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Urban water options contracts – rural to urban water trade

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Most urban centres across Australia are facing water shortages. In part, these water shortages are due to the variability of supply and demand caused by variable climatic conditions. Permanent supply augmentation to meet periodic water shortages can be costly. Water trade between rural and urban areas, through urban water options contracts, may be a less costly way to meet variability.

Urban water options could be used to improve system reliability and may reduce costs by delaying investment and reducing the frequency and severity of water shortages. This paper investigates the potential to use urban water options contracts, and develops a methodology for evaluation.

[†] The views presented in this paper, drawn from preliminary work in progress, are those of the authors and do not represent the official view of ABARE or the Australian Government.

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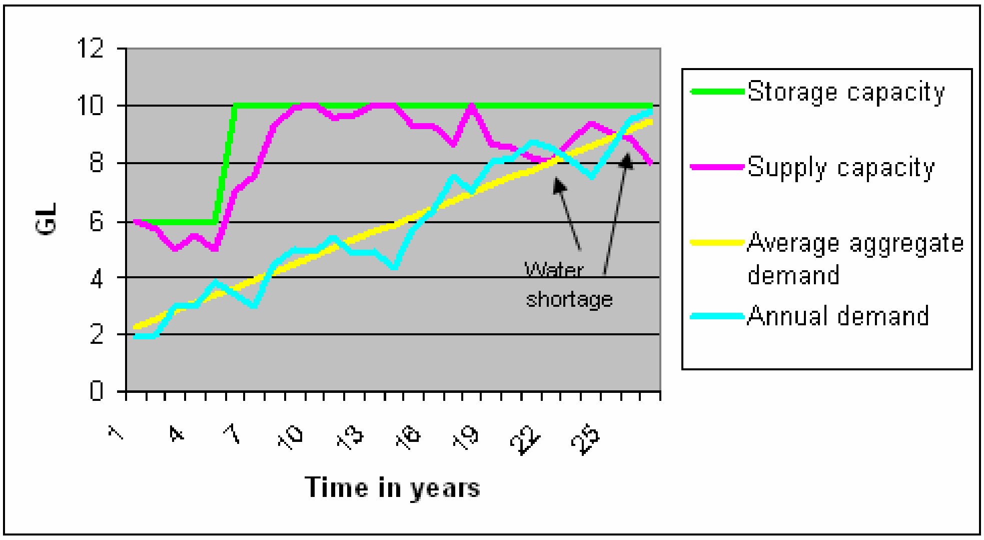
Introduction

Most urban centres across Australia are facing water shortages. These water shortages are due to a combination of increased aggregate demand and seasonal variability in both annual demand and inflows into storages. Over the past couple of decades population growth rates have generally been greater than the growth in water supplies, creating an imbalance between demand and supply (WSAA 2005). More recently drought has increased demand and decreased supply in increasingly overstretched water supply systems, exacerbating the supply demand imbalance.

The imbalance between aggregate demand and capacity has occurred as the number of sites suitable for constructing new dams has decreased while both the capital and environmental costs have grown. Non-rain dependent supply alternatives, for example desalination plants or recycling plants, are significantly more expensive than dams and have until recently not been constructed on a large scale in Australia. Over time, as growth in water harvesting capacity has fallen behind the growth in aggregate demand, water supply systems have moved increasingly closer to full utilisation — with most currently having no excess supply capacity. A stylised example of the interaction of storage capacity and supply capacity with average aggregate demand and annual demand is shown in figure 1. When annual demand is more than supply capacity a shortage will result.

Figure 1. A stylised model of an urban utility and water shortages



Investment in excess supply capacity has previously been used to manage seasonal variability. Currently, however, little to no excess supply capacity remains in most water supply systems and in some cases the amount of water that remains in storage for use the following year is declining. If drought occurs under these conditions it is likely that demand will exceed supply — resulting in a water shortage. The supply shortages in Australia have led to water restrictions in all but one of the mainland capitals (Quiggin 2005) with about half of the major cities using demand management to restrict use and encourage users to conserve water (Marsden and Pickering 2006). After all opportunities for demand management are exhausted, including the use of restrictions and price instruments, augmentation will need to occur. With the exception of Perth, little supply augmentation has occurred recently in Australia (WSAA 2005), although many cities have investigated supply augmentation alternatives and the costs of increasing supply.

After water supplies are balanced with average aggregate demand the effect of seasonal variability on this balance will need to be addressed. In the absence of demand growth excess supply capacity will significantly reduce the probability of a water shortage, but investment in infrastructure that is seldom used is likely to be expensive. With demand growth excess capacity will eventually be utilised, however, it may not be efficient to invest in excess capacity. As investment in new water supplies tend to be lumpy it will not be efficient to invest in new supply until demand has grown to the point that the benefits of increased consumption outweigh the costs of supply augmentation. Consequently, it may be efficient to run the supply system with little excess capacity until it is efficient for the next lumpy supply investment to occur. In the interim period a possible alternative to investment in excess supply capacity would be to secure a source of supply, as needed, through water options contracts, and in so doing so reduce the impact of a water shortage and possibly delay investment in additional capacity.

In rural Australia water trade has been taking place for over a decade with the most established markets in the regulated southern Murray Darling Basin. The trade of water in these intrastate markets has allowed water to move to higher value uses and improved efficiency. At the beginning of 2007 these markets were expanded to encompass interstate trade.

To date there has been limited trade between urban and rural areas. However as markets deepen there may be an opportunity for water option contracts to be used in some urban areas. Water trade through option contracts will be possible in regions where rural water supplies can be accessed. However, they will not be suitable in regions where rural supplies cannot be accessed.

The objective of this paper is to investigate the possibility of trade between urban centres and rural areas through urban water option contracts. In the first section background information regarding pricing and investment paths of urban water systems is discussed along with the operation of urban water option contracts. In the second section a methodology to value urban water option contracts is presented and results discussed. The third section contains concluding remarks.

