Estimating Temporary Water Trading Impacts through Integrated Modelling

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EXTENDED ABSTRACT

Temporary water trading is an established and growing phenomenon in the Australian irrigation sector. The most established and active temporary water markets are located in northern Victoria and southern New South Wales.

The impacts of such water transfers are expected to vary temporally and spatially. The aim of this paper is to specify a method to assess these impacts. Although water trading and its impacts have been discussed qualitatively in the literature; there are limited qualitative models available. In the past economists primarily modeled water trading without considering biophysical and systemic constraints. On the whole, these approaches overlook the important fact that the physical transfer of water does not occur at the same time as the economic (or "paper") trade. However, integrated modelling frameworks are suitable for representing the complex interactions between economic drivers and the biophysical processes underlying water markets.

In this paper an integrated approach is taken, where an economic model is linked to a hydrologic network simulation model. The economic model incorporates key trade drivers: commodity prices, allocation percentages and irrigation deliveries. The quantitative relationship between these drivers and the volume traded were derived from econometric analyses of past trading data. The hydrologic model is the Goulburn Simulation Model (GSM), which is based on the Resource Allocation Model (REALM) framework. It incorporates water delivery system properties and operating rules for the main irrigation and urban centres in the catchment area.

The integration framework (Figure 1) links the two models dynamically on a monthly basis. The economic model takes outputs from the water allocation model in order to calculate traded volumes. The water allocation model then takes this output from the economic model and routes the traded volumes to/from relevant nodes.

This integrated model is designed to be an aid to water managers in the region so that they can incorporate water trading impacts in their decision-making processes. This integrated model was calibrated on the Goulburn-Broken Catchment and found to be effective at estimating the impacts of temporary water trading.

Simulations were conducted for wet and dry spells, a range of commodity prices and different distribution system configurations. From these analyses potential bottle-necks to trade that constrain the economic benefits from temporary water trading were identified. Furthermore, it was found that in certain areas of the system, temporary water trading can make the impact of long drought spells worse.

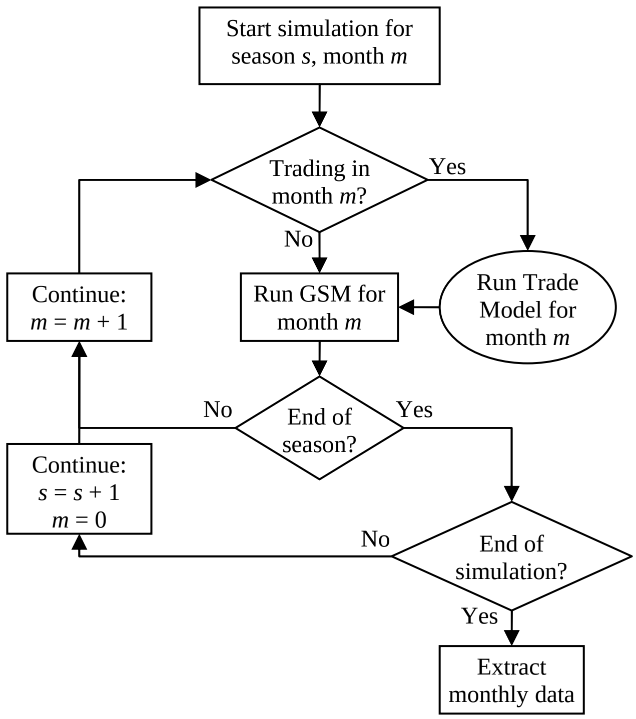


Figure 1. Simulation process of integrated model

1. INTRODUCTION

Initial attempts at modelling temporary water trading have focused on incorporating the economic drivers and elucidating potential benefits (Hall *et al.* 1993; Eigenraam *et al.* 1996, Tisdell 2001). These approaches tended to overlook the important fact that the time of trade and the time of physical water transfer are often not the same. The latter tends to occur when the buyer requests the water from the water supply authority.

On the other hand, the two main biophysical modelling frameworks used in Australia, IQQM and REALM, do not have an endogenous water trading feature. This limitation of existing water allocation models has required an integrated approach to modelling temporary water trading.

