COOPERATIVE RESEARCH CENTRE FOR **CATCHMENT HYDROLOGY**

MODELLING WATER REALLOCATION FROM TEMPORARY TRADING IN THE GOULBURN SYSTEM

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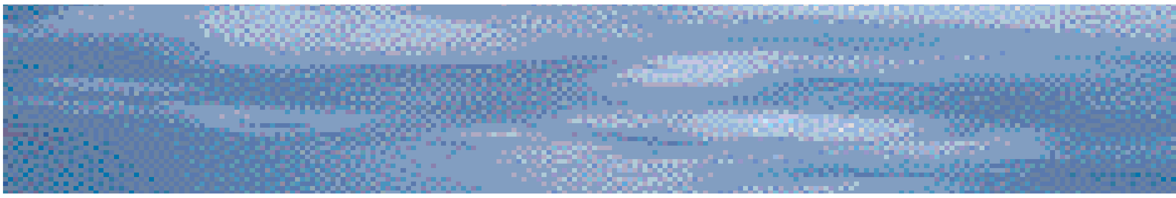
Report 05/06

June 2005

Erwin Weinmann, Sergei Schreider, Barry James, Hector Malano, Mark Eigenraam, Mariyapillai Seker, Tony Sheedy and Rukman Wimalasuriya



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Modelling Water Reallocation from Temporary Trading in the Goulburn System

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Preface

The last decade has seen significant water reform in Australian states, in line with the Water Reform Framework established by the Council of Australian Governments (COAG) in 1994. An important principle embodied in these reforms is the free trading of water which is expected to lead to more efficient water use but also has the potential to result in increased utilisation of limited water resources and to produce a number of third party impacts.

The state and local water authorities responsible for water resource planning and management rely on models of their complex water supply systems to guide their decisions on water allocation policies and management methods. The model used by Victorian water authorities is REALM (REsource ALlocation Model) which allows detailed simulation of the physical, operational and water allocation characteristics of urban and rural water supply systems. However, the REALM simulation package did not include the capability to model the reallocation of water entitlements resulting from water trading, nor any means to assess the economic impacts of various allocation and water trading policies.

Project 3A 'Hydrologic and economic modelling for water allocation' includes activities focussing on Victoria, New South Wales and Queensland. The specific objective of the Victorian component of project 3A was to enhance the existing REALM modelling capabilities to allow simulation of temporary water trading and the assessment of the direct economic impacts at the level of individual irrigation districts.

The project used the Victorian Department of Primary Industries' existing DPI Regional Water Linear Programming (LP) Model to develop a water reallocation module (WRAM-R) and to incorporate this in a new integrated modelling framework called 'WRAM-REALM'.

This report describes the features of the WRAM-REALM modelling framework and demonstrates its capabilities by application to the Goulburn System. The project outputs represent an important step towards modelling water trading and its economic impacts. The report also concludes that there is considerable scope for further improvements to this modelling approach and indicates possible directions for future work. This is an area of modelling that is critical to implementation and assessment of the new water reform agenda.

John Tisdell
Program Leader - Sustainable Water Allocation
CRC for Catchment Hydrology

Acknowledgments

This report summarises the results of research undertaken by the Project Team for Activity 3 within the Cooperative Research Centre (CRC) for Catchment Hydrology's Project 3A *'Hydrological and Economic Modelling for Water Allocation'*. The project benefitted greatly from the outcomes of the CRC for Catchment Hydrology's Project 3.1 *'Integration of Water Balance, Climatic and Economic Models',* led by Associate Professor Gary Codner of Monash University, and from contributions by Dr Wijedasa Alankarage, former PhD student at The University of Melbourne.

The economic modelling components described in this report rely heavily on previous work by the Department of Primary Industries (DPI). The Department's permission to use the DPI Regional Water LP Model and its continuing support of the project are gratefully acknowledged.

The authors wish to thank Dr Biju George from The University of Melbourne for his contribution to the development of the WRAM-R code, and Mr Kes Kesari of the Department of Sustainability and Environment for his assistance with test applications of the WRAM-REALM modelling system using the Goulburn System Model.

The project was completed under the overall direction of the CRC for Catchment Hydrology Project 3A Leader, Dr Bofu Yu, and CRC for Catchment Hydrology Program 3 Leader, Dr John Tisdell, both of Griffith University.

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Abstract

The initial scoping work within the CRC for Catchment Hydrology's research program on Sustainable Water Allocation identified an important gap in current water system simulation capabilities using the REALM modelling package: the reallocation of water from temporary water trading in rural water supply systems could not be satisfactorily modelled. On this background, the project team for Activity 3 within the CRC for Catchment Hydrology's Project 3A *'Hydrological and Economic Modelling for Water Allocation'* developed the WRAM-REALM integrated modelling system described in this report. The Goulburn System in northern Victoria, as represented in the Goulburn System Model (GSM), was used as a case study example for this project.

The project used and enhanced the existing features of REALM which allow calling of other programs during a simulation run to link it to a newly developed water reallocation module called WRAM-R. Rather than developing a new economic optimisation model to represent the economic drivers of water trading, the project team decided to build on the substantial development work that had previously been undertaken by the Department of Primary Industries (DPI) and which resulted in the DPI Regional Water LP model. This model was thus used to determine for each of the irrigation nodes participating in temporary trading a relationship between the trading price of water and the annual demand for water. These total demand curves were determined in a pre-processing step for 15 cases of crop water demand and supply availability, selected to represent the typical range of climate variability, and then made available to WRAM-R as data files.

Recognising that, in the northern Victorian irrigation systems, temporary water trading mainly results in modifying the availability of supply to given irrigation demands, rather than changing the demands themselves, WRAM-R simulates the effects of temporary trade as a reallocation of supply between irrigation demand nodes. Apart from the economic drivers of trading reflected in the demand curves, WRAM-R also includes features to reflect the effects of trading rules and effects of delivery capacity constraints, as well as a number of trader behavioural factors, which may vary between the different demand nodes.

WRAM-R also allows the trading behaviour of urban authorities to be represented through appropriately specified economic demand curves, trading rules and behavioural factors. Application of similar concepts to include trade by entitlement holders for environmental supplies is possible in principle, as long as these environmental flow entitlements are specified as exclusive rights and modelled in REALM as separate demands.

The WRAM-REALM output routines facilitate tabular or graphical presentation of simulation results and performance measures at the level of individual nodes or for the overall system. The water supply impacts of different trading scenarios can then be evaluated by comparing the results from different model runs.

The WRAM-REALM modelling system also outputs total gross margins for each of the irrigation demand nodes participating in trading, as an indicator of economic returns from irrigated agriculture, and to assess the direct impacts of water trading on these returns. Furthermore, the model outputs can provide water account information for use in an input-output model of the system, allowing the assessment of the broader economic impacts of different water trading scenarios.

The testing and initial application of the integrated WRAM-REALM modelling system to the Goulburn System has confirmed the feasibility of modelling in an integrated fashion the hydrologic and economic factors that affect the allocation and supply of water in complex rural water supply systems. It has also established the functionality of all the features in WRAM-R to simulate the reallocation of water that results from temporary water trading.

The comparison of simulated and actual trading prices and net volumes of water traded for the limited period for which data are available indicates that the modelling system is only partly successful in simulating the actual trading results over these drought years, which include the year of lowest seasonal allocation in a 113-year simulation period. Among the factors thought to be responsible for discrepancies

between simulated and actual trade results is the fact that the crop area and entitlement data incorporated in the GSM do not reflect some of the trends since the 1993/94 water year, which defines the benchmark conditions used for modelling. The use of historical utilisation factors in the GSM has been found to act as a significant constraint on utilisation of water following trading, but future model adaptations to reflect the Victorian Government's White Paper reforms are expected to overcome this limitation. Other limiting factors relate more directly to the modelling approach adopted in the WRAM-REALM system, including the limitations imposed by modelling water trading only at the annual level.

There is clear scope for further improvements to this modelling approach, based on the results of further exploratory applications and research. Some postgraduate research is already progressing to explore the potential of other economic modelling approaches using seasonal or monthly time steps to simulate trading behaviour. However the full benefits of any further developments of the water trading component of an integrated modelling system will only be realised if these developments are accompanied by efforts to obtain more comprehensive and current data on irrigated agriculture in the water supply systems to be modelled, and recalibration of the REALM model using these updated datasets.

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1. Introduction

Water management agencies in Australia operate in an environment that is characterised by continual change of the biophysical, socio-economic and water policy settings. In dealing with these changing factors, the water management agencies use a range of modelling tools to assess the likely impacts of various change scenarios and to evaluate possible adaptation strategies. Network based water allocation models form an important part of this modelling toolbox.