Background

Patterns of water consumption in Australia

In the 2004-05 financial year Australia consumed 18 767 GL of water, with agriculture accounting for 65 per cent (12 191 GL) while households accounted for a much smaller share at around 11 per cent (2 108 GL), see table 1. Consumption of water in all usage categories was less for 2004-05 than the previous recorded year, 2000-01, with aggregate consumption decreasing by 14 per cent from 21 702 GL.

Table 1. Water consumption and use in Australia, 2004-05

	2004-05		2000-01	
	GL	%	GL	%
Water consumption[a]				
Total	18 767		21 702	
Agriculture	12 191	(65)	14 989	(69)
Households	2 108	(11)	2 278	(10)
All other	4 468	(24)	4 435	(21)
Distributed use[b]				
Total	11 336		12 934	
Agriculture[c]	5 329	(47)	7 033	(54)
Households	1 874	(17)	2 056	(16)
All other	4 133	(36)	3 845	(30)
Rainfall				
Run-off	242 779		385 924	

Source: ABS 2006

a water consumption is equal to the sum of distributed water use, self-extracted water use and reuse water use less water supplied to other users less in-stream use and less distributed water use by the environment. **b** includes water supplied to a user where an economic transaction has occurred for the exchange of water. **c** supplied by irrigation authorities as is generally untreated.

'Distributed use' is defined as the share of total water consumption that was supplied when an economic transaction occurred, and does not include self extracted water or reuse water use (ABS 2006). Distributed water is held in storage for use later in the year, when it is delivered by a 'water provider'. A total volume of 11 336 GL of distributed water was delivered in 2004-05 with agriculture accounting for 47 per cent (5 329 GL) and households 17 per cent (1 874 GL). For agriculture, water in this category is for the most part used by irrigated agriculture, with around 70 per cent of irrigated land located in the Murray Darling Basin. The Murray Darling Basin is located in the south east of Australia and extends over the jurisdictional boundaries of New South Wales (and the Australian Capital Territory), Victoria, Queensland and South Australia. Irrigated agriculture accounted for 23 per cent of the total gross value of agricultural commodities produced in Australia in 2004-05 (ABS 2006).

Distributed water delivered to households decreased by 9 per cent over the period 2000-01 to 2004-05. On average this represents a decrease in personal consumption from 120 kL per person in 2000-01 to 103 kL per person in 2004-05. The decrease may be attributed, in part, to mandatory water restrictions in most States and Territories since 2002 (ABS 2006).

The water supply systems in Australia are highly dependent on seasonal conditions, with 96 per cent of distributed water in 2004-05 originating from surface water. The significant fall in both water consumption and delivery from 2000-01 to 2004-05 gives some idea of how seasonal variability can affect water availability, and hence its consumption. The runoff from rainfall fell almost 40 per cent from 385 924 GL in 2000-01 to 242 779 GL in 2004-05. As large storages are used to store rainfall runoff to smooth water consumption across seasons, a particularly dry year results in greater use of stored water and a particularly wet year lowers use. Consequently, the repercussions of a particularly dry year are often felt for a number of years after — as storages are allowed to recover with rainfall returning to normal patterns.

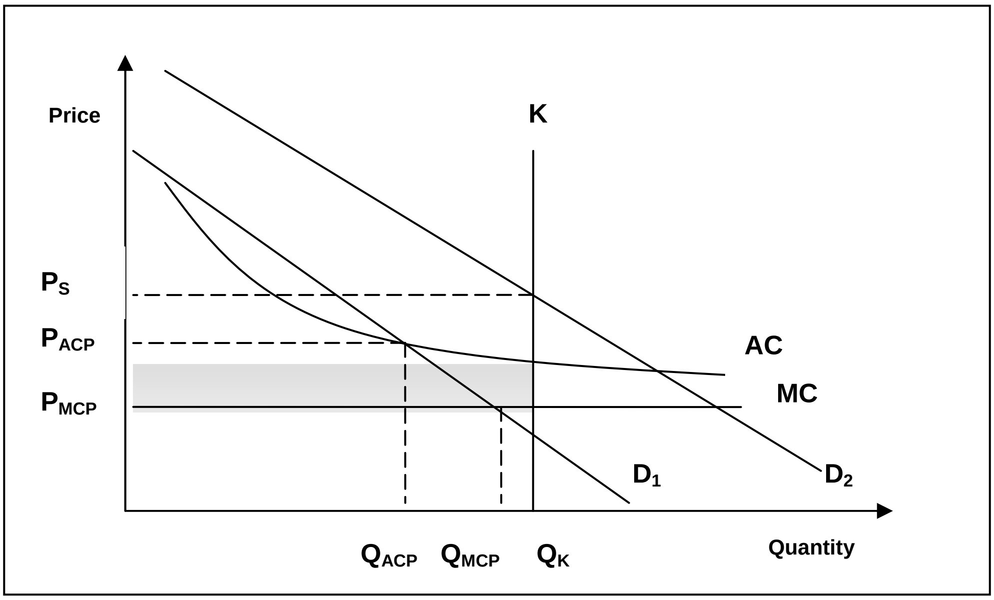
Pricing

Rural water in the southern Murray Darling Basin can be traded and so the traded price reflects the value of water or the users' willingness to pay. The traded price of water changes through out the season and from season to season, reflecting the relative scarcity of water. In urban areas, however, the 'price' paid for water is an administered charge and does not reflect the value of water to consumers, only the physical costs of supply and delivery. A scarcity fee for water is not charged during times of shortages, with excess demand generally being constrained by restrictions on use. Of Australia's eight capital cities, six had water restrictions in place in November 2006 with Hobart and Darwin the exceptions (WSAA 2006).

There are a number of reasons as to why restrictions may have been used instead of price to ration demand in Australia. First, price determinations that are arbitrated by a price regulator can be lengthy, whereas restrictions can be implemented independently of regulators (Byrnes et. al. 2006). Second, true quantity restrictions are theoretically more certain to meet a set demand target than price. For example, if price is used to ration demand the target may be exceeded if the price is not set high enough to sufficiently dampen demand — whereas true quantity restrictions limit consumption to the target.