Thus more recently, attempts have been made to model trading in a more integrated manner (Yu *et al.* 2003; Weinman *et al.* 2004; Wijedesa 2004; Zaman *et al.* 2005b). These approaches attempt to combine the key economic trade drivers with the biophysical constraints in which trading occur. These constraints include capacities of irrigation channels, reservoir management rules, delivery priorities, environmental flow requirements, water sharing arrangements, etc. Through integrated modelling, it is possible to identify and quantify the impacts of temporary trading on the irrigation system and *vice versa*. Thus, such an integrated model can enhance decision support capabilities of water resource managers and policy analysts.

This paper presents some preliminary simulation results of an integrated model developed for the main trading area in the Goulburn-Broken Catchment. First the two components of the integrated model are described. Then the details of the integration procedure are given. In section 4, the results of the base and trade scenarios are summarized. Details of trading impacts are discussed in section 5. We conclude the paper with some policy recommendations.

2. COMPONENT MODELS

The integrated model has two main components: an economic trading model and the Goulburn Simulation Model (GSM), which is a water allocation model.

2.1. Economic Model

The economic model was developed through econometric analyses of historic trading data. The economic model has been developed specifically for Zone 1A of *Watermove*. This is an online water exchange used primarily by irrigators in northern Victoria. Zone 1A covers the main irrigation districts in the region: Central Goulburn, Shepparton, Rochester and Pyramid Hill – Boort. Details about this exchange and its institutional background have already been reported in the literature (DSE 2001; Zaman *et al.* 2005a).

A similar economic model has been reported in Zaman *et al.* (submitted). The economic model presented in this paper is different in terms of the parameter values of the underlying trade volume and price functions. The specifications of the two functions used in this economic model are as follows:

$$P_t^{WM} = 1.99\, P_{t-1}^{F} - 0.90\, P_t^{B} - 10.11\, MI \quad (1)$$

(t-stat) (20.6) (-10.7) (-6.8)

$R^2 = 0.88$, F-stat=260, d=1.9, SE = 43, N=60

$$Q_t^{T} = 0.04\, AD_t^{Sys} + 0.31\, Q_{t-1}^{T} - 7.68\, A_t + 6.51\, A_{t-3} \quad (2)$$

(t-stat) (8.2) (3.7) (-3.5) (3.7)

$R^2 = 0.89$, F-stat=121, d=2.1, SE = 406, N=60

Where:

P_t^{WM} = average monthly water market price for month t;

P_{t-1}^{F} = average monthly feed price in previous month;

P_t^{B} = average monthly beef price in current month;

MI = month index (August =1).

Q_t^{T} = average weekly trade volume in month t;

AD_t^{Sys} = average weekly volume through Goulburn System in month t;

Q_{t-1}^{T} = average weekly trade volume in previous month;

A_t = average monthly allocation in month t; and

A_{t-3} = average monthly allocation three months previously.

Details regarding the data sources and significance of the parameters in the above functions have been reported in Zaman *et al.* (submitted). The only difference in the model used for this paper is the omission of the regression constant in both functions and the inclusion of the first three months of the 1998/9 season during calibration of the model. Thus, this model calibrated based on trading data for five seasons (1998/9 to 2002/3).

It is important to note that when the price function estimates a value equal to or less than zero, the model assumes no trade takes place in that month. Similarly, when the trade volume function estimates a value equal to or less than zero, the model economic model assumes that no trade takes place in that month. The economic model has been coded into an executable program, which is run in parallel with the water allocation model.

2.2. Water Allocation Model

The Goulburn Simulation Model (GSM) represents the main features of the irrigation water supply system and river channels in northern Victoria in a network of nodes and arcs (links).

This model is used planning and policy analyses by State agencies and rural water supply authorities (DSE 2003). As mentioned earlier, GSM does not have temporary water trading capability in-built. The work recently completed by Weinmann *et al.* (2004) has addressed this problem. However, the integrated model presented in this paper is different in that the economic model is different and the integration time step is monthly.