Over the years, two widely used water allocation modelling systems have evolved in Australia: the *REsource ALlocation Model (REALM),* which is used mainly in Victoria, South Australia and Western Australia, and the *Integrated Quantity and Quality Model (IQQM),* used in New South Wales and Queensland. The different approaches adopted for the southern and northern water supply systems reflect significant differences in their physical, operational and water allocation characteristics. While a common modelling approach would be desirable in principle, previous reviews have found that, at least in the short term, there are overwhelming reasons for the continued use and further development of the two currently used models.

The Victorian water authorities use REALM for long term planning of urban and irrigation water supply systems in different regions of the state. This generic water allocation modelling package allows the building of simulation models that reflect the specific physical, operational and water allocation characteristics of individual water supply systems or combined systems. The Goulburn Simulation Model (GSM), built using REALM, represents the complex water supply system which covers a large area in the basins of the Broken, Goulburn, Campaspe and Loddon Rivers in Northern Victoria. The water in the area modelled by the GSM is mostly used for irrigation purposes, because this area is one of the most developed agricultural regions in Australia. The GSM has been used for many years by both the regulatory agency, the Department of Sustainability and Environment (DSE), and the operating agency, Goulburn-Murray Water (G-MW), to support their water resource planning and management decisions.

The Council of Australian Governments (COAG) Water Reform Framework of 1994 was conceived on the background of "considerable concern about the state of the nation's water resources, and a recognition that an important part of the solution lay in significant policy and institutional change" (AFFA, 2004). The overall objective of the package of elements included in the framework was to provide a better basis for an economically viable and ecologically sustainable water industry.

One of the basic principles embodied in the COAG reforms is that the separation of the property rights in water from land, allowing free trading of water rights on a permanent and temporary basis, will increase the efficiency of water use. The opportunity for farmers to trade their water rights is expected to lead to an increased level of water utilisation, move water from less to more profitable industries and return more water to the environment.

Apart from the direct water management roles, an important task of the water agencies and other government departments responsible for strategic developmental planning in the region is to estimate how different water allocation scenarios in the Goulburn System affect the region's economic development. As the REALM-based GSM is a purely hydrological model, it is in itself not a sufficient tool for these purposes. A combination of water allocation and economic models is needed to perform such kinds of analysis.

On this background, Project 3A of the CRC for Catchment Hydrology Research Program on Sustainable Water Allocation was formulated with the aim of integrating hydrologic network models for water allocation management, economic optimisation models and regional impact analysis models. An important project objective is the development of economic models that allow the simulation of how water is reallocated at the regional scale as a result of temporary water trading. The development of a water reallocation model for the specific conditions of Victorian rural water supply systems, such as the Goulburn System, and its integration with the REALM-based GSM, are two major objectives of Activity 3 in Project 3A. This report summarises the research undertaken in relation to these objectives.

2. Existing Modelling Capabilities and Gaps

REALM is a well-proven tool to aid water resource planning and management in both urban and rural water supply systems (Perera *et al.,* 2003). The basic steps applied in the REALM based GSM to represent water supply system characteristics and water allocations in the Goulburn-Broken catchment are described in Section 3.1 and Appendix A. This description confirms the wide ranging capabilities of the REALM modelling system. However, as indicated in the introduction, the existing water allocation modelling tools have only limited ability to deal with some of the future change and adaptation scenarios that water management agencies may wish to evaluate.

Discussions with industry stakeholders and modellers at the outset of the project indicated that, based on how the GSM-REALM modelling system can deal with their analysis, the different types of scenarios can be divided into four groups:

1. Scenarios implemented by *changes to* the *GSM system characteristics* - using existing REALM capabilities (e.g. carrier capacities, operating rules, allocation rules)
2. Scenarios implemented by *changes to GSM input files* (e.g. climate change, catchment land use change, significant trends in irrigation or other demands, including effects of permanent water trading)
3. Scenarios requiring *enhancements to REALM or new modules interacting with REALM, and possibly changes to calibrated GSM parameters* (e.g. temporary water trading, within-season changes to irrigation demands)
4. Scenarios requiring *additional information from specialised economic modelling tools* (e.g. modelling of alternative water pricing structures, permanent water trade, long term structural adjustments to irrigation farming)

All scenarios will require post-processing of GSM outputs to assess direct or indirect economic impacts (e.g. through an input-output model of the region).

The analysis of scenarios in Groups 1 and 2 is currently already possible in principle, using existing modelling capabilities. However, the efficient analysis of multiple scenarios and any post-processing of results would be facilitated by the development of consistent input and output file format protocols, and by enhanced input preparation, pre-processing and post-processing facilities, in line with the CRC for Catchment Hydrology Catchment Modelling Toolkit concepts. These enhancements, while desirable, are outside the scope of this project.

The specialised economic modelling tools required for the analysis of the Group 4 scenarios are not further discussed in this report; they are partly being addressed in Project 3B, *'Evaluation of Permanent Water Markets'*.

The principal gap in current modelling capabilities to analyse the most important range of scenarios relates to REALM's inability to reflect the seasonal reallocation of water between model nodes (and thus adjustments to water entitlements) in response to temporary water trading. The specific focus of this report is thus on the REALM model enhancements to provide this additional functionality.

3. Overview of Adopted Water Reallocation Modelling Framework

3.1 Modelling Requirements

It needs to be stated at the outset that the development of an economic optimisation model that incorporates all the physical, operational and water allocation complexities of the real system is currently not considered feasible. The approach thus needs to combine appropriate economic and hydrologic water allocation models as components of an *integrated modelling framework.*

The basic principle adopted in developing this framework is that the modelling approach should build on the existing capabilities of REALM. Any new economic modelling capability should thus not be at the cost of reduced generality or accuracy of the existing water allocation modelling tools. This approach also allows making maximum use of previously prepared data sets and model calibration results.

An economic model is principally required to represent the *economic drivers of temporary water trading for rural industries,* but the framework should also allow the drivers for other participants in the water market (e.g. urban water authorities and stakeholders representing water allocations to the environment) to be modelled.

The modelling framework has to allow effective dynamic interaction between REALM and the economic model to ensure consistency between the two models and to reflect the impacts of physical system constraints on water reallocation. Finally, these basic model functionalities need to be supplemented by routines that express the impacts of regulatory constraints on temporary water trading and, as far as possible, the influences of a range of behavioural factors.

3.2 REALM Modelling Principles and Existing Capabilities

The generalised computer simulation package REALM (REsource ALlocation Model) facilitates the building of models to simulate the operation of integrated rural or urban water supply systems. These systems typically comprise multiple sources of supply which are linked through an extensive system of carriers to a widely distributed set of demands. The physical attributes of these many system components, together with a complex set of water allocation rules and system operation rules, determine the variation of the supply-demand relationship from year to year. The success of a model in simulating this complex reality depends on how well it is able to represent the influential physical, water allocation and operational characteristics of a specific system. REALM's simulation capabilities have evolved over many years to meet the specific modelling requirements of the two water management agencies involved, the DSE and GMW. In the following, the major capabilities are briefly described; a more detailed description relating to the specific requirements of this project is provided in Appendix A.

The *physical system characteristics* are represented in a REALM model by the hydrological characteristics of the different water supply sources (inflows to storages and tributaries, rainfall/evaporation on storages), capacities/losses of different carriers, and the climate and land use characteristics that determine water demand at various model nodes. As far as possible, these system attributes are based on measurable characteristics, but certain attributes (e.g. losses from carriers) need to be determined by calibration to other observed system variables.

The *water allocation characteristics* represented in REALM models include different forms of water entitlements and the rules that govern their adjustment in response to seasonal climate conditions (seasonal allocation or restriction rules), and encompass different forms of water allocations to the environment.

The rules governing *water supply system operation* can be divided into two groups: (i) user-defined operating rules (e.g. flood operation of storages) and (ii) system-wide operation in relation to a set of over-arching water assignment criteria (e.g. transmission losses must be supplied before demands). The order of importance of each rule is determined by rule penalties which are assigned by the user for the first group but are pre-determined for the system wide rules. The rules are modelled through an optimisation procedure using a network linear programming (NLP) approach. REALM incorporates the RELAX software which uses an objective function that minimises the sum of flow times penalty in the modelled network to obtain an optimised distribution of flows each time step while not exceeding any capacity constraints and also achieving a water balance at each node. A set of convergence criteria and tolerances is used to determine when the solution has converged to an acceptable accuracy. A more detailed description of how the water supply system operation is modelled in REALM can be found in Perera and James (1999) and Perera and James (2000).