The water restrictions currently in place in Australia do not constitute true quantity restrictions. For example, water users may be restricted to watering outside every second day of the week using an 'odds and evens' system, however, there is no restriction on the volume of water that can be consumed. Users are likely to change behaviours to comply with restrictions, but not necessarily significantly reduce consumption. Pricing which reflects the scarcity value of water would provide additional incentive to reduce water consumption.

Figure 2. The pricing of water



The stylised cost curves of an urban water utility are shown in figure 2. At D_1 the efficient price is the marginal cost price P_{MCP} and the efficient quantity Q_{MCP}. However, an urban water utility is a natural monopoly with large lumpy infrastructure costs and declining average cost. As marginal cost is lower than average cost at Q_{MCP} a loss would be made (shaded rectangle). This loss could be subsidised by the government or the average cost price P_{ACP} could be used. This average cost price (P_{ACP}) is higher and output (Q_{ACP}) lower than under marginal cost pricing. When demand increases (from D_1 to D_2) the capacity of the system is reached and if scarcity pricing is used the price rises to P_S which clears the market and reflects the scarcity value of water. It should also be noted that when discussing the capacity of a water system being reached it usually refers to the supply capacity of water held in storage, not the capacity of the storages themselves. Generally utilities set a set supply target, so that consumption does not lead to the reduction of the volume of water in storage past a set target. For example, urban utilities may constrain demand as the amount of water left in reserve reaches 20 per cent.

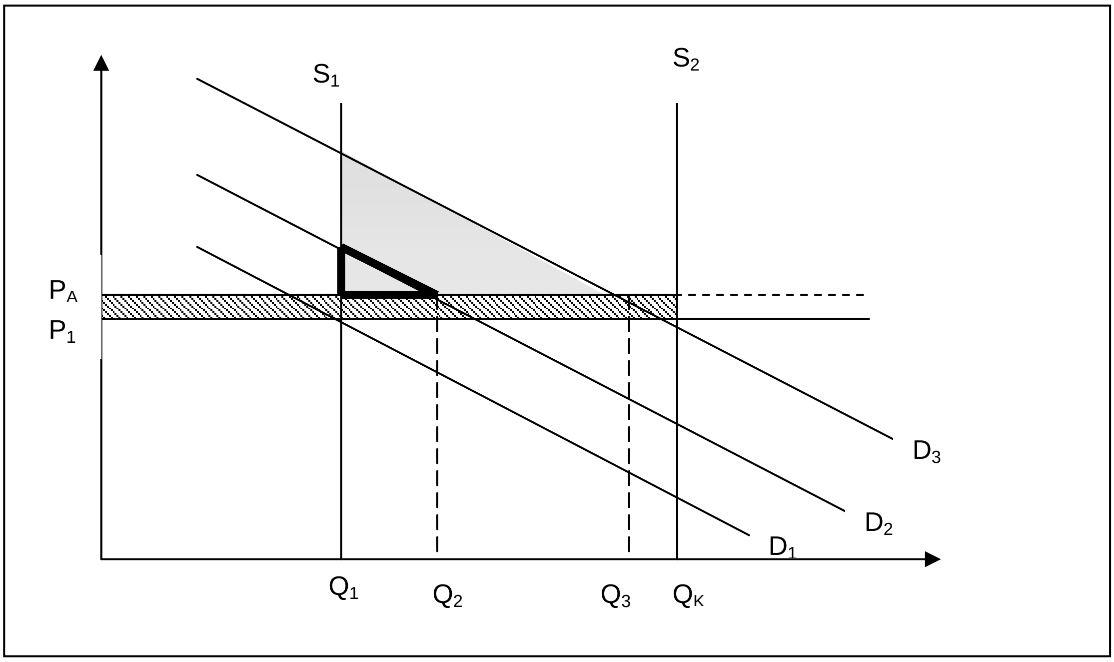
Investment

If an efficient pricing system is in place the investment path for a utility can be determined. An efficient pricing system is one that charges for the marginal costs of supply and delivery as well as a scarcity fee when water is scarce. This pricing system will ration demand as capacity is reached, and will indicate when supply augmentation is necessary. As demand grows the price will continue to increase until a point is reached where the benefits of increased consumption outweigh the costs of supply augmentation.

Although an efficient pricing system and investment path may ensure that supply balances with *average* aggregate demand, the water system will still be subject to seasonal variability. The effect of seasonal variability (for example due to decreased rainfall or increased temperature) will depend on the state of supply in the water supply system. In any year water supply capacity consists of two components, the amount of water in storage from the previous year and the inflows in the current year. In the past, seasonal variability has been addressed with excess supply capacity, however, the size of the stored component has decreased more recently, due to inflows being less than the long term average (Marsden and Pickering 2006) and a lower rate of growth in storage capacity (and hence supply capacity) relative to the growth in demand (WSAA 2005). Currently seasonal variability is being addressed with water restrictions — in many areas this has resulted in more punitive restrictions being imposed than the restrictions already in place to address the shortage due to the imbalance between average aggregate demand and supply.

Investment in water supply augmentation is 'lumpy' as large capital works are built that are not divisible into incremental units. An investment is efficient when the benefits of increased consumption outweigh the costs. Sometimes, due to the lumpy nature of investment, an investment may be efficient and result in excess capacity. However, excess capacity that, on average, results in the costs of augmentation outweighing the benefits of increased consumption is inefficient. Figure 3 illustrates the case of a lumpy supply augmentation from S_1 to S_2. When demand increases from D_1 to D_2 the annual benefits of increased consumption (the black-outlined triangle) are outweighed by the annualised cost of the augmentation (the hatched rectangle). This augmentation would result in excess capacity (Q_2 to Q_K), however, because the cost of augmentation outweighs the benefits the investment would not be efficient. Over time as demand increases to D_3 the annual benefits of increased consumption (the grey shaded triangle) will be greater than the annualised cost of the augmentation (the hatched rectangle). The augmentation would result in excess capacity (Q_3 to Q_K) but because the benefits of increased consumption outweigh the costs of augmentation the investment would be efficient.

