product of the two.

The hedge will be more effective, the more price inelastic or non-price responsive the demand for water is. This is because the price effect becomes more dominant and the value of the allocation derived from the entitlement increases even though the yield falls. Higher security water enticements are more effective as yields do not tend to fall a sharply when water availability declines. As a consequence the value of the allocation derived from a higher security entitlement tends to move more closely in line with prices in the seasonal allocation market.

4.2. WATER MARKET RISK AND ENTITLEMENT VALUES

The value of permanent water entitlement should reflect their value as instruments to hedge risk, as well the productive value associated with the entitlement yield. This was recognised in NSW by IPART in its 2010 Bulk Water Price Determination to the extent that it attracted a high charge (IPART, 2010). It was also noted by the Productivity Commission in a review of the pries responsiveness of irrigation water demand in the Southern Murray Darling Basin (Appels, Douglas and Dwyer, 2004).

The value of the premium for the permanent water entitlement as a mechanism for creating an effective hedge depends on the level of price variability in the water market. It is clear from the results presented in the previous section that the institutional arrangements under which the CEWH operates can have a substantial impact on price variability. In particular, access to the allocation market to allow trade between agricultural and environmental water uses substantially reduces price variably and the incidence of extreme price events. There are therefore two implications:

- Without trade, the hedging value of a high security entitlement will increase. This effectively increases the cost of securing fixed investments that are at risk if adequate water supplies are not available.
- With trade, the hedging value of a high security entitlement will decline. This effectively reduces the cost of securing fixed investments that are at risk if adequate water supplies are not available.

4.3. DETERMINING THE HEDGING VALUE OF A PERMANENT WATER ENTITLEMENT

The key questions that then arises is how significant the change in the costs of managing risk is as a result of different institutional arrangements under which the CEWH operates. One way to approach this problem is though portfolio theory using a variation on the CAPM asset-pricing model (first published by Sharpe, 1964, Lintner, 1965 and critiqued by Roll, 1977). The CAPM model prices an asset in proportion to the risk that can be diversified or hedged, relative to the risk that cannot be diversified.

To measure the hedging value of a permanent water entitlement as a premium over the purely productive value of the entitlement, the CAPM has been applied to an investment in a horticultural enterprise. Such an investment can be thought of as comprising two separate assets:

- The investment in land, infrastructure and perennial crops; and

- An investment in high security water entitlement.

Each of these assets has an expected return, an expected level of variability and an expected level of covariance or co-movement with the other assets in the portfolio. The return on the investment in land, infrastructure and perennial crops is simply the unhedged rate of return from our example. We can take this unhedged rate of return as an undiversified reference point.

The β value is the ratio of the covariance between the rate of return on a water entitlement and the unhedged rates return to the variance of the unhedged rate of return:

$$\beta = \frac{Cov\left(R_{Entitlement}\right)}{Var\left(R_{unhgedged}\right)}$$

β measures the variability of the return on a water entitlement relative to the (benchmark) variability of unhedged returns. A β value of zero implies the risks associated with holding an entitlement are independent of the risks of the investment in land, infrastructure and perennial crops. A β value of one implies that the risks associated with holding an entitlement is the same as the unhedged risk. That is, the portfolio risk purchasing a water entitlement is the same as investing in a larger enterprise. If holding a water entitlement is an effective hedge, β will be negative. In this case, holding permanent water entitlements allows the construction of an overall portfolio risk that is less than any of individual components and reduces the overall risk exposure of the portfolio. If the hedge is perfect β will be equal to minus one. A perfect hedge provides a risk free investment opportunity.

A β value greater than or equal to zero and less than one allows risk to be diversified. The purchase of a permanent entitlement adds to an individual overall exposure as the level of investment has increased; however, the total portfolio risk is a linear combination of the components of the portfolio, which is less that the unhedged risk on the investment in land, infrastructure and perennial crops. This gives rise to the CAPM formula.