The model can also simulate a number of important *behavioural characteristics* affecting water use (e.g. water use efficiency and utilisation of available allocations). This is achieved through a number of factors built into the model which need to be determined by calibration or based on experience values.

REALM simulation is generally at a monthly time step and extends over a representative long period of historic streamflow, rainfall and evaporation data (typically around 100 years) to reflect the impacts of highly variable climate conditions on water demand and supply. It is also possible to use inputs of stochastically generated sequences of climate data, or sequences that reflect various climate change scenarios.

However, while the long term simulation runs capture the variation of climate conditions over an extended period of time, each individual run is undertaken with model parameters remaining fixed to represent the system conditions at a specific point in time (past, current or future). The adopted set of model parameters defines a specific scenario with regard to the level of system development, allocation policies and system operating rules. By analysing the system performance for a number of scenarios, the benefits and impacts of different policies and system development or management options can be investigated. The impacts of time trends (e.g. climate change, gradual demand increases) are usually examined by comparing the system performance for current and future conditions (say after a period of 20 years).

The monthly time step imposes limitations on the modelling of physical and operational system characteristics that experience substantial within-month variation. Examples of REALM modelling capabilities limited by long time steps are storage operation during floods, routing through carriers, accurate representation of diversion capacity constraints.

The irrigation water requirements of the crops established at the different irrigation demand nodes are estimated externally to REALM using the Program for Regional Irrigation Demand Estimation (PRIDE). This pre-processing program uses crop area and crop type data at irrigation nodes as basic input. The maximum irrigable areas for different crop types remain fixed during a model run and supplies are restricted in response to reduced allocations during droughts. Various scenarios of structural change to irrigated land use can be modelled through modifications to the crop area and crop type inputs for different model runs.

The fact that water demands in REALM are pre-processed precludes the dynamic updating of crop areas or irrigation demands due to restricted allocations during a run (as is possible in IQQM). This has important implications on how water reallocation due to temporary water trading is modelled in a REALM-based modelling framework.

3.3 Criteria for Selection of Economic Model

The major prerequisite of the economic model to be combined with REALM is that it meets the needs of the Victorian water agencies for water allocation planning and is consistent with their current economic modelling practices. Hence, selection of an economic model has been based on the stakeholder participatory approach. A number of meetings with the water agency stakeholders (G-MW and DSE) and with economists from the Department of Primary Industries (DPI) were organised in order to formulate the major requirements for this economic modelling tool. This direct stakeholder involvement throughout the integrated modelling system development ensured that the model would satisfy user requirements and expectations. It also allowed maximum use to be made of existing economic modelling expertise and software.

Some broad requirements of the economic models for use in Activity 3 of Project 3A can be formulated.

Firstly, the models should be targeted at supporting decision making by the major stakeholders, the water agencies. This means that these models have to represent the economic processes, especially water trading, at the scale of irrigation areas to the entire catchment (rather than at the scale of individual irrigators). Secondly, the models must be able to work with the level of agricultural enterprise data typically available for project areas. Thirdly, they must be free-market based models taking into account the processes initiated by the COAG water trading reform. Finally, the models (or additional modules in the modelling framework) need to reflect a number of spatial and temporal constraints on water trading, as described in DNRE (2001) and Wijedasa (2004).

3.4 Selection of Preferred Approach

The following options were considered in selecting a preferred approach:

(i) use of existing models approved by the project stakeholders

(ii) modification of existing modelling tools to meet specific Project 3A requirements for the Goulburn System

(iii) adaptation of a new model being developed in a parallel Project 3A activity for the Murrumbidgee Catchment

(iv) development of purpose-specific new modelling tools.

While Option (iv) would have provided the greatest opportunities to fully achieve the project objectives, the limited project timeframe and funding precluded the selection of this option.

Option (iii) appeared attractive in principle, as it would have allowed savings in software development effort. The Water ReAllocation Model (WRAM), developed by Dr Bofu Yu as part of the same CRC for Catchment Hydrology project, uses linear programming (LP) optimisation to determine an optimum crop mix for each node, allowing for water trading between different irrigation nodes (Yu *et al.,* 2003). WRAM is intended to interact dynamically with the IQQM (Integrated Quantity- Quality Model) of the Murrumbidgee System, through adjustments to the crop areas based on economic modelling results. However closer analysis of this option indicated that the substantial differences between the two catchments in terms of the nature of irrigation development and water allocation modelling systems precluded effective adaptation of the WRAM model to interact dynamically with the REALM-based model of the Goulburn System. The main difficulty relates to the fact that crop areas are not directly modelled in REALM, but are dealt with in a pre-processing step, using a separate irrigation demand estimation model (Program for Regional Irrigation Demand Estimation – PRIDE, Erlanger *et al.,* 1992).

The existing models evaluated in Option (i) included the models developed by the Victorian Department of Primary Industries (DPI) and a water reallocation model developed by A. Wijedasa as part of PhD research project at the University of Melbourne (Wijedasa, 2003; Malano and Wijedasa, 2003; Wijedasa, 2004). In the DPI models, economic information and farming systems details need to be combined with plant irrigation requirements and water deliveries in order to determine water trading volumes and prices. The model developed by Wijedasa is based on calculated surplus or deficit of irrigation water within an irrigation demand centre. This model has been shown to be able to predict volumes of water traded with good accuracy in the limited number of seasons tested. However, the estimation of water surplus or deficit is based on the results of a survey of water traders rather than on economic criteria, and this model has thus only limited scope for modelling a broad range of future change scenarios.

This evaluation resulted in the selection of Option (ii), using the modelling approach adopted by the Victorian Department of Primary Industries (DPI), which combines two models:

(i) a linear programming (LP) regional water trading model for determining excess water demand and supply schedules for irrigation regions, and

(ii) a spatial equilibrium model for calculating the equilibrium water price over the entire system participating in water trading, and the movement of water between irrigation regions.

A description of the principles of this economic modelling approach, referred to as the Water Policy Model (WPM) can be found in a series of papers by DPI authors (Eigenraam *et al.,* 1996; Eigenraam, 1999). For reasons of model generality and flexibility (further explained in later sections of the report), it has been decided to only adopt part (i) of the Water Policy Model. This model component will be referred to as the DPI Regional Water LP (RWLP) Model. Appendix B outlines the basis of this model, and Chapter 4 summarises its main features.

3.5 Key Elements of the Adopted Modelling Approach – Requirements for Adaptation and Development

The approach chosen to represent the impacts of temporary water trading on water supply in the Goulburn System requires three separate modelling components to be adapted or developed and then integrated into an overall modelling framework, as illustrated in Figure 1:

(i) The *pre-processing model* that prepares a database of demand curve and gross margin data for each of the major irrigation nodes in the GSM, and for selected levels of irrigation water demand and available supply (the elements shown on the right-hand side of the diagram). This modelling component is directly based on the DPI Regional Water LP model, suitably adapted to reflect the special characteristics of the Goulburn System and the effects of different seasonal climatic conditions. Section 4 of this report gives an outline of the basic features of this component and its implementation as part of the integrated modelling system.

(ii) The *water reallocation model* WRAM-R that uses the database of demand curves from (i) with GSM outputs on seasonal conditions to determine for each water year how much water is reallocated between the GSM nodes participating in temporary water trading. The results of WRAM-R are passed on to REALM as updating information. This modelling component, which also reflects the impacts of regulatory constraints on water trading and allows for some irrigator behavioural factors, is described in Section 5.

(iii) A *modified version of REALM* that allows the GSM to be run a second time for each water year (July to June), thus reflecting the impacts of water trading on water entitlements and outputs at different nodes. The purpose of this second run is to ensure that the modelled system outputs after water trading correctly reflect the impacts of any system capacity constraints. The dynamic interaction between REALM and WRAM-R is managed by a DRIVER program. These REALM enhancements are discussed in Section 6, together with other software development aspects of the integrated modelling framework.

Figure 1 also illustrates how the outputs of REALM and WRAM-R can be used to assess the economic impacts of different scenarios of climate conditions, agronomic inputs and water trading regulations.