Figure 3. Supply augmentation and excess capacity



Investments in excess supply capacity (although utilised during a water shortage and hence effective at reducing the probability or severity of a water shortage) may be inefficient and likely to be costly as a significant supply buffer may be required to remove the impact of seasonal variability. For example, the Economic Regulation Authority in Western Australia found that for the Water Corporation in Perth to eliminate the probability of a total sprinkler ban a supply buffer of almost 14 per cent would be required, while no supply buffer would result in a 3.75 per cent probability of a total sprinkler ban (Marsden and Pickering 2006). Investment in excess capacity that may be seldom used is likely to be expensive and inefficient. Instead, water options contracts may be a more efficient method to secure access to additional water, potentially lowering the cost of water restrictions to urban communities and delaying investment in additional capacity until it is efficient.

Moreover, delaying investment in additional capacity, even if the investment is efficient, may be beneficial. This is due to the intertemporal effects of annual changes in demand and supply. These small changes may mean that although it may be efficient to augment supply in the current period if the benefits of increased consumption are only just equal to the costs it may be prudent to wait until the benefits of augmentation significantly outweigh the costs of augmentation. Thereby delaying the investment by the length of time for which the options are used.

Urban water option contracts

Urban water options would be used for the purpose of increasing the reliability of the water supply system, as an alternative to acquiring permanent supplies on an annual basis. Option contracts would be used to tide over shortages caused by seasonal variability which may occur more frequently when little to no excess capacity is maintained. Options contracts could also be used for supply interruptions due to contamination or mechanical failure, however, they will have different probabilities of exercise and are not considered here.

How the option contract would work

An urban water option contract would involve an urban water utility buying a 'call' option contract from an irrigator. An option premium would be paid annually that gives the urban utility the right, but not the obligation, to buy (call) a set quantity of water from the irrigator at a set exercise price. The irrigator would retain ownership of the permanent entitlement.

A standard financial option is valuable, and would be exercised, when the market price of the asset exceeds the exercise price of the option contract. In the case of urban water option contracts there are two steps to the urban utility exercising the option. First, the scarcity value of water in the urban area must be greater than the exercise price and second, the exercise price must be lower than the market price in the rural area. If the urban scarcity value is higher than the exercise price, but the exercise price is higher than the market price, the option would not be exercised and the urban utility would buy water in the market.

The scarcity value of water would be the trigger for the option contract as it is the urban utility's supply situation that is used to trigger the option — as scarcity values are not actually observed (currently at least). The scarcity value of water is recognised in rural markets and is observed in the traded price of water. In the urban utility the supply demand balance provides a good proxy for the scarcity value of water. As a shortage increases the scarcity value of water may increase to a point where the value of water to the urban community is greater than the marginal value of water to irrigators.

For both parties (the irrigator and the urban utility) to enter the option contract they must have different expectations about the future value of water in the rural market. If they have the same expectations the option contracts will not work. In this case, if the exercise price is set higher than the expected market value of water the urban utility will not enter the contract on the expectation that the water can be bought for less in the market. If the exercise price is set lower than the expected market value of water the irrigator will not enter the contract on the expectation they would not be compensated (by way of the exercise price) for the marginal value of water. Hence, when entering an option contract the urban utility must have expectations of what the traded price of water will be at the time the water shortage occurs in the urban area.

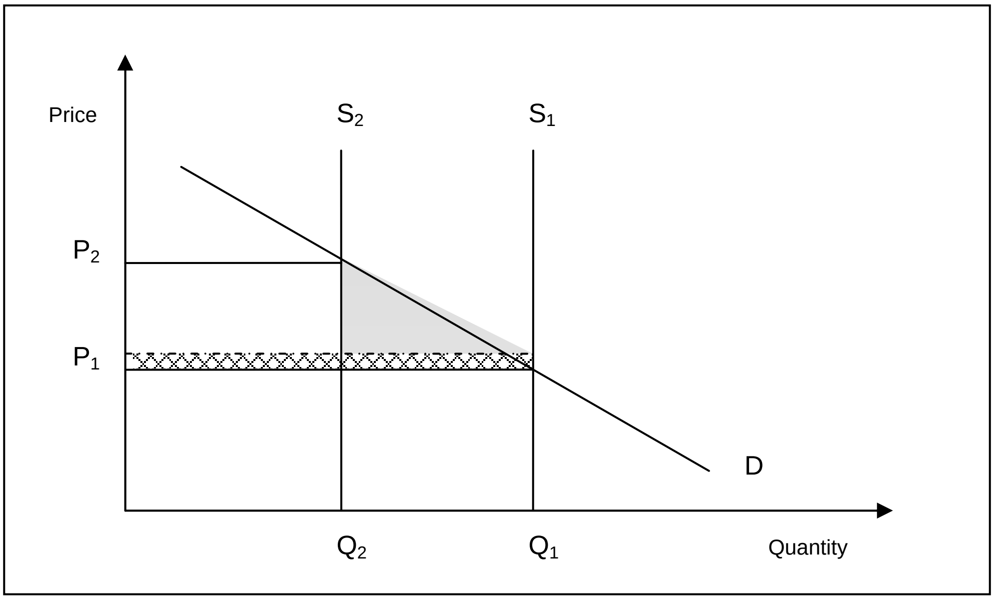
In practice it is unlikely that the urban utility would not exercise the option contract, in favour of buying water in the market. This is because it is likely to be difficult for the urban utility to enter the market and buy a large quantity of water. Further, this strategy would not provide an adequate level of supply security. The use of option contracts allow the urban utility to know in advance the quantity that would be available and the cost of sourcing the water. If the urban option contracts can not be valued in relation to the market another form of valuation is needed. As water can not be bought from the market the costs of other supply alternatives may be compared to the cost of exercise. The valuation of option contracts using this technique would still require two steps. First, the option contract is valued in relation to the other supply alternatives available — this analysis is in the following section. Second, the option contract is valued in relation to the market value of water and whether the benefits generated from accessing the option water would outweigh the costs of exercise. That is, at the point that the scarcity value of water in the urban area is greater than the exercise cost the increase in consumer surplus will be greater than the costs. In this way the change in consumer surplus may also be referred to as the value of the option.