The CAPM formula expresses the required rate return on an asset relative to a hypothetical 'risk free' rate of rerun, typically a treasure bond rate, and the undiversified rate of return:

$$R_{Asset} = R_{RiskFree} + \beta\left(R_{Undiversified} - R_{RiskFree}\right)$$

By definition a risk free asset is independent of any other market risks. However, a β value of zero does not imply an asset is risk free. Here, we need to replace the notion of a 'risk free' asset with a diversified market rate of return.

$$R_{Entitlementt} = R_{Diversified} + \beta\left(R_{Unhedged} - R_{Diversified}\right)$$

We can take the discount rate used to demine the productive value of a permanent entitlement to be the diversified rate of return. Conversely we can use the CAPM rate of return on the entitlement to revalue to a permanent entitlement to account for value as a hedge.

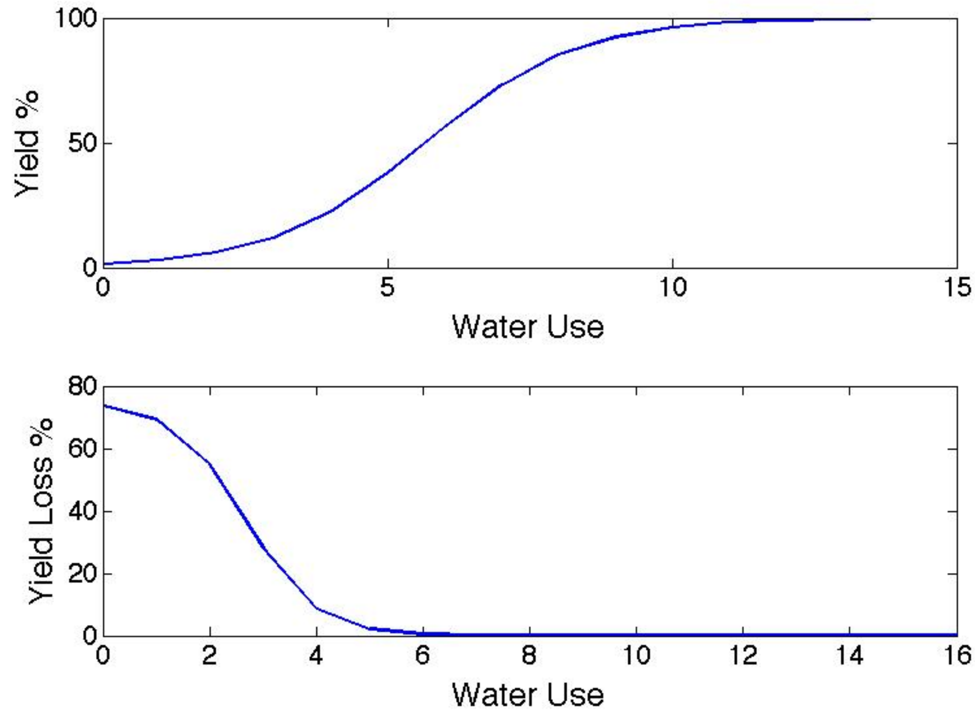
$$V_H = \mathrm{E}\left(PA_H\right)\sum_{t=1}^{N}\frac{1}{\left(1+R_{HS\ Entitlementt}\right)^t}$$

4.4. AN APPLICATION TO A HORTICULTURAL ENTERPRISE

To apply the risk valuation model described above to value permanent water entitlements, a simple farm enterprise model was constructed to represent an investment in horticulture. The investment is considered over a fixed time horizon assuming a terminal salvage value. The enterprise has the option of purchasing high security water entitlements and purchasing water in the allocation market. Water allocations and market prices are taken directly from the environmental flow modelling pretend in Section 0 of this report.

Returns are the product of net output margin, prices less costs expressed on a unit of output basis, and yield per hectare. Yield is a function of the sum of useful rainfall and the volume of irrigation water applied. There is long-term yield damage when water availability falls below initial threshold level. The yield and long term yield loss functions are illustrated in Figure 5. Yields recover over time so long as water availability does not fall below a second critical threshold level.

Figure 5. The yield and yield loss functions



It is assumed that net margins and yields are uncorrelated. Hence the effectiveness a permanent water entitlement as a hedge is dependent only on the price of water in the entitlement market. The model is solved as a stochastic optimisation of the net present value of returns. In addition, there are ancillary financial calculations associates with debt financing. Given the enterprise an initial equity level and interest rate, annual debt levels for the enterprise are calculated. The model is specified in Appendix B.