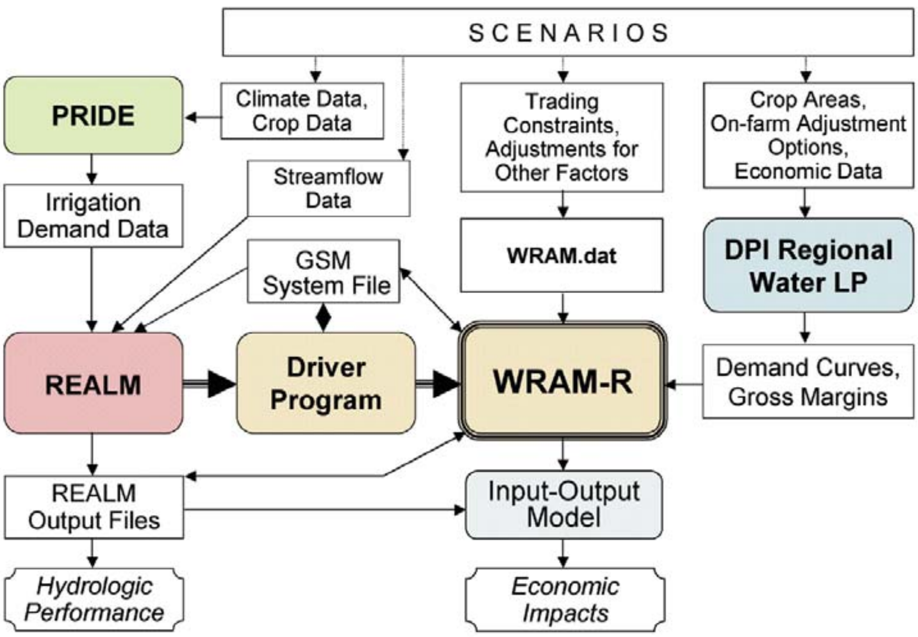


Figure 1. Schematic Diagram of the Integrated Modelling Framework for Water Reallocation Resulting from Temporary Trading.

4. Demand/Supply Curve Pre-Processing Model

4.1 The Concepts of Total Demand, Excess Demand and Excess Supply

In economics, the concept of a *demand curve* is used to express the relationship between the price of a good and the quantity demanded. Similarly, a *supply curve* expresses the relationship between the price of a good and the quantity available for supply. In the context of this specific application, the term *'total demand'* relates to the total volume of water demanded at a particular node over a full irrigation season. It combines all irrigation water demands at that node, and includes all forms of allocation under which this water might be obtained (supply to basic entitlement, 'sales' water, or water obtained by temporary trading). Figure 2 shows a typical total demand curve for a region.

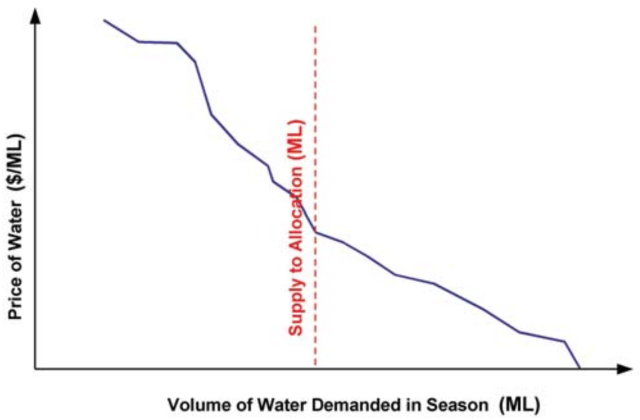


Figure 2. Total Demand Curve for Given Conditions of Seasonal Irrigation Demand and Supply.

On the supply side, the amount of water delivered to a region to supply the underlying demand for water is limited by effects of water entitlements, water allocation rules, seasonal water availability and, in some cases, delivery capacity constraints. A 'cap' on total diversions may also act as a constraint on the volume supplied. [In the GSM, the maximum 'supply to allocation' is further constrained by a *'limit curve'* which reflects historic water usage (utilisation).] For this limited *'supply to allocation',* farmers are paying in accordance with the adopted tariff structure. This basic volume of supply available to the region (without trading) determines if the farmers in the region have excess supply available or a shortfall in relation to their basic demand for this season.

The 'supply to allocation' line in Figure 2 divides the demand curve into two branches:

i the right (or lower) branch, where there is *'excess demand'* in relation to the volume supplied to allocation, and

ii the left (or upper) branch, where the demand is less than the 'supply to allocation' and where *'excess supply'* is thus available.

The excess demand or supply can thus be determined by subtracting the 'supply to allocation' volume from the demand. Excess supply has a negative sign but for plotting the excess supply values are converted to positive values. The resulting excess demand and supply curves are indicated in Figure 3.

The *excess demand curve* for a region thus indicates to what extent it is worth for the farmers in this region to buy extra water to irrigate their existing mix of crops, given certain commodity prices and production costs. Conversely, the *excess supply curve* represents the domain of the water market where it is more profitable for farmers in this region to sell part of the water allocated to them for the current season rather than applying it to irrigate crops in their existing crop mix. The price of water in Figure 3 refers to the price at which water is bought or sold on the water market.

While the concepts of total demand, excess demand and excess supply have been explained specifically in relation to irrigation water demands, these concepts can also be applied to demands for other water use sectors, including environmental demands.

4.2 Derivation of Demand Curves

The total demand curves for individual irrigation nodes in the Goulburn and Campaspe systems are produced using the Victorian Department of Primary Industry (DPI) Regional Water Linear Programming Model. Further in the text we will refer to it as the DPI RWLP Model. The basis of this model is more fully described in Appendix B; this section only provides a broad outline of the major steps in the modelling.

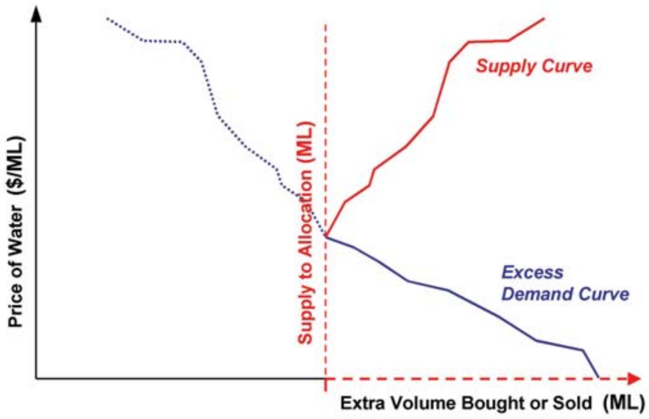


Figure 3. Excess Demand and Supply Curves for Given Conditions of Seasonal Irrigation Demand and Supply.

In the derivation of the demand curves, each significant irrigation node of the GSM is considered as an agricultural region comprising up to three aggregated farms representing different industries: dairy, mixed farming and horticulture. (The GSM includes more than 60 water diversion nodes but only 14 major irrigation nodes are represented in detail in the DPI RWLP Model; they account for about 85% of total water diversion in the system. Similarities in irrigation enterprises allow these modelling results to be applied to a further 5 nodes with significant irrigation demands.) The lumped representation of farms within the same industry (e.g. dairy) at a node means that all farmers within the node are assumed to fully cooperate and to not compete for the water resources available.

The crop data for a given node are used for optimising the gross margins and the cropping systems of the major agricultural industries represented at this node. The summation expression for gross margins for different farming industries includes terms for the cost of the water obtained as 'supply to allocation' (in accordance with adopted water tariffs) and the cost for the water bought (or income from water sold) by each industry (at a given trade price for water). This optimisation is realised using the LP algorithm (the LP solver is taken from the software library "What's best") where the objective function is maximising the total gross margin of the given node. The outputs of this optimisation process are the optimal cropping system, the corresponding total gross margin for the node and the amount of water (in ML) sold (excess supply) or bought (excess demand). The total demand for water at the given trading price is obtained as the sum of the 'supply to allocation' and the excess supply or excess demand.

The major behavioral assumption in the LP model is that the irrigators select their water use strategy trying to maximise the gross margins. The special constraint applied here is that the optimisation works under the short run assumption. This means that the areas for any of the crops could be reduced from the area irrigated under maximum water allocation but not increased. This constraint applies to a situation where, during periods of limited supply, irrigators will apply less irrigation water to some part of their existing crop areas rather than planting alternative crops, and where there is little opportunity for increasing crop areas within a season. This modelling assumption closely reflects current irrigator behaviour in the region.

The optimisation process explained above for a particular node is repeated for different water trading price levels within some reasonable band. The pairs of water trading price – water quantity resulting from these runs define the demand curve for the particular node. The important difference of the algorithm described here and the original version of the DPI RWLP model is that the latter one employed one additional step which was a linear approximation of the demand curve points by a linear regression. This step has been omitted in this application, because the non-linearity of the water demand curves is a significant feature of the water market, which must not be ignored.

The solution obtained by optimising the DPI RWLP model is dependent on two important climate related variables: (i) the seasonal water demand, i.e. variation of net crop water requirements with seasonal rainfalls, and (ii) the supply to allocation for the current season (this determines how much additional water needs to be bought at the trade price for water rather than at the cost price of water). For reasons of computational efficiency, the continuous domain of possible combinations of seasonal irrigation demand and allocation conditions has been represented by a discrete set of 15 combinations, as detailed in Appendix C. The computation of gross margins is based on the assumption of fixed commodity prices and input costs, regardless of seasonal climatic conditions. The excess demand/supply curves for each of the 19 irrigation nodes are derived under each of the 15 combinations of irrigation demand and supply.