An urban water option contract is a multiple exercise option. The option period or duration is determined by the nature of the variability the urban utility is trying to reduce. A long term contract, over a number of decades may be used to modify release rules from storages — maintaining less reserves in storage than would otherwise be held, to manage seasonal variability, or to delay augmentation (Lund et. al. 1995). Intermediate contracts, over three to 10 years, may be used to help reduce the susceptibility of the supply system to seasonal variability during the period prior to the completion of augmentation. The expected frequency of the variability will determine the probability of exercise.

The benefit of option contracts

The benefit to urban water consumers from the urban utility entering into the option contract is that more water is available which will either lead to an easing of restrictions, with the size of the saving dependent on the cost of meeting the restrictions, or a lower price if scarcity pricing is used. The absence or easing of water restrictions will reduce the opportunity costs of peoples time since a major cost of water restrictions is the time it takes to abide by restrictions (for example, hand watering instead of using automated sprinklers). If a scarcity fee were used to ration demand then the cost of water supplied through the option contracts would be lower than the scarcity fee (otherwise the options would not be exercised).

Figure 4. The benefit and costs of using option contracts during a drought



The effect of obtaining water from option contracts during a drought induced shortage is shown in figure 4. Supply falls from (S_1 to S_2) due to decreased inflows (while temperature and demand remain unchanged). The reduction of supply (S_1 to S_2) results in a water shortage (Q_1 to Q_2). The water shortage may result in either water restrictions or a scarcity fee for water (of the size P_1 to P_2). The option contracts will only be exercised if the costs of doing so are outweighed by the benefits. This is assessed by comparing the cost of the exercising the option contracts (the hatched rectangle), including both the exercise price and annual premium, with the size of the consumer surplus (the shaded triangle). In this example the benefits of increased consumption (consumer surplus) outweigh the costs of exercising the options and the option contracts would be exercised until the quantity of water Q_2 to Q_1 had been sourced to ease the water shortage. This may involve a number of contracts.

Conditions of option contracts

Option contracts will be possible in regions where rural water supplies can be accessed. Given this access it is likely (although not necessary) that the urban centre is located relatively close to the rural supply, perhaps in the same catchment or basin, and may experience similar climatic conditions. For example, a drought may decrease inflows into both urban storages and rural storages simultaneously. Such a correlation of inflows would mean that lower reliability entitlements would have relatively low allocations and that rural water prices would be high at the same time as the water shortage in the urban area. Hence, in the presence of this correlation the option contracts would need to be over rural water entitlements with high reliability. For example, high security water entitlements in New South Wales. Option contracts over high reliability entitlements will increase the likelihood that water is available in dry conditions. If the option contracts are over lower reliability water there is a greater chance that the option contract will not be honoured. For example if the allocation against the general security entitlement is not enough to honour the option contract, if it were exercised, the irrigator would need to buy water on the market to supply to the urban utility.

While the exercise price would have to be relatively high in a dry year to reflect the marginal value of water to irrigators this does not mean that options are not cost effective — this will be determined by comparison to other supply alternatives. If the relationship was permanently characterised by low correlation option contracts for lower values of water could be sought, or on lower reliability entitlements.

The seller of the option contract, here the irrigator, receives the annual option premium plus the exercise price for any water called when the option contract is exercised. In addition to the monetary compensation for surrendering water when called, the irrigator retains ownership of the permanent entitlement.

The underlying idea of the option contract is to create a risk sharing mechanism that ensures that the risk transferred from the urban utility to the irrigator is mutually beneficial (Gomez-Ramos and Garrido 2003). Irrigators are rewarded for bearing risk and urban utilities can increase system reliability at a more competitive cost than other supply alternatives.

The model

The valuation of an urban option contract is from the perspective of the urban utility because the purchaser must perceive benefits for options contracts to be feasible (Michelson and Young 1993). The objective of the urban purchaser is to minimise the expected cost of meeting an anticipated water shortage for a period of selected frequency.

The value of an urban option contract is derived by comparing costs of an option contract with the costs of the most likely supply alternatives. The valuation of option contract occurs in this way because the options can not be valued in relation to the market price for water as it is not possible to purchase the volumes required. The present value of an option contract is calculated using the following formula and follows the method used by Michelson and Young (1993).

$$V = \sum_{t=0}^{T} \rho_t \{[\mathrm{I}_{t=0} r + M - (1 - P_t)R]_t - E_t P_t + I_{t=0} - [I_{t=0}(1-\alpha)^T]_{t=T}\}$$

Where: t = year

T = contract termination year

ρ_t = discount factor, where $\rho_t = 1/(1+r)^t$

V = present expected value of the contract ($/ML)

I = investment cost of alternative to secure urban water ($/ML)

r = annual interest rate

M = annual maintenance cost of the alternative ($/ML)

R = residual value of water in non shortage years ($/ML)

E_t = exercise price ($/ML)

P_t = annual probability of exercising option ($0 \leq P_t \leq 1$)

α = annual rate of depreciation of alternative investment (per cent)

The present value of the option contract (*V*) indicates whether options are less or more costly than the supply alternatives. A positive present value indicates option contracts are less expensive than the alternatives, while a negative present value indicates that option contracts are more expensive than the alternatives and that the value of the option contract is worthless.

The alternative investment cost to secure water is the cost of the water infrastructure ($I_{t=0}$). In this analysis, the investment cost of the alternative is estimated from the levelised (annualised) cost of a range of representative infrastructure investments from three Australian cities; Adelaide, Perth and Sydney (Marsden and Pickering 2006). Although urban water option contracts may not currently be possible for Sydney, due to its lack of connectivity to a major irrigation system, the costs of supply alternatives for this city are included as an indication of the range of costs around Australia. The per mega litre infrastructure cost was calculated as the present value of a series of levelised (annualised) cost. A discount rate of five per cent and an economic life of 50 years were assumed‡. The per mega litre levelised cost and the calculated capitalised cost of the infrastructure for a range of augmentation alternatives are given in table 1. The per mega litre capitalised cost for the five lowest cost alternatives were used in the model; $2000, $4000, $11000, $15000 and $20000.