In GSM, the main urban and irrigation centres (areas) are represented by nodes. Two or more irrigation nodes combine to make an irrigation district, e.g. the Central Goulburn district consists of the Rodney, Deakin and Tongala nodes. One or more irrigation district combines to make a water trading zone in *Watermove* (Figure 2).

3. INTEGRATED MODEL

The philosophy behind the integration method is to enable temporary water trading to be modeled as representing irrigators' desires to:

- Change their water availability during the irrigation season; or
- Adjust their crop water requirements as the season progresses.

These changes can be due to various seasonal conditions. Either of these desires can be the driving factors for sellers or buyers in the temporary water market. For instance some farmers, who tend to use less water than their permanent water entitlement, may feel that the seasonal conditions allow them to sell some of their allocated water – thus reducing their water availability. On the other hand, another set of farmers may feel that the price of their goods is so low then they may reduce their cropping areas and sell that water saved in the market.

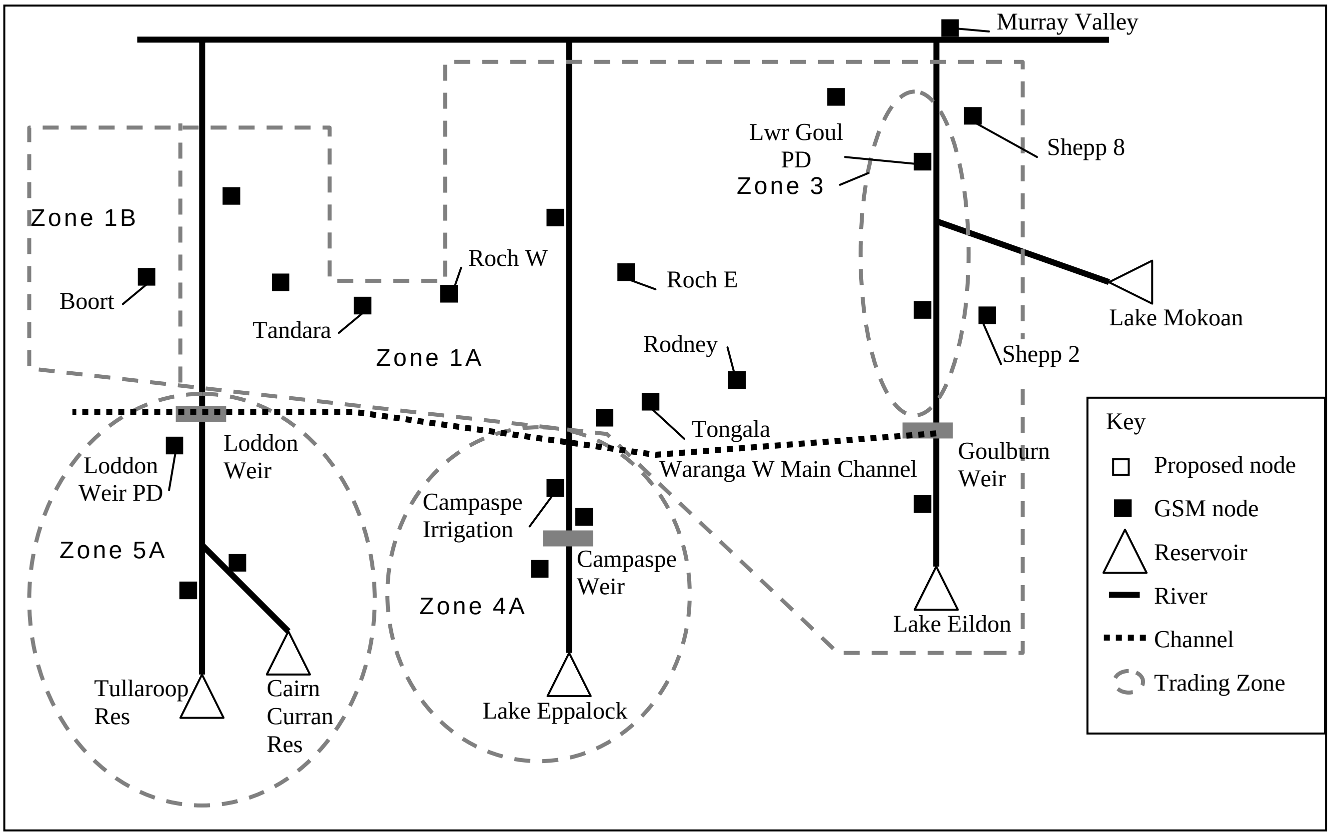


Figure 2. GSM nodes and trading zones

Application of this trading philosophy at GSM nodes required some aggregation due to certain data limitations. For example, the market data did not specify the usage of the traded water. Also, at each GSM node, crop areas are not specified, rather a lump some volume of water is estimated as the total crop water requirement. Thus it was not possible to represent individual traders in each irrigation area but the net trade volumes were the key measures of the integration process.

The integrated model is essentially the GSM run with the trade model called as an external routine at the end of each month during a simulation. After the total Zone 1A trade volume is estimated, the net volumes at each node are calculated based on historic trade distribution data. Then at each node, the annual water use limit is