The full set of model parameters is provided in Appendix B. The key financial parameters are listed below:

- The capital investment is $50,000 per hectare with a salvage value of $5,000 per hectare;
- The level of permanent entitlement purchased is 10Ml per hectare.
- The investment horizon is 40 years;

- The interest rate is seven per cent; and
- The initial equity position is 75 per cent.

4.5. RESULTS AND DISCUSSION

The three scenarios with the greatest range in price variability were evaluated. The mean margin of output price over variable inputs costs, excluding water was set at $62 to ensure that the enterprise was viable, having a positive rate of return under each scenario.

Summary results from enterprise model are shown for each scenario in table 7. These include:

- The return to capital, including the value of permanent entitlement held, per hectare;
- The net present value of the investment over the 40 year horizon, per hectare;
- The terminal debt position of the enterprise after 40 years, per hectare; and
- Average income, annual net return less debt servicing, per hectare.

The impact of the permanent entitlement hedge on enterprise return with the higher average water price and greater price variability under the NTNC is quite substantial. The enterprise NPV is almost 50 per cent higher with the hedge. As the capital base includes the value of the water entitlements the rate of return is lower. Net income is more that 50 per cent higher as the equity position improves under the hedge and declines without it. The variability in financial position of the enterprise, as measured by the relative standard errors, is much higher without the hedge.

The introduction of carryover provisions in the NTC scenario reduces the impact of the hedge. However, the NPV of the enterprise and income is around 33 per cent higher. The equity position without the hedge improves from 75 per cent to around 92 per cent even without the hedge. The variability in financial position of the enterprises is higher without the hedge but the difference has declined.

The introduction of carry over and trade provisions in the TC scenario reduces the impact of the hedge further. The NPV of the enterprise is around 20 per cent higher and income is about 25 per cent higher. The equity position without the hedge improves from 75 per cent to around 94 per cent without the hedge. The variability in financial position of the enterprises is higher without the hedge but the difference has declined further.

Table 7 Summary results from the horticultural enterprise model enterprise models for the three selected environmental management scenarios; relative standard errors are in parenthesis.

	No Trade No Carry		**No Trade with Carry**		**Trade and Carry**	
	Hedged	Unhedged	Hedged	Unhedged	Hedged	Unhedged

Rate of Return	105.5% (2%)	1.10% (11%)	1.32% (2%)	1.46% (9%)	1.44% (3%)	1.57% (6%)
Enterprise NPV	$82.780 (2%)	$46,591 (11%)	$82,045 (2%)	$61,680 (9%)	$78.882 (3%)	$66,243 (6%)
Terminal Debt	$31 (673%)	$9,975 (37%)	$0	$3,106 (61%)	$29 (347%)	$2,403 (70%)
Average Income	$3,440 (34%)	$1,229 (84%)	$4,663 (31%)	$3,246 (57%)	4,523 (31%)	$3,665 (43%)

The value CAPM Beta values and value of permanent water entitlements for the three scenarios are shown in table 8. The Betas are all negative reflecting that the entitlements an effective hedge under each scenario. In line with the financial results the absolute value of the Betas is greatest under the NTNC scenario followed by the NTC and then TC management scenarios. This is also seen in the value of the hedge. The direct value is the net present value of the allocations valued market prices. The difference reflects market prices as yields are not greatly affected by the management scenarios.

Under the NTNC scenario the ability to hedge returns with a permanent entitlement attracts over a 100 per cent premium over the direct value of the water in agricultural use. This premium drops to around 25 per cent under the NTC scenario and t0 less that 10 per cent with under the TC scenario.

Table 8 CAPM Beta and high security water entitlement values for the three selected environmental management scenarios

Scenario	CAPM Beta	Direct Value	Hedge Value	Total Value
NTNC	-0.51	$3,622	$3,096	$6,718
NTC	-0.44	$2,034	$547	$2,581
TC	-0.24	1,265	102	1,367

5. SUMMARY AND POLICY IMPLICATIONS

The transfer of water from agriculture to meet environmental demands imposes costs in terms of agricultural returns and reduced economic activity in rural communities. The extent of these costs depends in large part on the volume of water that is redirected for environmental use. However, the costs also depend substantively on the arrangement that govern the incentives and options that face the environmental water manager.