Table 1. Investment costs and capacities of supply augmentation investments

City	Supply alternative	Quantity GL[a]	Levelised $/ML	Capitalised $/ML [b]
Sydney	Appliance standards and labelling	13	100	2000
Sydney	Leak reduction	30	200	4000
Perth	Groundwater from Yanchep	10	600	11000
Perth	Groundwater from South West Yarragadee	50	800	15000
Adelaide	Piping from Clarence	60	1100	20000
Sydney	Desalination	180	1800 [c]	33000
Adelaide	Desalination	50	2200	41000
Adelaide	Water recycling – localised	60	5200 [c]	96000
Perth	Piping from Ord	150	6600	122000
Adelaide	Piping from Ord	220	7000	130000

Source: Marsden and Pickering 2006

a Quantities rounded to nearest 5. **b** Prices rounded to nearest 1000. **c** The lowest price was taken from the given band.

‡ $$P = A \cdot \frac{(1+i)^n - 1}{i(1+i)^n}$$

P = present value ($/ML), A = annualised payment ($/ML/year), i = discount rate, n = economic life in years

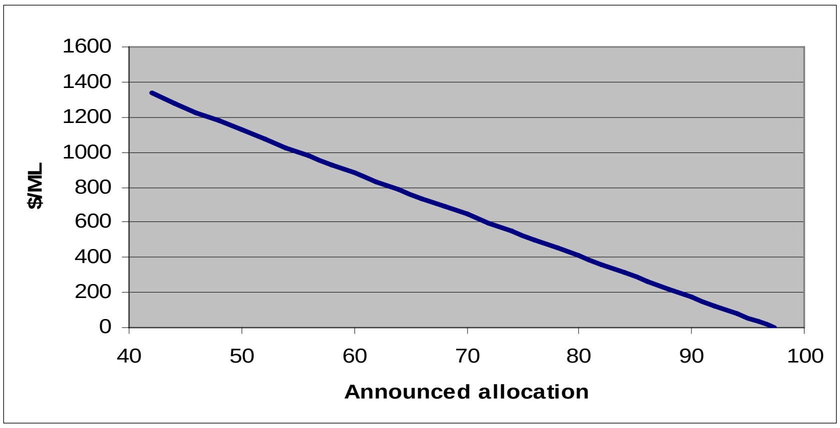
The opportunity cost of capital is calculated assuming an annual interest rate, r, of five per cent. This is the rate of interest that could be earned if the capital was invested in another asset with a similar risk profile.

The annual maintenance cost of the supply alternative (M) is assumed to be one per cent of the capital cost of the alternative investment. Anecdotal evidence indicates that this may be used as a rough approximation for water infrastructure, however, the maintenance costs for specific infrastructure were difficult to obtain. The maintenance costs may vary substantially across different infrastructure alternatives and is an area for further research and inclusion in future work. The effect of the maintenance cost is to increase the overall cost of the alternative, hence high maintenance costs would decrease the competitiveness of the alternative compared to the option contract.

The value of water secured with the alternative during non shortage periods $(1-P_t)R$, is assumed to be stored and sold at the corresponding levelised cost (see table 1) for that alternative (assuming that the price of water reflects the cost of supply). The effect of storing this water in years when there is not a shortage would be expected to decrease the probability of exercising the option contract, however, this was not accounted for in the model and is an area for further development of the model. The effect of this water is non shortage years is to decrease the overall cost of the alternative, and the higher the value of the water from non shortage years the more competitive the alternative compared to the option contract.

For each option contract the exercise price (E_t) is set in relation to the expected value of water to the urban utility. In this analysis a somewhat conservative approach was taken in valuing the option contract by using the marginal value of high security water as the option exercise price. The following exercise prices were used; $200, $400, $600, $850 and $1100 per ML. These prices reflect the marginal value of high security water at varying levels of announced allocations for high security water allocation in New South Wales, see figure 5. In using these values we are essentially assuming that the option contracts would be exercised when only a very small volume of general security water is available and hence market prices reflect the marginal value of high security uses (for example, horticulture). These marginal values for water were obtained from a model of irrigated horticulture, the method is described in Appendix A. A conservative exercise price may be used when valuing the option contracts in relation to other supply alternatives, to provide a prudent estimate of the value of the option contracts. However, in practice, it would be expected that the majority of option contracts held in the urban utility's portfolio would have exercise prices that reflect the marginal value of water when there are also general security allocations.

Figure 5. Marginal value of water and allocations for high security water in New South Wales



The annual probability of exercise (P_t) is assumed to be 0.3. This figure is the expected number of shortages over a ten year period for Canberra (CIE 2005). While this probability of exercise may be an over estimate the value of this parameter does not significantly changes the results, as reflected in the sensitivity testing below. It should be noted that it is possible that the option contracts could be exercised in sequential years, for example, two years in a row.

The annual rate of depreciation of the infrastructure (α) is assumed to be two per cent, assuming flat line depreciation over a 50 year economic life. Little information on depreciation rates for water infrastructure was found in the literature.

The analysis is conducted for a ten year and a thirty year contract period (T).

The value of the option is the difference between the investment cost of infrastructure, to provide excess supply capacity (after netting out the value of the asset at the end of the contract period and any benefits of water stored during non shortage periods) and the cost of buying the option contract. This value is calculated for the entire contract period by treating all variables in present value terms in two steps. First, for each year except the first and last, t = 1,2,…,T–1, the net benefit is calculated by taking the opportunity cost of the alternative ($I_{t=(0)}r$) plus maintenance costs (M) less the value of water stored in non shortage periods ($(1-P_t)R$) and subtracting the expected cost of exercising the option (E_tP_t). For the first year, t=0, the outlay on the infrastructure alternative, $I_{t=0}$, was added to this value, while for the last year, $t = T$ the cost of the infrastructure alternative at the end of the contract period $[I_{t=0}(1-\alpha)^T]_{t=T}$ was subtracted from this value. Second, the value of the option is obtained by summing the discounted annual net benefits over the contract period. The value of the investment alternative is expected to decrease due to depreciation. By buying an option contract the urban utility does not incur the loss of value in the alternative. This addition of the change in the value of the investment is more of a 'book' entry for the sake of comparison, as it is not likely that an urban water utility would be able to sell unwanted infrastructure — such as a desalination plant.