The final, fourth step is to make this total demand curve and total gross margin (or income) information for each node under each irrigation demand and supply scenario available in a database for use by the water trading or water reallocation model.

4.3 Data

The major input data required for the DPI RWLP model are details of the agricultural enterprises and crop areas at each irrigation node. Unfortunately, reliable and up-to-date data on irrigated crop areas at the desirable degree of resolution and in the required format are not readily available, and it is thus necessary to apply some degree of processing to the available data.

In principle, the modelling of irrigation demands using the PRIDE model requires similar data on crop areas as the economic modelling, but a different set of considerations was applied when adjusting the limited data to suit the specific PRIDE model requirements. [The crop areas estimated from census or survey data have been adjusted during the PRIDE and REALM calibration process to allow for various forms of water losses and local differences in crop water demand that are not accounted for in PRIDE. While this may be appropriate to satisfy water balance requirements, it could be a possible source of bias in the economic modelling results.]

Furthermore, the various crops planted in the region are represented in the PRIDE model by only a small number of crop types (annual pasture, perennial pastures, lucerne, summer and winter crops, orchards and grapes). In reality, the crop diversity is much higher. For example, orchard crops include pome fruits, stone fruits and citrus. However, crop water use coefficient and crop area data are not readily available for more detailed division, and this division into broad groups was adopted as being sufficient to differentiate between the major water use patterns for demand modelling in PRIDE.

To provide adequate differentiation for economic modeling, the selected crop types also need to be representative with regard to the gross margin produced per unit area. Therefore, orchard crops were further subdivided into grapes, citrus, pome fruits and stone fruits, and the monthly water use requirements for these crops estimated from those of the 'orchard' crop in PRIDE.

Crop Areas for GSM

The crop area data used to estimate the irrigation demands for application in the Goulburn Simulation Model (GSM) represent MDBC Cap conditions, i.e. 1993/94 levels of development and crop areas. The *actual crop areas* for the 1993/94 season were estimated based on a number of farm irrigation censuses conducted by G-MW in the period from 1990/91 to 1996/97. Appendix D describes the basis for these crop area estimates. However, these estimates of actual crop areas for 1993/94 were calibrated against actual water usage over the 1992 to 1995 period. Thus, the final crop area numbers used in the GSM include a calibration adjustment factor. The *adjusted crop areas* used in the GSM Cap model are presented in Table 1 of Appendix D.

Crop Areas for DPI RWLP Model

Estimates of *actual crop areas* (without the adjustments introduced in the calibration process) are required in the economic optimisation model to estimate farm water demands and gross margins for different farming enterprises. The basis for estimating actual crop areas for the 19 irrigation nodes assumed to participate in trading is described in Appendix E, and the crop area estimates are shown in Table 1 of Appendix E.

[While there is considerable anecdotal evidence that crop areas and crop types have changed significantly over recent years (generally there appears to be a trend towards higher value crops), unfortunately the more recent crop area surveys suffer from limited coverage and reliability, and were considered to be unsuitable as a basis for the modelling in this project.]

Other Data for DPI RWLP Model

The economic modelling also requires data to link crop areas with the three industries being modelled, dairy, mixed farming and horticulture. Winter/summer crops and lucerne form part of the mixed farming industry, while orchards and grapes make up the horticulture industry. However, the perennial and annual pasture areas are part of both the dairy and mixed farming industries, and data on the breakdown between these industries is not readily available. This limitation was overcome by the use of maximum area constraints for irrigated land and dryland under the three industries (Table 2, Appendix E).

Another important input for the DPI RWLP model is information on water entitlements and fees paid for water. This information is summarised in Table 3 of Appendix E.

Appendix E also explains the basis used to estimate maximum stock numbers for the livestock industries.

4.4 Program Implementation

The dynamic structure of the integration of GSM with economic modelling is described in detail in Section 6. Only some specific programming issues related to the preparation of demand curve data are addressed in the current section.

The DPI RWLP model had been coded using quite sophisticated EXCEL utilities and macros using the proprietary "What's Best" LP solver. This precluded direct integration of the economic modelling component into the overall modelling framework. The DPI RWLP model thus needs to be run as a *pre-processing step* for the water reallocation modelling in WRAM-R to produce data files containing the demand curve data for each node. Compared to the original version of the DPI RWLP Model, the following modifications have been implemented for this project:

1. The total demand curve and gross margin data has been produced not just for the average climate conditions of the past century, as was done in previous applications, but for a set of representative climate conditions which reflect the typical range of seasonal irrigation demand and supply levels. This representative set comprises combinations of three levels of water demand (average and average ± 20%) and five levels of supply (expressed in terms of selected percentile values of supply, determined from long term simulation results), as detailed in Appendix C.
2. The actual demand curve points rather than the linear approximation of the demand curves have been used. This is a very important modification of the original method and reflects the fact that demand curves are highly non-linear (flatter for high quantities of water and steeper for lower quantities). This non-linearity has a significant effect on the water market behaviour.

5. Water Reallocation Model (WRAM-R)

5.1 Introduction and Overview

The term *'water reallocation'* is used to describe the impacts of water trading on the supply of water to different demand nodes in the water allocation model. The basic assumption underlying the water reallocation model is that the traded volumes of water will not change the level and distribution of the basic irrigation demands (determined by the PRIDE model as 'unrestricted demands') but rather the extent to which these basic demands will be able to be supplied in a particular year, allowing for the supply limitations imposed by current water entitlements, maximum utilisation limits, seasonal allocations and distribution system capacity constraints.

The *basic driver for water trading* is assumed to be the motivation of the irrigators at a node to maximise their total gross margin, in conformity with the assumptions and constraints built into the DPI RWLP Model described in the previous section. As both water demand and supply depend on seasonal climate conditions, the drivers need to be sensitive to varying climate conditions. Any imbalances in the gross margins obtainable at different nodes for a given water price will create a tendency for water trading which in reality will be resolved on the open water market, subject to the rules imposed by any regulatory authorities. In the water reallocation model, the operation of this water market is simulated by an *equilibrium model* which determines at which price the total volumes of water bought and sold over the entire trading region will balance, and how much water will be bought or sold at each node.

To provide a realistic simulation of the actual behaviour of the market, the water reallocation model needs to make provision for a number of *modifying factors* which will allow improved prediction of the actual volumes of water traded compared to the results obtained directly from the economic model, which makes a number of simplifying assumptions. These modifying factors need to reflect the major *regulatory constraints* which may restrict trade under certain conditions, and any identified *trading behaviour factors* which affect the extent to which the predicted water trade will actually be taken up.

The outputs from WRAM-R for the current year include the trading price of water in the trading region, the volumes of water bought or sold at each node and the total gross margin at each node allowing for the impacts of water trading. Finally, the model uses the calculated volumes of reallocated water for each node to adjust the allowable limits of water usage at the nodes, and passes them back to REALM for a rerun over the current water year which reflects the impacts of water trading.

The flow chart in Figure 4 outlines the steps involved in determining the water trading characteristics for one year within a REALM simulation run. The approach used in modelling the individual steps is detailed in Section 5.4.

5.2 Model Development Process

For reasons of expediency, a two-stage process was adopted to develop the WRAM-REALM modelling capabilities. The code development for WRAM-R followed an extended scoping and conceptual model development process, as described in Chapter 3.

The purpose of the 'proof of concept model' built in the first stage was to confirm that WRAM-R was able to interact dynamically with REALM and that the basic principles and methods to be incorporated in the water reallocation model were workable and likely to lead to acceptable modelling results. This initial model implementation allowed for the effects of climate variability by assigning each year to one of the 15 discrete demand curve cases (no interpolation) and was restricted to 11 trading nodes.

Once the proposed modelling approach was shown to be workable in principle, the FORTRAN code of the enhanced version of WRAM-R was developed by SKM in a more generic fashion which would lend itself to future enhancements, even beyond the term of this project. Incorporated in this version are interpolation routines to allow water reallocation to be modelled in a continuous rather than discrete fashion, and a more complete set of modifying factors to allow for the impacts of constraints on water trading and behavioural characteristics of water traders. The expected impacts of these modifications on calculated gross margins are also allowed for.

The progressive testing of the two model versions to establish their basic functionality and the validation of the enhanced WRAM-R model in a range of test applications is described in Chapter 7. The steps in Figure 4 and the descriptions of model components in the following sections relate to the finally adopted (enhanced) version of WRAM-R.

