Intelligent Software Development

Water Saving Incentives: An Agent-Based Simulation Approach to Urban Water Trading

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Abstract. New policies, such as urban water trading, have been proposed to manage water allocation among households in the current water crisis. Intelligent Software Development's (ISD) agent-based water network simulation, SIMULAIT WATER, was used to analyse urban water trading and water saving incentives. Agents represent households of various demographic types and their demand for water, modelling low, medium and high water users, or those in low, medium and high financial positions, respectively. Currently it is believed that charging a greater second tier price will provide an incentive for low water users to trade. Contrary to this notion, we found that further incentives were required to encourage low water users to trade. This could be achieved by reselling allocated water at a higher price than it is purchased. Such a scheme is also fairer because those in low financial positions will pay less as an incentive to save water, and those in high financial positions will have to pay more for traded water, also providing them an incentive to save water. Surprisingly we found that increasing the allocation of tradeable water could decrease overall water consumption. Finally we found that implementing a buyer administration fee rather than a seller fee when trading reduces water consumption of higher water users, and does not impact on households in low financial positions that use less water. The utility of SIMULAIT WATER has proven effective in analysing various pricing and trading structures that are financially beneficial and ultimately save water. The complex interdependencies of the many factors that influence water consumption and price makes SIMULAIT WATER critical in aiding with the analysis of this complex system.

1. INTRODUCTION

The sustainability of Australian water supplies presents a significant challenge for the future. New policies, including urban water trading, have been proposed to manage water allocation among households. With urban water trading households are given a set allocation of water [7]. Households that use less than their allocation may trade (or sell) their surplus water to households that require greater than their allocation. Households that require more than their allocation in addition to any traded water obtained must pay an expensive *scarcity price* per kL of additional water, where the scarcity price is adjusted depending on the scarcity of available water.

There are a variety of reasons to support urban water trading. Firstly, to facilitate a change in culture in Australia from one where water is considered a cheap and infinite, to one where water is a valuable and limited resource. Secondly, allowing market mechanisms to define the financial value of water depending on its scarcity will lead to natural adjustments in the use of water in times of crisis, and thus remove the need for (politically unpopular) water restrictions. Lastly, as the price of water increases with scarcity, entry of private industry into the water supply market will become viable. As a result, the responsibility of water supply will likely shift from governments to private industry, and encourage competition, and thereby innovation to identify efficient methods of supplying water.

Researchers have hypothesised that with urban water trading, as water becomes scarce, (a) households have incentive to trade as the scarcity price will be expensive; (b) high water uses have an incentive to find low cost water traded from other households [7]. Additionally, the impact of urban water trading parameters (e.g. allocation provided to households) on household water bills and consumption within different demographics is largely unknown.

In this study we investigate the water saving hypothesis of urban water trading, and analyse the impact of urban water trading on households. Intelligent Software Development's (ISD) advanced *agent-based* simulation tool SIMULAIT WATER was used to conduct the study. Agents are autonomous software programs that exhibit human-like behaviours, such as goal-directed, reactive and social capabilities [6]. Each agent can mimic the behaviour of individual elements (e.g. households) in a system, as well as their interactions (e.g. negotiations among households). In this study, agents in SIMULAIT WATER model individual households and their purchasing and water consumption behaviours. Three types of demographic household types were modelled: low water users and those low financial positions; average (medium) water users and those in average financial positions; and high water users and those in high financial positions. Agent simulations have been successfully applied to analyse various aspects of the environment, water systems and policies [1-5]. They have not however, been applied to investigate urban water trading, or pricing policies in the Australian context.

In our analysis, we challenge the current hypotheses regarding urban water trading. We find that although high water users have an incentive to obtain cheaper traded water, low water users do not have any incentive to use less water and trade to high water users. Incentives can be provided by allowing households to trade their water at a greater price per kL than they purchase it for. Such a scheme is also fairer because those in low financial positions will pay less as an incentive to save water, and those in high financial positions will have to pay more for traded water, also providing them an incentive to save water. We also found that increasing the allocation of tradeable water given to households could decrease overall water consumption. A tradable water allocation that is too low will prevent opportunities for households to trade and save water. Finally we found that implementing a buyer administration fee rather than a seller fee when trading is beneficial and fairer. It reduces water consumption of higher water users, and does not impact on households in low financial positions that use less water.