Results

Results for 10 year option contracts are presented in table 2. It can be seen that the value of option contracts are generally positive. For example, an option contract with an exercise price of $400/ML (which corresponds to the level of scarcity when high security announced allocations are 80 per cent) and an alternative investment cost of $11000/ML, is $5495/ML less expensive than the alternative in present value terms. This is equivalent to an income stream of $711 per year over ten years. The value of the option contract is negative when the alternative investment cost is relatively low and the exercise price relatively high. For example, an alternative investment cost of $2000/ML and an exercise price of $850/ML indicate that an option contract would be $840/ML more expensive than the alternative, and thus the option contract is worthless. A negative value indicates that the urban utility would be better off investing in the alternative investment, although for the majority of augmentation options positive values would be expected (the alternatives considered in the model are the lowest cost alternatives from table 1).

Table 2. The value of option contract ($/ML) – 10 year duration

Alternative investment cost	**Option exercise price $/ML**				
$/ML	200	400	600	850	1100
2000	741	255	-232	**-840**	-1448
4000	1969	1482	996	388	-220
11000	5982	**5495**	5009	4401	3793
15000	8437	7951	7464	6856	6248
20000	11223	10736	10250	9642	9034

Results for the 30 year option contracts indicate that they are more valuable than ten year contracts for all combinations of alternative investment cost and exercise price (see table 3). However, the perceived risk to the irrigator would be expected to increase with a longer commitment. For both the ten year and 30 year contracts the value of the option contract decreases as the exercise price increases, and increases as the cost of the alternative investment increases.

Table 3. The value of option contract ($/ML) – 30 year duration

Alternative investment cost $/ML	**Option exercise price $/ML**				
	200	400	600	850	1100
2000	1568	600	-369	-1579	-2790
4000	4105	3136	2168	957	-253
11000	12418	11449	10481	9270	8060
15000	17491	16523	15554	14344	13133
20000	35696	22299	21331	20120	18910

The value of the option contract for all results omits the cost of the option premium. The option premium would be expected to be negotiated by the urban utility and the irrigator. It is expected that the benefit to the urban utility from entering into the option contract would be split with the irrigator in such a way that the irrigator is compensated for their risk while the urban utility retains a benefit large enough to make the contract valuable. The transaction costs of the contract are not explicitly accounted for by the model and would reduce the overall value of the option contract.

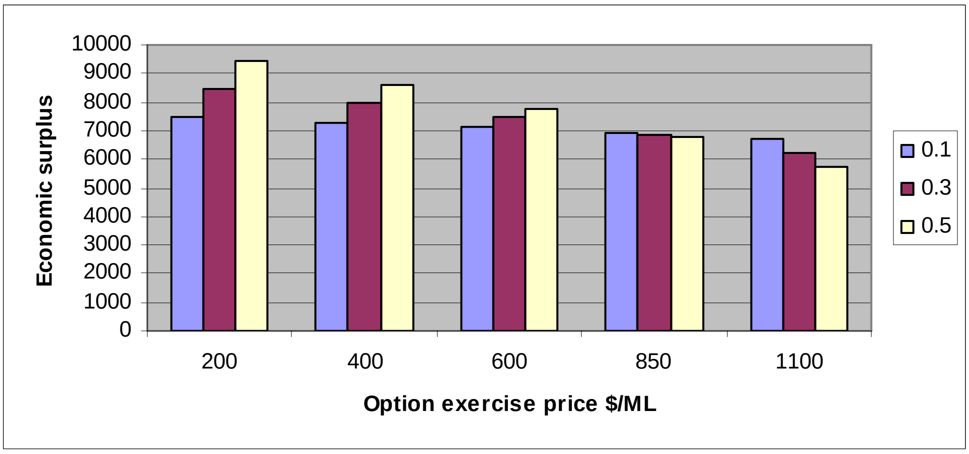
Given the significant benefit that the urban utility would receive from entering into option contracts, it is expected that after taking into account the effect of the option premium and contract transaction costs that option contracts would still be a more competitive method of sourcing water during a shortage caused by seasonal variability, for most combinations of alternative investment cost and exercise price.

Sensitivity testing

Given that seasonal variability can be unpredictable and that long term climatic change may result in changes to the nature of seasonal variability, the sensitivity of the results to changes in the probability of exercise is tested. The sensitivity test is conducted by holding all other variables constant while changing the expected probability of exercise. Both decreased and increased probabilities of exercise are considered, including a probability of 0.1 (one year in every ten) and 0.5 (five years in every ten).

The results for a ten year option contract, with the alternative investment cost of $15000/ML, is shown in figure 7. It can be seen that for each probability of exercise the value of the option contract decreases as the exercise price increases. This is because the exercise price increases the costs of the option contract relative to the alternative investment making the option contract less competitive. In addition to the downward trend in value for each probability of exercise, the values of the option contracts change in relation to each other as the exercise price changes. For example, when the exercise price is low (for example $200/ML) the low probability option (0.1) is the least valuable relative to the higher probability option contracts. When the exercise price is high however, (for example $1100/ML) the low probability option (0.1) is the most valuable relative to the higher probability option contracts. These changes are due to the changing relationship between exercise price and total exercise cost (which is determined by the probability of exercise) with the cost of the alternative investment.

Figure 7. Values of option contract with different probabilities of exercise, $15000/ML alternative investment cost



The probability of exercise is likely to change over time as the mix of rain dependent and rain independent water supply technologies changes. For example, the water production capability of a desalination plant is not affected by surface water inflows produced by rainfall. Although desalination plants, being energy intensive, are susceptible to energy supply and so a water supply system dominated by desalination plants may have an water option contract that relates the probability of exercise to energy supply variability to the plants (if energy supply variability was a problem).

Concluding remarks

Urban water option contracts are not valued in the way standard option contracts are — in relation to the market price of the asset. This is because in the case of urban option contracts the market can not be used to source water with an adequate level of supply security. Instead, the option contracts are valued in comparison to other supply alternatives and in terms of the changes to consumer surplus from their use.