adjusted by the net trade volume (up for buyers and down for sellers). This represents changes in water availability at the node as restriction curve is calculated from the annual water use limit in GSM. The total crop water estimate for that month is also adjusted by the net trade volume. More details about the restriction curve and crop water estimates used in GSM can be found in the users' manual (DSE 2003). Figure 3 shows the outcome of the integration process for a net buying node in an irrigation season. These changes should result in more water being delivered to the node, compared to the situation when GSM was run by itself.

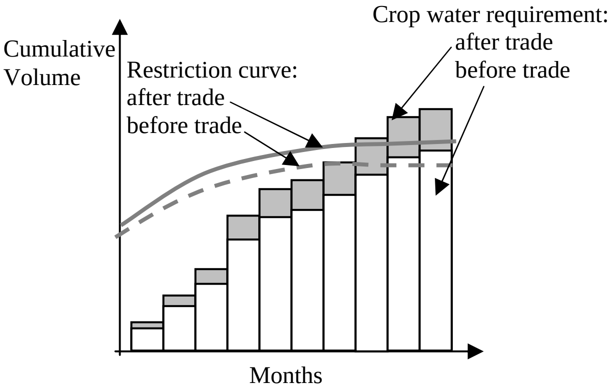


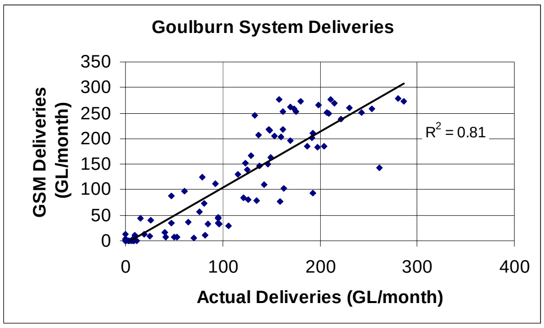
Figure 3. Integration process for a buying node

4. SIMULATION RESULTS

The simulations commenced at the start of the 1994/5 season. This was the first season in which the Muray-Daring Basin Cap was implemented (DNRE 2001). Also from this season, temporary water trading had increase considerably, compared to earlier seasons. The simulations ended with 2002/3 season as this was the extent of the data files available for GSM. This simulation period covers spells of high and low allocations, as well as a range of key commodity prices.

4.1. Base Scenario

The base scenario consisted of running GSM by itself. This was the no-trade scenario. Although GSM is not used for the day-to-day running of the irrigation system, one can compare the simulated deliveries and allocations with actual data to see how well the model represents the actual system (Figure 4). Over the nine seasons, GSM achieved a high degree of correlation with the actual irrigation deliveries in the Goulburn system. The modeled allocations in GSM were also highly correlated with actual allocations (Figure 4). In this context, the Goulburn system consists of the four main irrigation districts in the catchment: Central Goulburn, Shepparton, Rochester and Pyramid-Hill Boort. This shows that GSM replicates the irrigation system of the Goulburn-Broken Catchment quite well.