In the context of incentives it is reasonable to expect, and taken in this report, that the environmental manager would:

- Seek to meet environment objectives at the loses possible economic costs; and
- Have a strategy to meet those objectives that is transparent to all water uses and open to public accountability.

The efficiency with and therefore the cost at which the environmental manager can deliver environmental objectives depends on two institutional arrangements:

- Whether the manager is permitted to trade in the physical or allocation water market; and
- Whether the manager has access to carryover arrangements.

The role of institutional arrangements that will govern the operation of the CEWH have not be given detailed consideration in the Murray Darling Basin planning process to date. The results derived in this report indicate that if the CEWH operates in isolation from the allocation market and is unable to cess full carryover provisions such as capacity sharing arrangements, the costs of meeting environmental flow objects will be substantially higher. These include both the direct costs of funding the CEWH and foregone costs to agriculture.

In addition, trade and carryover arrangements have a substantial impact on the volatility of market prices. An estimate of the premium currently paid for higher security water entitlements can be used to measure the value of a change in the level of risk at the level of an agricultural enterprise corresponding to changed institutional arrangements governing the actions of the environmental manager. From the perspective of an agricultural enterprise contemplating a longer-term investment, a reduction in the volatility of market prices associated with specific institutional arrangements is a valuable risk management mechanism that reduces the overall risk associated with on-farm investments.

In summary, the results showed in meeting the specified environmental demands:

- With trade and carry over provision in place high security water entitlements are estimated to trade at around $1,400ML with a premium that high security entitlements provide against market risk of a bit under 10 per cent. This is a reflection of the high level of level of reliability of high security entitlements in the Goulburn system.

- The costs of high security water entitlements would be in the order of $5,000/ML higher without access to trade and carryover provisions. This due in part to higher market prices, 35 per cent, and the premium that high security entitlements provide against market risk, 65 per cent. This is reflection of how effective the high security is a tool to manage the much higher level of price volatility

- With the introduction of carryover provisions the difference falls to around $1,200/ML About 60 per cent of the increase is due to higher market prices and 40 per cent to a risk premium.

Trade furthermore has a large impact on the level and volatility of water that is available for agricultural production. While trade is largely countercyclical in terms of price, it adds to the average volume and variability of water that can be used for irrigated agriculture. So for the potential gains from trade to be realised there needs to be sufficient flexibility within irrigated agriculture to respond to market opportunities, in terms of the ability to either make additional use of or forego water use within a season. Given the natural variability in seasonal conditions that exist in the Southern Murray Darling Basin this flexibility clearly exists. However, trade will impact on this pattern and give rise to changes in the mix of highly resilient enterprises such as horticulture and irrigated pasture and cropping.

5.1. GOVERNANCE ISSUES

While there are substantial economic benefits from allowing the CEWH to access the water allocation market, the associated greater flexibility in terms of the actions that may be taken by the environmental manager also raises some potential concerns that need to be considered. The volume of water under the control of the CEWH is large and its action in the market will influence market prices. There are two possible consequences:

- Market power might be exercised, in the sense that the environmental manager may seek to manipulate water prices through their trading activity in order to minimise CEWH costs. Hence the first incentive to minimise total economic costs is important and would need to be reflected in the overall objectives that the CEWH must adhere to.

- The inability to anticipate the actions of the CEWH in the market can be disruptive and impede efficient market operation. In particular beneficial impacts on investment and production on the part of agricultural enterprises are likely to be limited if the actions of the environmental manager are perceived to be arbitrary and non-transparent. Hence the second incentive of having transparent objectives and strategies to meet those objectives is also important.

It might also be seen as desirable to place constraints on the allocation market operations of the CEWH. This could include limiting access to the market for purchases when allocations are low or to limit volumes traded. However, imposing constraints of this type will impose economic costs on all parties, and some judgment is therefore required as to whether the benefits of such constraints exceed the costs.