The utility of ISD's agent-based water network simulation SIMULAIT WATER has proven effective in analysing various pricing and trading structures that are financially beneficial and ultimately save water. The agent-based simulation is unique in both its approach and its functionality for analysing water policies and systems as it: models the higher-level and intangible factors required for strategic water infrastructure and policy planning, including economic, political (i.e. water policy), environmental, human and social elements which are an integral parts of a water systems. Additionally it provides an architecture that can model a complex distributed water network which can be difficult using mathematical models or similar approaches. Therefore SIMULAIT WATER is ideal for analysing strategic water infrastructure and policy planning.

2. SIMULATION MODEL

Our simulation comprises 3000 agents that represent individual households, one agent that represents a water authority who sets the pricing policies and charges for water, and an agent to represent the water supply that distributes water to households. The 3000 household agents comprised of 1000 each of low, medium and high demographic types (which we will refer to as low, medium and high households). Households' water consumption and price payed is simulated over one year.

2.1 Household Agents

Each household agent comprises an economic model that describes the household's demand for water at a particular price. We base our agents on Adelaide households. The average water consumption under the current two tier pricing is 280 kL. In our model low, medium and high agents use 140 kL, 280 kL and 420 kL of water respectively. The elasticity (slope) of the demand curve is set at the lower, mid and higher range of the industry standard for the three types of agents. Therefore price fluctuations for low agents' have a greater influence on water consumption than high agents. The economic demand also considers a minimum amount of water required for essential usage, and a maximum price that the household can afford to pay for water.

We have also incorporated a *discount factor* into the household's economic demand model. The greater the discount the agent receives (i.e. the profit from trading/selling water), the greater the quantity of water the agent will be willing to save. Agents also have a minimum discount threshold which the agent needs to receive before it will consider saving any water. Low agents were given a lower threshold, and were willing to save a greater amount of water for the same discount, than high agents.

2.2 Urban Water Trading Scheme

Our simulation uses an *automatically pooled* water trading scheme. In this scheme households which save some of their allocation of water will have their savings automatically "traded", and the water pooled for higher water users to purchase. Such a scheme is an ideal first step, from a practical and cultural perspective, to a full trading system where households must (or can) trade directly with each other. Therefore households can "trade" without having to physically negotiate with other households. Households just use and pay for water as they currently do with the current two tier system. Over time, households are likely to become accustomed to trading directly with others (if given the option), as the infrastructure and appropriate systems are put into place to facilitate and simplify trading.

The two pricing schemes that were implemented are:

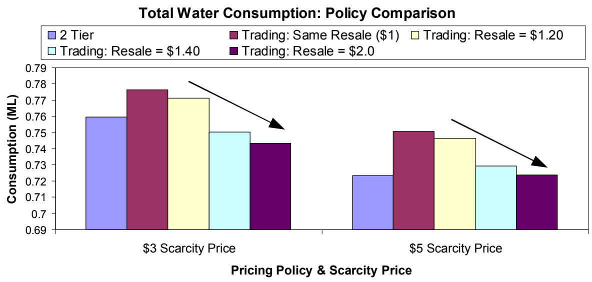
- *2 tier*: Households pay a supply charge plus $x per kL up to *u* kL (the first tier), and $y per kL thereafter (the second tier).
- *Tradeable water with scarcity pricing*: Consists of two tiers. The first tier has two rounds. In the first round agents are given an allocation *u* at $x per kL which they can trade. Any water which is not used in the first round is "traded" (possibly at a profit), and added to a pool of water for the second round of the first tier. In the second round, each agent who requires more than the first round allocated water gets another allocation of non-tradable water, which is the pool of water evenly distributed among the agents. Any savings in the second round is again pooled and distributed, and this repeated until all the second round of water is allocated. In the second tier each agent pays a scarcity price $y for each additional kL of water. In addition to the per kL price of water, households pay a supply charge, a seller administration (which we denote *admin*) fee every time water is

traded, a buyer admin fee every time traded/pooled water is purchased.