Urban option contracts could be used to smooth seasonal variability and possibly delay investment in new infrastructure. Once familiarity with option contracts is gained and probabilities of exercise and exercise costs were better understood it may be possible for urban utilities to modify water release plans and hold less in reserve.

Option contracts offer a number of benefits. They provide a risk sharing mechanism that rewards irrigators for entering the contract and surrendering water when called, and improves the supply reliability of the urban water system. This benefits the urban consumers by reducing the opportunity cost of restrictions, reducing the price of water if scarcity pricing is used to clear the market, and by increasing consumer surplus by allowing consumption to be higher than it would be during a water shortage.

As noted in the model specification, the model could be developed further and a number of parameters could be refined. These include the benefit of the water in non shortage years, maintenance costs and depreciation rates for different infrastructures, the effect on the probability of exercise from water being stored in non shortage years if the alternative investment were made. Finally, the potential to use option contracts to modify release rules from urban storages, helping to further smooth urban supply.

Appendix A: Estimation of the marginal value of high security water in permanent horticultural crops

The marginal value of water in a horticultural region at different levels of allocation of high security entitlements was estimated by taking in to account that water is efficiently allocated between trees of different ages for each crop and between crops for the whole region. The approach taken thus implies that water trading occurs within the horticultural region and consequently the marginal values estimated represents the common market price for high security water in the region. The marginal values are derived by solving a model of the regional horticultural industries which incorporates, for each crop and age, a short run yield response to added water. An algebraic representation of the model is given as follows.

$$\underset{X_{it},Y_{it}}{\text{Max}} \ \pi = \sum_{it} A_{it}\left(Y_{it}P_i^o - X_{it}P^w - Y_{it}C_{it}\right) \qquad (1)$$

subject to

$$Y_{it} = R_{it}\left(a_i + b_i X_{it} + c_i X_{it}^2\right);\ \text{for } \nabla \ i \text{ and } t \qquad (2)$$

$$\sum_{it} A_{it} X_{it} \le \varpi \qquad (3)$$

Where;

π	=	short run annual profits from horticultural industries or returns to land, water and the fixed investment ($/year).
A_{it}	=	area of trees of age *t* of crops *i* (ha).
Y_{it}	=	yield of trees of age *t* of crops *i* (tonne/ha).
R_{it}	=	ratio of yield of trees of age *t* to yield of prime bearing age of crop

i (tonne/ha).

X_{it}	=	Volume of water used for trees of age *t* of crop *i* (Ml/ha).
P_i^o	=	Price of product of crops *i* ($/tonne).
P^w	=	Delivery charge for water ($/ML).
C_{it}	=	Variable production cost for trees of age *t* of crop *i* ($/tonne).
a_i	=	intercept term of yield response for trees of prime bearing age of crop *i* (tonne/Ml).
b_i	=	linear slope term of yield response for trees of prime bearing age of crop *i* (tonne/Ml).
c_i	=	coefficient on the quadratic term of yield response for trees of prime bearing age of crop *i* (tonne/Ml^2).
ϖ	=	high security water allocation for the horticultural region (Ml/year)

For each crop and age, the production technology or yield response to water is given in equation (3). The equation (4) states that the quantity of water applied for trees of all ages and crops in the region cannot exceed the regional water allocation. First order conditions for this short run profit maximization problem are derived as follows.

$$\sum_{it} A_{it} X_{it} \leq \varpi \text{ and } \lambda\left(\sum_{it} A_{it} X_{it} - \varpi\right) = 0 \qquad (4)$$

The complementarity slackness condition for the efficient allocation of water between trees of different ages and crops given in equation (4) states that sum over trees of all ages and crops, the annual water use cannot exceed the annual high security allocation for the region. If the annual water use in the region is less than the allocation then the value of water associated with this allocation constraint, λ is zero.

The optimization problem given in (1)—(3) is solved for a range of values for high security water allocation, ϖ and the resulting values for λ which are the marginal value water measured. The data used for various parameters are given in table A1.

Table A1 Data used

Parameter	Crop			
	Pome fruits	Stone fruits	Citrus	Wine grapes
Area (A_{it})	5705	14000	19871	70291
Output price(P_i^o)	1200	475	500	550
Water delivery charge (P^w)	40	40	40	40
Variable cost (C_{it})	800	294	200	238
Average water use (Ml/ha)	12	7.5	15	10
a_i	-7.09	-8.64	-3.78	0.95
b_i	8.26	10.23	4.45	4.10
c_i	-0.36	-0.70	-0.14	-0.20

References

ABS (Australian Bureau of Statistics) 2004, *Water Account: Australia 2000-01*, cat. no. 4610.0, Canberra.

Byrnes J., Crase, L. and Dollery B. 2006, ‘Regulation versus pricing urban water policy: the case of the Australian National Water Initiative’, *The Australial Journal of Agricultural and Resource Economics*, pp 437-449.

CIE (Centre for International Economics) 2005, *Economic benfit- cost analysis of new water supply options for the ACT*, Canberra & Sydney, April.

Lund J. R., and Israel M., 1995 ‘Water Transfers in Water Resource Systems’, *Journal of Water Resources Planning and Management*, vol. 121, no. 2.

Marsden J. and Pickering P., 2006 ‘*Securing Australia’s Urban Water Supplies: Opportunities and Impediments*’ Marsden Jacob Associates, November.

Michelsen, A. and Young, R. 1993, ‘Optioning agricultural water rights for urban water supplies during drought’, *American Journal of Agricultural Economics*, vol. 75, November, pp. 1010–20.

Quiggin J., 2005 ‘*Urban water supply in Australia: the option of diverting water from irrigation*’ Murray Darling Program Working Paper M06#3, presented at the State of Australian Cities Conference, Brisbane 1-4 December.

WSAAa (Water Services Association of Australia) 2005, *Testing the Water*, WSAA Position Paper No. 01, Melbourne, October.

WSAA (Water Services Association of Australia) 2006