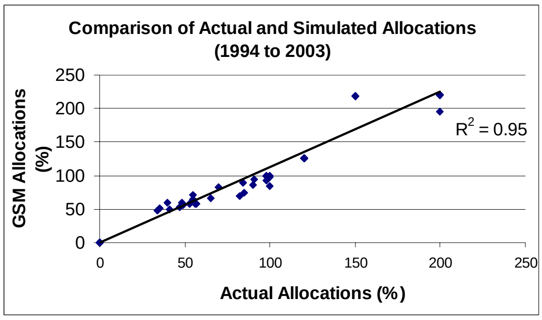


Figure 4. Base scenario results

4.2. Trade Scenario

The trade scenario consisted of running the integrated model for the nine seasons. The impacts of trading were determined by comparing the flows in the system in this scenario with the base scenario.

The first step is to determine whether all the trades were successful, i.e. did the paper transactions in the water market translate to physical transfers of water in the allocation model (Table 1)? In the first five seasons, the traded volumes tended to be constrained, particularly in the 1994/5 and 1996/7 seasons. This was not surprising as these seasons had the highest allocations in the simulation period. Thus the irrigation channels tended to operate at full capacity, particularly in the summer months. This limited the amount of traded water that could be delivered in these seasons. The main constraints to temporary trading tended to occur in the summer months (December to February). The bottlenecks tended to be on the Waranga Western Channel and immediately downstream of Goulburn Weir.

Table 1. Trade scenario results

Season	a	b	c	d	e	f
1994/5	76,920	13	18	-6	5	
1995/6	63,326	5	14	3	4	
1996/7	70,048	28	9	21	4	
1997/8	71,349	2	12	-25	6	
1998/9	52,332	1	4	-2	5	28,074
1999/0	48,247	0	2	-7	5	40,346
2000/1	50,421	-4	2	19	4	54,309
2001/2	48,576	-6	4	-25	5	48,743
2002/3	36,262	-12	14	-48	6	42,659

Notes:

a. Total estimated Zone 1A trade volume (ML)
b. Trade volume constrained as % of total Zone 1A trade
c. Total estimated Zone 1A trade value ($m)
d. Net loss in water value as % of total trade value
e. Trade volume as % of Goulburn System delivery
f. Actual Zone 1A trade volume, which began in 1998/9 season.

In the last three seasons of the trade scenario, the changes in delivery tended to be greater than the volumes traded (hence in the table these are shown as negative values in column 'b'). The integrated model identified several spatial and temporal knock-on effects of trade that account for these system responses. Essentially, temporary trading alleviated some existing delivery system constraints and compounded others. In these three, relatively drier seasons, trading allowed the farmers to be more flexible with their water usage and in their management of water availability. As a result, more water could be diverted from willing sellers and delivered to willing buyers.

These additional deliveries, on top of the traded volumes, are considered as indirect benefits of trade in this modelling exercise. Thus, in column 'd' in Table 1, the negative values represent seasons where the additional benefits from trade exceed the losses from trade constraints. This result also highlights some of the tradeoffs taking place within a trading zone. The loss in water value, arising from bottleneck to trade, are sometimes compensated by more water going to / sold from another area leading to a net social benefit over the whole catchment.

In terms of matching actual deliveries, the integrated model performs better, but the improvement is not statistically significant. The overall correlation for the nine seasons remains at 0.81. This is not surprising considering traded volumes represent only a small percentage of total deliveries in the Goulburn System (column e of Table 1). This is arguably one of the key results of this research. Although temporary water trading adds value to water in irrigation areas (column c, Table 1), it is very much a marginal activity. The results of the integrated model show that even in low allocation seasons, with high commodity prices, the volumes traded do not exceed 6% of total system deliveries.

It was also noted that the integrated model estimates of temporary water trading, which took into account constraints and knock-on effects (column a adjusted by column b), were closer to the actual traded volumes (column f) than the outputs of the econometric model (column a). The only exception was the 2001/2 season, when the econometric model estimate was closer to the observed data.