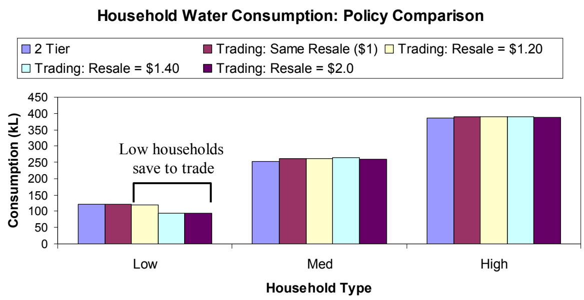
3. WATER SAVING INCENTIVES

In this section we show the results of simulations using 2 tier and tradeable water policies (Figure 1). Individual household water bill and consumption, as well as total water consumption from all households, is presented. A first tier allocation of 200 kL was used at $1 per kL, and a second tier (or scarcity price) of both $3 per kL and $5 per kL. The supply charge is $160 and there is no buyer or seller admin fee. The resale price is the price that water is traded at (sold and purchased). Individual household water bill and consumption for a $5 per kL second tier price show similar trends as Figure 1 (B) and (C) (data not shown).

(A)



(B)



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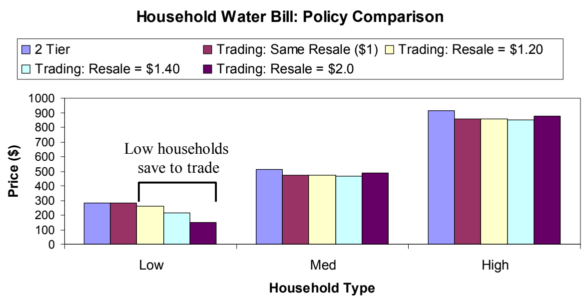


Figure 1: Comparison of household water and bills consumption with different pricing policies.

We first compare 2 tier and trading with same resale price in Figure 1. The total water consumption by all households actually increases with trading compared to the two tier policy. This is exaggerated when the scarcity price increases, which contradicts the hypothesis that a trading scheme with high scarcity price will reduce water consumption. The reason for this behaviour is that low water users in both policies will consume equal amounts of first tier water at the same price, and trade the remainder of their allocation. There is no incentive for low water users to trade more. Medium and high water users *do* have an incentive to trade and attain cheaper water, as has been hypothesised. With trading higher water users will have access to cheaper water traded by low water users, rather than paying the expensive second tier scarcity price as with the two tier scheme. Therefore medium and high water users will effectively use more water.

Although there does not seem to be an incentive to save and trade water with the trading pricing policy, the scheme does provides the flexibility to save and trade water if required – if the appropriate incentives are put in place.

In order to provide incentives for households to save water, we propose that households can re-sell their tradable water allocation for a higher price than they purchase it for. Therefore the greater the first tier water allocation that is saved, the greater the *discount* they will receive in their household water bill. Figure 1 also shows the results of the trading policy with a tradable resale price of $1.20, $1.40 and $2. Figure 1 (A) shows that the total water consumption from all households decreases with increasing resale price. This occurs because low water users now have an incentive to trade water as they can receive a discount (or profit) for doing so. Higher water users use similar or less water because they are paying a higher price for traded water, also providing an incentive to use less water. Such a pricing policy seems fairer than the 2 tier scheme because users in low financial positions save money in order to save water, while those in higher financial positions pay more for their additional water, which also provides an incentive to save water.