5.2. AREAS FOR FUTHRER CONSIDERATION

The results presented in the paper indicate that restricting the ability of the CEWH to purchase water in the entitlement market when water available is low or that trade volumes may be disruptive do not impose large costs. This is because the environmental manager, as represented in the model takes, the impact of trade on agricultural returns into account. Hence, the constraints imposed were not tightly binding. This suggests that restricting access to the allocation market by the CEWH in some instances may be a useful safeguard. This appears to be an area worth more extensive investigation.

There is an opportunity to try and integrate the consideration of costs in the development of flow objectives, particularly in the specification of the level of reliability that needs to be achieved. Attempting to meet targets with absolute certainty will at times bring environmental goals and irrigated agriculture into sharp conflict. A degree of flexibility can serve to limit these conflicts. While the model presented here can be used to assess these trade-offs, the question of how much flexibility is required depends on the impact of delaying releases on resource conditions.

One limitation of the modelling work to date is the consideration of the value of carryover provisions to agriculture. The rules based optimisation framework is well suited to this problem to estimate an optimal agricultural carryover strategy.

References

Appels, D., Douglas, R. and Dwyer G. (2004) Responsiveness of Demand for Irrigation Water: A focus on the Sothern Murray-Darling Basin, Staff Working Paper, Productivity Commission.

Heaney, A., Beare, S. and Brennan D. (2012) Managing environmental flow objectives un uncertainty: The case of the lower Goulburn River floodplain, Victoria. Paper presented to the 56th conference of the Australian Agricultural and Resource Economics Society, February 7-10, Freemantle, Australia,

IPART (2010) Determination of bulk water charges for State Water Corporation From 1 July 2010 to June 2014, Sydney.

Lintner, John (1965). The valuation of risk assets and the selection of risky investments in stock portfolios and capital budgets, Review of Economics and Statistics, 47 (1), 13-37.

MDBA (Murray–Darling Basin Authority). 2009. The Living Murray Annual Implementation Report and Audit of the Living Murray Implementation Report, Canberra.

____2010a. Guide to the proposed Basin Plan: Overview, Murray–Darling Basin Authority, Canberra.

____ 2010b Guide to the proposed Basin Plan: Technical Background, Murray–Darling Basin Authority, Canberra.

____ 2010c Technical Backgound Appendix B: Hydrologic indicator sites; Goulburn-Broken region, Murray–Darling Basin Authority, Canberra.

____ 2012a The Proposed Basin Plan – a revised Draft, Murray–Darling Basin Authority, Canberra.

____ 2012b Hydrologic modeling to inform the proposed Basin Plan: Methods and results, Murray–Darling Basin Authority, Canberra.

Roll, R. (1977): "A Critique of the Asset Pricing Theory's Tests," Journal of Financial Economics, 4, 129–176.

Sharpe, William F. (1964). Capital asset prices: A theory of market equilibrium under conditions of risk

APPENDIX A WATER ACCOUNTING AND ALLOCATION RULES

The following describes the water accounting rules used in the optimisation model. Annual variables are in italics and constants are bolded.

1. *October Carry In* = maximum of [(*May Carry In* + *Winter Spring Inflow) * (1 –* ***Evaporation****)*, **Dam Capacity**);
2. *Spill* = minimum of (*May Carry In* + *Winter Spring Inflow* - Dam Capacity, 0);
3. *Downstream flows = Natural inflows below the dam + Spills;*
4. *Water Available = (October Carry In + Balance of Inflows)* * (1 –***Evaporation****)* - **critical reserve**;
5. *Allocation = minimum of (*2 * *Entitlement, Water Available);*
6. *Allocation = minimum of (Entitlement, Average Use Adjustment);*
7. *May Carry In = Water Available – (1+****System Losses*** *)* Allocation.*

The model parameters were supplied by the Victorian Department of Sustainability and Environment and included:

- Evaporation = 3.64 per cent
- Critical reserve = 146,251 ML
- Total entitlement = 985,865 ML
- System losses = 11 per cent

The adjustment for average use is a function of the allocation given the allocation is above the level of entitlement:

$$Average\ Use = 0.036 + 1.245 InitA - 0.274 InitA^2$$

Where InitA is the initial allocation specified in (5).

Adjustments to the code were made to account for the carryover of environmental allocations.