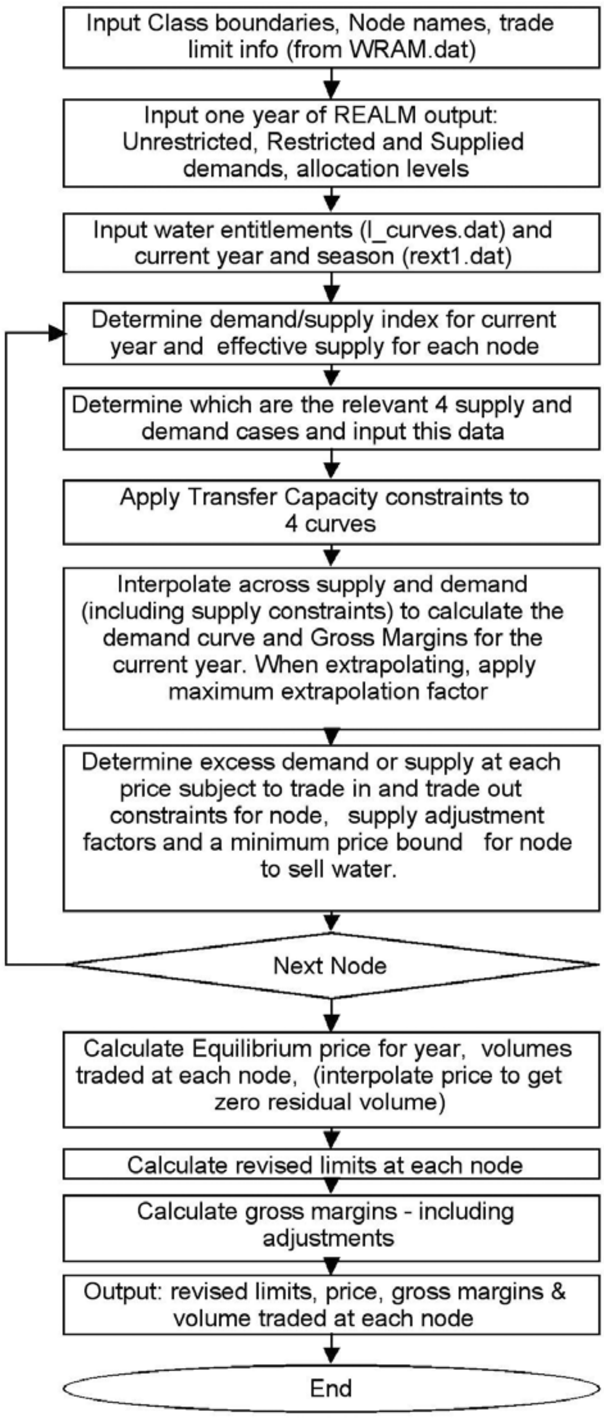


Figure 4. Outline Flow Chart for WRAM-R.

5.3 Input Data

A detailed description/specification of inputs is presented in Appendix F 'WRAM-R Input and Output Data'. The inputs are divided into two groups:

(i) Inputs *not* dependent on REALM simulation:

- number of demand nodes involved in trading
- for each demand node: node name and values of trader behavioural factors (hedging factor for water sales, minimum water price and expected supply weighting factor
- values of global constraints (e.g. maximum extrapolation factor)
- number of demand and supply cases; names of demand curve files for all cases
- for each demand node and supply case: value of supply at class interval boundary and mid-point
- for each demand node: values of perceived supply capacity constraint, trade in and trade out limits

(ii) Inputs dependent on REALM simulation (from relevant REALM specification or output files):

- current year and month
- variables required for dynamic updating of trading constraints
- for each node: initial water entitlement for current year (without trade)
- for each node and for each month in current year: values of seasonal allocation level, unrestricted demand, restricted demand, supplied demand (delivery to node).

5.4 Algorithms and Assumptions

This section describes in more detail the algorithms used in the following steps of the WRAM-R flow chart shown in Figure 4.

Once the demand curves, which reflect the main drivers of temporary water trade, have been input, there are a number of other programming steps required in WRAM-R to reflect the influence of other factors on water trading: the current climate conditions, the constraints imposed by the physical system and water trading rules, and a number of factors which affect irrigators' trading decisions. In the following paragraphs, the assumptions made for these factors and the algorithms employed in WRAM-R to implement them. As modelling of water trading in WRAM-R is done at the annual level, the aim is to reflect the overall impact of the factors over the whole irrigation season, rather than to model the variation of trading during the season.

(a) Effective Supply for Season

WRAM-R carries out the water trading calculations for the current year at the end of the water year (June), when the actual climate conditions for the whole year and the final seasonal allocation of water for the year are known. However, irrigators have to make the most of their temporary water trading decisions earlier in the season when, in most years, there is considerable uncertainty about the final allocation level. This situation is reflected in the model by determining available supply for the season as a weighted function of the initial (August) and quasi-final (February) allocation levels. The following function is used:

$$Supply_{eff} = \frac{w * Alloc_{Aug} + (1-w) * Alloc_{Feb}}{Alloc_{Feb}} \; Supply$$

where:

w is a weighting factor which can vary between 0 (assuming that decisions are made near the end of the season) and 1 (assuming that all trading decisions are made very early in the irrigation season). The default value of 0.5 assumes that most trading decisions are made midway through the season.

(b) Demand and Supply Conditions for Current Year

Depending on the climate conditions for the current water year, the total annual (unrestricted) demand at a node and the total volume of supply made available to the node will vary significantly. To allow the selection of the appropriate economic demand curve data for the WRAM-R modelling, the total annual demand for the year is characterised by a demand index. Similarly, the total annual supply to a node is characterised by a *supply index*. In the following, the meaning and calculation of these indices is explained.

Total supplementary crop water demand (or unrestricted water demand) varies from relatively low demand in wet years (typically between 60 to 90% of average demand) to relatively high demand in wet years (typically between 110 to 140% of average demand). The demand index is taken to be the same across the whole trading region and is calculated as the ratio of the current year's demand to the average demand at an indicator node (in this case Rodney). For the simulation period from 1891/2 to 2003/4 the demand index varied between 0.45 (in 1992/3) and 1.65 (in 1967/8), but was in the range from 0.8 to 1.2 in more than 90% of years.

As indicated under (a), the volume of supply of interest for the modelling of water trading (and expressed by the supply index) is the *expected* volume of supply for the water year. The range of variation of supply between wet and dry years is somewhat smaller than for demands, as the very high demands in the driest years cannot be fully supplied. Because different nodes are supplied from different sources and are affected by different delivery capacity constraints, the supply index for a given year may vary significantly from node to node; it is therefore calculated separately for each node. The supply index for the current year can be related to nominated percentile values from the distribution of supply index values to select the relevant demand curve data for interpolation (see (c)).

(c) Interpolation/Extrapolation for Seasonal Climate Conditions

As explained in Section 4.2 and detailed in Appendix C, in the pre-processing model the variation of climatic conditions is represented by 3 demand cases and 5 supply cases, i.e. a total of 15 cases of demand and supply conditions. The following table summarises these cases.

Table 1. Demand and Supply Curve Groups.

	Supply Group				
Demand Group	**1**	**2**	**3**	**4**	**5**
Wet (W)	W1	W2	W3	W4	W5
Normal (N)	N1	N2	N3	N4	N5
Dry (D)	D1	D2	D3	D4	D5

The initial step in the interpolation routine for the actual demand and supply conditions in the current year is to select the four 'nearest neighbour' cases to be used for the interpolation. This is done by comparing the actual supply values with the boundary values for each case.

The interpolation uses the representative 'mid-point values' for each case as supports. Linear interpolation has been found to give an adequate representation of the variation between the cases. For the lowest and highest demand or supply cases, some extrapolation beyond the domain defined by the supports may be required. To avoid unrealistic values, the extent of extrapolation is limited by a user-defined maximum extrapolation factor. The interpolation routine proceeds in two stages: in the first stage interpolation with respect to supply is undertaken to determine demand curves at the upper and lower support values of demand corresponding to the actual supply value, then in the second stage these two curves are again interpolated at the actual level of crop water demand.

The final result of the interpolation (or limited extrapolation) is a *new total demand curve* for each node which reflects the impacts of the climate conditions on demand and supply for the current water year.

(d) Impact of Transfer Capacity Constraints on Trading

The impacts of capacity constraints in the transfer and delivery routes of the supply system are particularly important during peak demand periods in an irrigation season. These constraints on deliveries are partly overcome by careful scheduling and rostering of supplies which have the effect of redistributing the supplies over a longer period. The GSM models these capacity constraints in the form of specified monthly maximum monthly supply capacities for individual supply routes. The monthly volumes of supply to the different demand nodes (the maximum volumes that can be reallocated in WRAM-R in response to trading) thus already reflect the effects of capacity constraints on deliveries before trading.