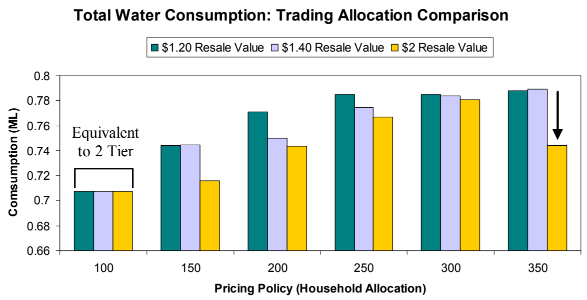
If implemented, the tradable water resale price, in addition to the scarcity price, can be dynamically adjusted according to water scarcity to control water consumption. The first tier purchase price should be fixed so that all households can have access to reasonably priced water for essential needs.

Our simulations also identified non-typical economic behaviour that may result from a trading scheme with a very high resale value. Low households economic behaviour becomes one where their demand has a positive elasticity. As a result their economic demand transitions from a typical "pay more demand less" decision making behaviour to an atypical "pay less demand less" decision making behaviour. Therefore households, who have an incentive to pay less (reduce their costs), are able to do so while reducing their demand for water (where the demand for water in this situation would typically increase).

4. TRADING ALLOCATIONS & PRICE

Simulations were run comparing the effect of varying household water allocations and price, and their impact on household water bills and consumption. A first tier price of $1 per kL and scarcity (second tier) price of $3 per kL were used. The supply charge is $160 and there is no buyer or seller admin fee. Results are presented in Figure 2.

(A)



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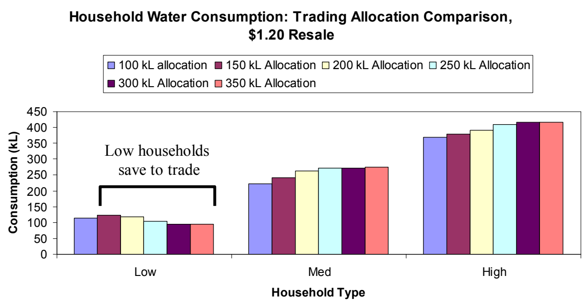

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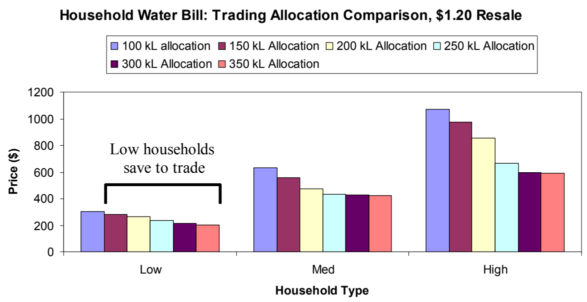
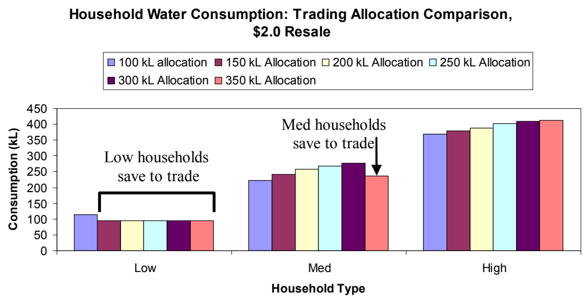


(D)



(E)

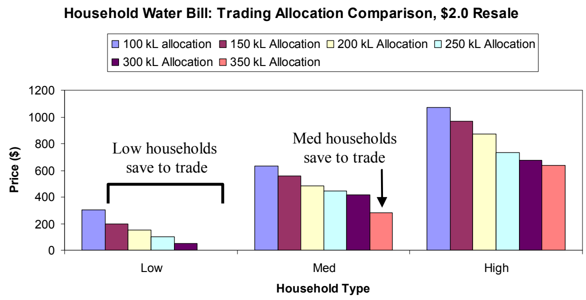


Figure 2. Comparison of household water bills and consumption with different tradable allocations and resale price using the trading price policy.