APPENDIX B THE ENTERPRISE MODEL

The enterprise is intended to represent an investment in horticulture. The investment is assumed to have a life of N years. The capital investment in assets excluding water is K_0 dollars per hectare with a salvage value of K_{N+1} per hectare. The enterprise has the option of purchasing any combination of high and general security entitlements, A_{EH} and A_{EG}, again on a per hectare basis at prices V_H and V_G, respectively.

The enterprise returns and net output price, P:

$$P_{Output} \sim normal\left(\mu_{Output}, \sigma_{Ouptut}\right)$$

Returns are the product of net output margin, prices less costs expressed on a unit of output basis, and yield per hectare. Gross revenue is the simple product of net output price and yield per hectare, y.

The absolute maximum yield is YMAX. At any point in time there is a maximum possible yield $Ymax_t$. The realized yield is a function of total water use, W_t:

$$yield_t = \frac{Y\max_t}{1+\exp\left[\left(-(\beta_0+\beta_1 W\right)\right]}$$

There is long-term yield damage and recovery. The loss in maximum potential yield is:

$$yieldLoss_t = \begin{cases} \dfrac{MaxYieldLoss}{1+\exp\left[\left(-(\gamma_0+\gamma_1 W\right)\right]} & W < threshold \\ 0 & otherwise \end{cases}$$

If water use is above the threshold then yields can partially recover at rate d. This lead to the dynamic specification of maximum yield:

$$Y\max_t = \begin{cases} Y\max_{t-1} - yieldloss_{t-1} & if\ W_{t-1} < threshold \\ Y\max_{t-1} + \delta\left(YMAX - Y\max_{t-1}\right) & otherwise \end{cases}$$

Water use is the sum of the allocation, useful rainfall and any net purchase (less sale) of water in the allocating market, w:

$$W_t = A_{EH}A_{H,t} + A_{EG}A_{G,t} + \frac{rain_t}{100} + w_t$$

$$rain : \log normal\left(\mu_{rain}, \sigma_{rain}\right)$$

Rain is expressed in mm and converted ML per hectare. Water purchased or sold in the allocation market is the prevailing price.

Water use is determined by maximising the net present value of the stream of annual profit, subject to the constraint on maximum yield:

$$\underset{W}{Max}\sum_{t=1}^{N}\left(\frac{P_{Ouput,t}Y\max_t}{1+\exp\left[\left(-(\beta_0+\beta_1 W\right)\right]}-P_t w_t\right)/(1+r)^t$$

$Subject\ to:$

$$w=\begin{cases} W-A_H-A_G-rain & if\ W>rain \\ -A_H-A_G & otherwise \end{cases}$$

$$Y\max_t=\begin{cases} Y\max_{t-1}-yieldloss_{t-1} & if\ W_{t-1}<threshold \\ Y\max_{t-1}+\delta\left(YMAX-Y\max_{t-1}\right) & otherwise \end{cases}$$

In additional there are the financial calculations associates with debt financing. Given the enterprise has an initial equity level EQ and an interest rate, annual debt levels are calculated as follows:

$$Debt_t=(1+i)Debt_{t-1}-payment_{t-1}$$
$$Debt_0=EQ\left(K_0+V_H ET_H+V_G ET_G\right)$$
$$annuity=\frac{iDebt_0}{1-(1-i)^{-N}}$$
$$payment_t=\begin{cases} annuity & if\ \ annuty<netrevenue_t \\ netrevenue_t & otherewise \end{cases}$$

Disposable income, Y, is:

$$Y_t=\begin{cases} netrevenue_t-payment & if\ \ netrevenue_t<payment \\ 0 & otherwise \end{cases}$$

The parameters used of the enterprise model are shown in Table B1.

Table B1. Parameters used to represent the irrigation enterprise

Parameter	*Value*	*Parameter*	*Value*
N	40 years	Threshold	4Ml/ha

K_0	\$50,000/ha	MaxYieldLoss	75
K_{N+1}	\$1,000/ha	γ_0	4
μ_{Output}	\$100	γ_1	-1.5
σ_{Output}	\$15	i	0.07
MAXYIELD	100		
β_0	-5.0		
β_1	7.5		