5. KEY TRADING IMPACTS

The key trading impacts were on allocations in drought years and the alleviation/deterioration of existing delivery system bottlenecks.

5.1. Impacts on allocations during droughts

Trading in the earlier seasons resulted in lower starting volumes in the reservoirs of subsequent seasons. This resulted in lower allocations than in the base scenario for the latter seasons in the simulation period. This impact can be seen in the allocations of the 2002/3 season (Figure 5).

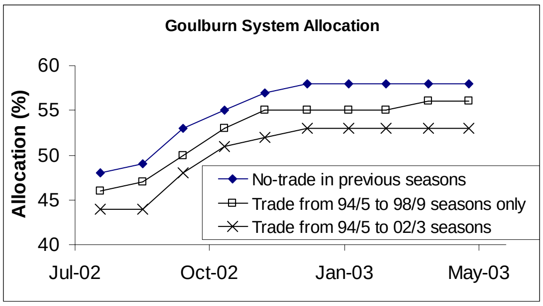


Figure 5. Trading impact on Goulburn allocation

After simulating temporary trading for the nine years, the allocations in the 2002/3 season had decreased by four to five per cent points compared to the base scenario.

This knock-on affect is dramatic in drought years when the reservoirs are not refilled. For instance the impact of temporary trading during the first three seasons was ameliorated by the heavy rainfalls during the 1996/7 season. However, from that season, there were no really wet seasons and therefore the additional usage of water in the drier years compounded the effect of the drought in 2002/3.

5.2. Impacts on delivery system bottlenecks

In some seasons, temporary trading alleviated delivery bottlenecks identified in the base scenario (Table 2). For example, selling activity in the Pyramid-Hill Boort district removed the constraint just downstream of the Waranga Basin in November 1994. Also the channels from Goulburn Weir were full in the summer months, resulting in all downstream areas experiencing shortfalls in the base scenario. Although this section was still a constraint on deliveries in the trade scenario, selling activity in the Pyramid-Hill Boort district allowed more water to be diverted to the other districts.

Table 2. Net change in system bottlenecks

Season	Net decrease
1994/5	1
1995/6	4
1996/7	0
1997/8	-2
1998/9	2
1999/0	1
2000/1	-1
2001/2	-1
2002/3	2

Temporary trading also had the opposite affect on some sections of the delivery system. For example, in the 1998/9 season the section downstream of Goulburn Weir was constrained from December to January in the base scenario. However, in the trade scenario, this section was also constrained in February.

The ability of the integrated model to estimate this impact of temporary water trading is a key step in identifying some of the third party impacts. Some of these impacts are positive, e.g. selling activity from Pyramid-Hill Boort to Shepparton, allows more water to be delivered to Central Goulburn through the constraint downstream of Goulburn Weir. These impacts were quantified in the integrated model and given a value based on the market price estimated by the economic model. On the other hand, some impacts on third parties were negative, e.g. the deterioration of the constraint downstream of Goulburn Weir (in February 1999) meant that some irrigators could not get the water they required. This impact was also quantified and valued as a social cost.

6. CONCLUSIONS

The aim of developing an integrated trading model is to improve estimates of temporary water trading and its impacts on the irrigation system. An integrated model also allows water managers and policy analysts to determine the impact of the irrigation system on temporary water trading.

A simulation of nine season of temporary water trading in the Goulburn-Broken Catchment has identified some bottlenecks to trade. These tend to occur in the summer months and are located on the Waranga Western Channel and in the channels immediately downstream of the Goulburn Weir.

The main impacts of temporary trading on the irrigation system have been the decrease in allocations during drought spells and the alleviation/deterioration of some delivery constraints.

The results of the integrated model also highlighted that not all system bottlenecks result in trade bottlenecks. The economic model is required to identify the directions of trade, which would then determine which of the existing constraints are also trade bottlenecks.

The next phase of this research is to investigate the affect of uncertainties in model parameters on the results of the integrated model.

7. ACKNOWLEDGMENTS

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