Figure 2 (A) shows that a low household water allocation provides the lowest water consumption. When the allocation is too low (near households' minimum essential water requirement) households must use their entire allocation, and thus do not have any opportunity to trade. In this situation, all households require more water than their allocation, and therefore must pay for expensive scarcity water. Overall, water is expensive and households' bills are large for all demographic types, resulting in low water consumption. Such a pricing scheme can be considered equivalent to a 2 Tier scheme where $1 per kL is paid for the first 100 kL, then $3 per kL thereafter, and no water is traded.

Figure 2 (B) and (D) show that increasing household water allocation reduces water consumption (until the minimum water requirement is met) by low water users. This is due to low water users having sufficient water to trade and return a sizable discount such that they are willing to save an even larger quantity of water. Medium and high household types increase their consumption as the water allocation increases due to the availability of less expensive (than scarcity price) water traded by low water users. This results in an overall increase in water consumption as the water allocation increases, as shown in Figure 2 (A).

However, in Figure 2 (A), the total water consumption decreases for the highest water allocation and highest resale value. This is due to medium households commencing to save and trade water (Figure 2 (D)). As with low water users, medium household types now have sufficient water to trade, and the resale price will return a suitable discount such that they are willing to save and trade water. High water users in this case increase their water usage they have access to more less expensive tradable water from both low and medium households.

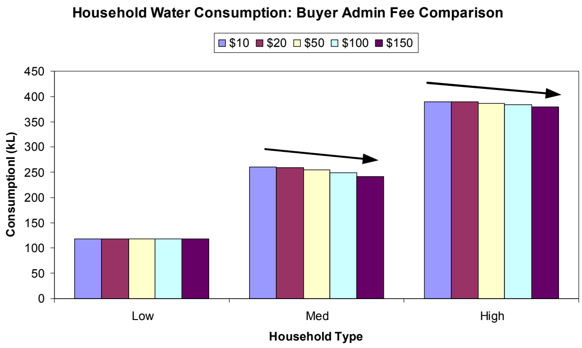
The resale price and/or allocation can be adjusted such that the high water users will have incentives to save and trade water, reducing water consumption further. In this extreme case, all household types will need someone who would be willing to buy their tradable water. This could potentially be irrigators, industry or Government.

Household water bills for all demographic types decrease as water allocations increase.

5. SELLER AND BUYER ADMIN FEES

In this section we analyse the impact of buyer and seller admin fees on households. Simulations were run using first tier price of $1 per kL and scarcity (second tier) price of $3 per kL, a supply charge of $160, and a water allocation of 200 kL. The results of simulation are shown in Figure 3.

(A)



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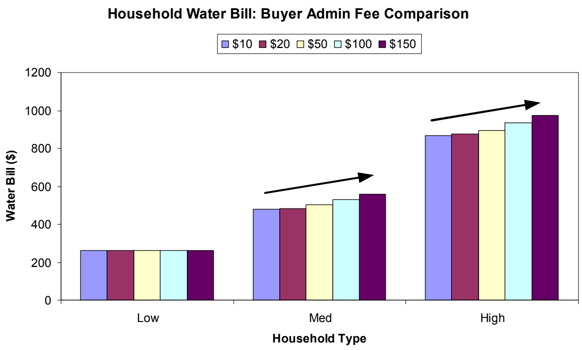

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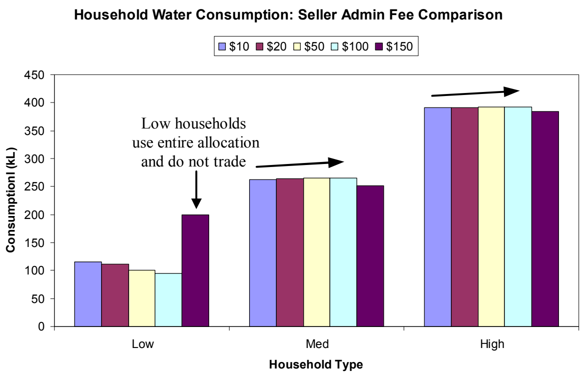