The aspect that is important for the modelling of water trading in WRAM-R is the extent to which irrigators allow for the *perceived impacts of capacity constraints* in their water trading decisions. For the demand nodes that are significantly affected by delivery capacity constraints, it is known that in years of high irrigation demand the capacity constraints tend to impose an upper limit on the total annual volume of water delivered to the node. This will generally act as a disincentive to trading, except for irrigators who wish to increase their total entitlement to give them a greater share of the restricted supply in peak periods rather than a larger total supply.

The results of earlier GSM runs (comparison of deliveries and restricted demands) have been used to identify indicative upper limits to annual supply to each trading node that experiences significant shortfalls in supply as a result of limited delivery system capacity. Perceived capacity constraints have been specified for each of the 15 cases of demand and supply conditions, but they only affect trading in years of higher than average demand and supply. The adopted limits correspond to conditions when there is a significant shortfall in supply relative to unrestricted demand (in the order of 10 to 20%).

In the WRAM-R interpolation routine these values of *perceived total annual transfer capacity* are applied as constraints which modify the total demand curves, so that the value of any additional water beyond this constraint is assumed to be zero. In other words, it is assumed that irrigators will know that, once this limit of total supply is reached, the theoretical economic value of water (as calculated by the DPI RWLP Model) can no longer be realised.

However, the ability of the channel system to deliver any additional volumes of supply that may have resulted from temporary trading, particularly during periods of peak demand, still needs to be checked. It has therefore been decided to model the detailed impacts of any delivery capacity constraints through a second run or *'check run' of GSM,* after WRAM-R has reallocated some of the supply to 'buyer' nodes (as indicated in Figure 5 below).

(e) Impact of Trading Rules

The trading rules for the Goulburn-Murray System (as defined in DNRE, 2001) are quite complex and, at the current stage of development, WRAM-R can only represent certain forms of trading rules. Fortunately, most of the major nodes in the trading region currently modelled are not affected by any constraints on temporary trading.

The model is currently able to reflect trading constraints which can be expressed in the form of upper limits on the annual volume water traded in or out of a node. This includes the special case of nodes prohibited from buying or selling, for which a trading limit of zero is specified. [The trade in and trade out constraints define, respectively, the maximum value of excess demand or excess supply for a node.]

(f) Impact of Trader Behavioural Factors

The direct use of the demand-price relationship derived in the pre-processing step would involve the assumption that trading decisions are entirely determined by the economic factors reflected in the DPI RWLP economic optimisation model. However, it is known that irrigators' trading decisions will also be affected by other factors which could be referred to as 'trader behavioural factors'. The following factors have been allowed for in the model:

(a) It has been observed that, for a range of reasons, many irrigators are reluctant to sell part or all of their allocation, even if this appeared to be the appropriate course of action on economic grounds. [One possible reason for this 'hedging' behaviour is that gravity irrigators in the Goulburn System lose access to the portion of 'Sales' water above 30% of water right if they temporarily transfer any of their water entitlement – private diverters lose access to any 'Sales' water if they trade (DNRE, 2001).] This reluctance to sell is reflected in the model through a *'hedging factor for sellers'* which has a default value of one but can be varied to values less than one for nodes where there is clear evidence of hedging behaviour. [The hedging factor is applied as a multiplier of the calculated excess supplies at each water price.]

(b) In most cases it is also reasonable to assume that farmers would only sell any water if the water price exceeds a certain *minimum price.* This reflects the fact that there is a cost associated with transactions on the water market. It is to be expected that the minimum price for water to be sold on the market varies between nodes, in accordance with the characteristics of the dominant industries. [The minimum price is applied as a threshold value; at water prices below this threshold the excess supply is assumed to be zero.] A minimum water price applies not only to water sales by irrigators but also to excess water sold by urban water authorities.

It should be noted that, because in WRAM-R water trading is only modelled at the annual level, many behavioural factors which may explain fluctuations of the water market over the season do not need to be considered.

(c) Equilibrium Price of Water and Volumes Traded

The equilibrium price in a water trading region is the price of water at which the volumes requested by buyers and the volumes offered for sale balance exactly. In WRAM-R this water price is determined by first summing at each water price increment the volumes of excess demand (import) and excess supply (sales or export) across all the nodes in the trading region (after the impacts of steps (d) to (f) below have been allowed for). The two price levels with net excess and net supply closest to zero are used in a linear interpolation procedure to determine the exact equilibrium price.

The volumes of water bought or sold at each node at the equilibrium price are also determined by linear interpolation between the values at the two adjacent price levels.

(d) Revised Limit Curves

The volumes of water bought and sold calculated in the previous step represent respectively the increments or decrements in the total water entitlements held at the nodes participating in trading. This information is passed on to REALM/GSM in the form of an adjustment to the limit curves which define the maximum usage corresponding to a given seasonal allocation. The WRAM-REALM modelling process assumes that the traded volumes correspond directly to either a fixed increase or decrease in maximum usage at all seasonal allocation levels.

(e) Calculation of Adjusted Gross Margins

The data imported from the pre-processing step includes the total gross margins at each node for each water price level. The interpolation procedure in step (c) is also applied to interpolate the total gross margin at nodes for the climate conditions of the current year. From this the total gross margin achieved at the equilibrium price can be determined, as an indicator of total farm returns for the current year. By comparing the total gross margins with and without water trading, an estimate of the direct economic benefits of temporary water trading can be obtained.

The various modifications to the original demand-price relationships which have been introduced in steps (d) to (f) may result in biased values of the total gross margins under equilibrium conditions. Additional calculations are therefore required to adjust the gross margins and compensate for any errors introduced by constraints and non-optimising trader behaviour. The following adjustments have been made in WRAM-R:

(i) for effects of differences in water price if equilibrium price is less than the price at limit imposed by delivery capacity constraints or trading out constraint

(ii) for reduced returns from sub-optimal farmer behaviour (less water sold than assumed in economic optimisation model)

(f) Trading of Unused Allocations

The computation of the equilibrium price and of the traded volumes of water in step (g) is based on comparing the total demand with the *total volume of supply* to the node in the current year, which is restricted to be the lower of:

(i) the unrestricted water demand for the current season's supplementary crop water requirements (as determined from the PRIDE model) and

(ii) the historic water usage (as indicated by the value of usage for the current seasonal allocation specified by the limit curve)

The first limit reflects the fact that the purpose of irrigation supply is to satisfy crop water demands (and any associated water losses). The second limit reflects past experience that in high allocation years only part of the total pool of sales water has been used by irrigators. While this definition of excess demand and excess supply may be appropriate for reproducing historic water use, it does not lend itself readily to dealing with the impacts of increasing water usage and with the fact that in some nodes (e.g. private diverters) there may be significant volumes of *unused allocations* available for sale.

The adopted method to deal with the sale of unused allocations is to define a separate trading node with a dummy demand equal to the part of the unused allocation available for sale. This unused allocation varies from year to year and thus needs to be updated dynamically at the end of each year in accordance with the final allocation for that year and the total volume supplied during the irrigation season (as computed in the initial GSM run for that year). The hypothetical demand curve for this node reflects the minimum price at which farmers would be prepared to sell their excess allocation.

The current WRAM-R model of the Goulburn System includes two additional nodes to represent the significant unused allocation volumes of Goulburn Private Diverters. [The trading of currently unused entitlement volume held by urban water authorities in the Lower Goulburn is modelled in a similar fashion.]

5.5 Output

A detailed description/specification of outputs is presented in Appendix F 'WRAM-R Input and Output Data'. The outputs are divided into two groups:

(i) Outputs of water trading modeling results for current year (not needed for REALM simulation) – water price for trading region, volume of water bought or sold at each node and total gross margin produced at each node.

(ii) Outputs needed for REALM simulation with impacts of temporary water trading – revised limit curves (maximum usage for current seasonal allocation)

6. Integration into GSM/REALM Modelling Framework

6.1 Overview

As outlined previously, an integrated economic and water allocation modelling framework has been adopted to allow maximum use of existing modelling capabilities and to avoid the loss of generality or accuracy from the highly developed existing economic and hydrologic water system models. This integration is achieved by linking the new Water Reallocation Model WRAM-R to a REALM model (e.g. the GSM) in such a way that relevant input data can be readily accessed by both models, and state variables of one model can be updated using results from the other model.