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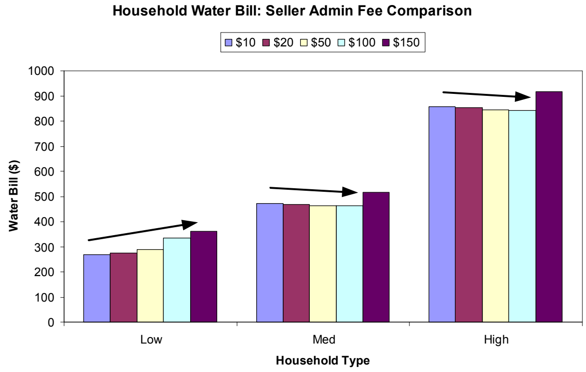

Figure 3: Comparison of buyer and seller admin fees for a trading price policy.

From Figure 3 (A) and (B), as the buyer fee increases, tradable water becomes more expensive for medium and high households, and thus their consumption decreases and household water bill increases. The buyer fee has no impact on low households. They continue to save and trade water, and their consumption and water bill remains constant.

From Figure 3 (C) and (D), as the seller admin fee increases, low households consume less water because water is effectively more expensive. As a result, they will demand less *and* they will need to save more water in order to receive a sufficient discount. If the seller fee is too high ($150 in the figures) then low households are better off (in terms of price) using all of their allocation (likely more than they require) rather than trading. Water usage by medium and high households increase with increasing seller fee due to greater access to inexpensive water as a result of not paying any admin fee and a greater quantity of inexpensive water traded by low water users. However, at the highest seller fee ($150 in the figures), medium and high household consumption decreases. This is due to low water users consuming their entire allocation of water and not trading. Thus medium and high households must pay the expensive scarcity price for their additional water, encouraging them to use less water. Low household water bills increase with increasing seller admin fee, while medium and high households decrease until the seller fee threshold is reached when low households no longer trade.

From our results, implementing a buyer admin fee is more beneficial and fairer as it decreases water consumption by medium and high water households, and does not impact on low water users.

6. CONCULSION & FUTURE WORK

ISD's agent-based simulation SIMULAIT WATER was successfully used to analyse water saving incentives of urban water trading among households of differing demographic types. It was hypothesised that increasing the scarcity price would provide low and high water users an incentive to trade. However, using our model we found this was not the case with low water users, and they required further incentives to use less water and trade. This can be achieved by reselling allocated water at a higher price than it is purchased. Such a scheme is also fairer because those in low financial positions will pay less as an incentive to save water, and those in high financial positions will have to pay for traded water, providing them as an incentive to save water.

Additionally we found that increasing the allocation of tradeable water could decrease overall water consumption. A greater allocation provided households more scope to trade, greater discounts (profit) capability, and thus more water saving incentive. A tradable water allocation that is too low will prevent opportunities for households to trade and save water. Finally we found that implementing a buyer administration fee rather than a seller fee when trading is beneficial and fairer. It reduces water consumption of higher water users, and does not impact on households in low financial positions that use less water.

The utility of ISD's agent-based water network simulation SIMULAIT WATER has proven effective in analysing various pricing and trading structures that are financially beneficial and ultimately save water. SIMULAIT WATER was able to effectively model the economic, political, social (demographics and household negotiations) elements of water policies. The complex interdependencies of the many factors that influence water consumption and price is what makes SIMULAIT WATER critical in aiding with the analysis of this complex system. Obtaining the same insight would be extremely difficult with crude and manual analysis.

Further work includes analysing alternative water trading approaches and parameters in a detailed demographic model of a specific city (or cities). Other elements that require further investigation include: analysis of trading among individual households, in addition to the automatically pooled trading; a two price resale system where sellers sell at one price (e.g. $1.20) buy buyers buy at a higher price (e.g. $3); a combination of restrictions, scarcity pricing, and admin fees; and to include large water users in the model, such as industry.

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