The overall integration of the new modelling components with REALM/GSM is illustrated in Figure 5. The REALM/GSM modelling components are shown on the right hand side, the Water Reallocation Model on the left, and the linkages between them in the middle.

The REALM/GSM modelling is at a monthly time step, progressively over a water year. As the water reallocation from temporary trading is modelled annually, it operates on total demands and supplies for an irrigation season, and the interchange of information between the models is required only once a year, at the end of the water year and the start of a new one.

6.2 Adopted Method of Integration

As discussed in Section 5, WRAM-R requires an estimate of the supply and demand conditions for the year it is about to simulate. This was achieved by running two REALM model simulations, which are integrated with WRAM-R. The first REALM simulation is over the full model period (e.g. 1891-2004). The second simulation is actually a series of one year simulations, each being initialised with the starting conditions of the full simulation at that time. For example, the full model run from 1891 to 2004 is set running, and at the end of each time step REALM calls the REALM Driver executable program to check whether it has come to the end of June. If so (e.g. end of June 1891), the program starts a one year version of REALM running. In this example, this simulates the period from July 1891 to June 1892 assuming no trade and adopting the starting conditions from the full run at the end of June 1891. This process is presented in Figure 6 below. The components of the process enclosed in the red dashed rectangle represent those which are carried out by the Driver program which is described in more detail on the next page.

In order to use REALM to perform this process, some additional capabilities were required of REALM, and included:

- Enhancement of the REALM macro language;
- Output of variables such as storage values to a text file at every timestep;
- Allow the REALM system file to be re-read after every year.

The existing REALM macro language was enhanced as part of this project and formed the basis of the REALM Driver program. The REALM macro language works by reading a specified script file which contains instructions for REALM to execute. For example, the script file could contain instructions for REALM to load an existing scenario file, alter the specification of the input files to be read, alter aspects of the system file itself, save the scenario file under a new name and then run the new scenario. The REALM macro language is described in the report: “REALM Macro Development” (SKM, 2003).

The major enhancements of the REALM macro language required for this project included:

- the ability to adjust the limit curves;
- the ability to read the current season and year of a running REALM simulation;
- the ability to process “IF” statements based on month and year variables; and,
- the ability to run a dos command (e.g. execute another file, copy files, run a batch file etc.).

A copy of the text file which the REALM Driver program reads is presented in Appendix G.

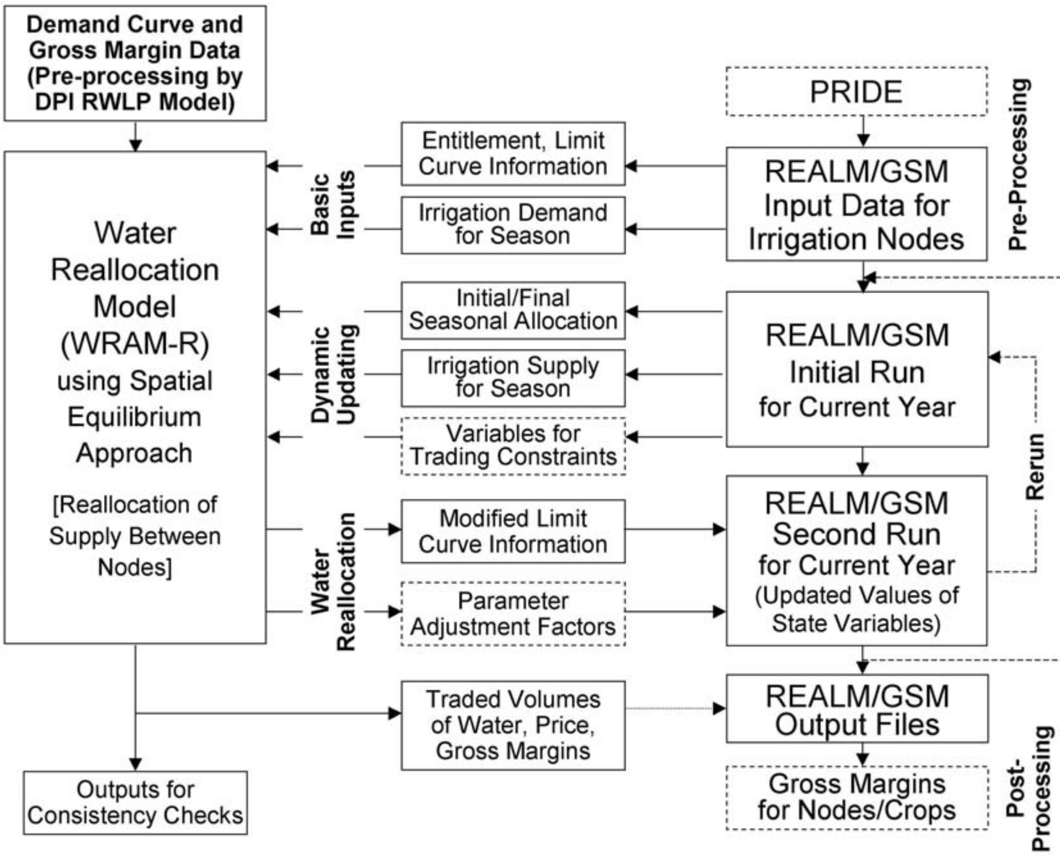


Figure 5. Schematic Diagram of Integration Framework.

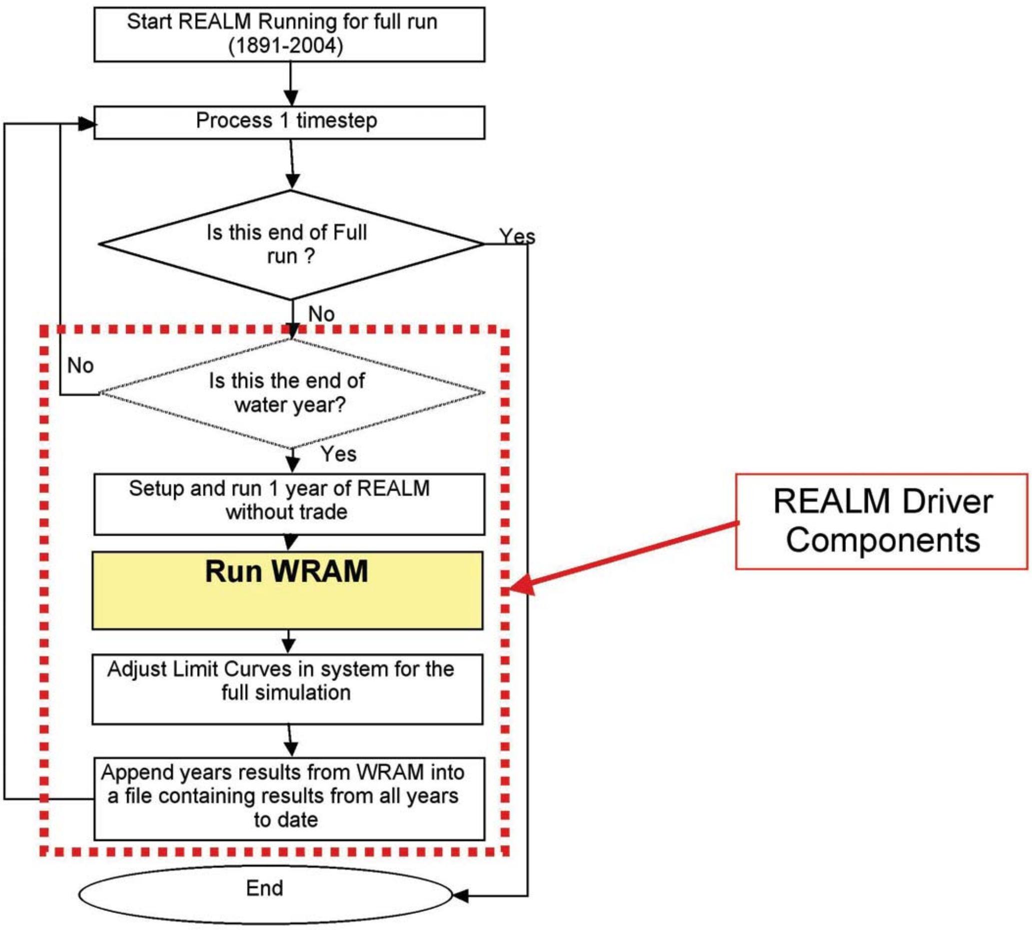


Figure 6. Components of REALM Driver Program.

7. Model Testing

As described in Section 5.2, WRAM-R was developed in two stages, first as a 'basic' or 'proof of concept' model version and then as the finally adopted 'enhanced' model version. Each of these versions was tested progressively to ensure the correct implementation of all the code development steps and the functionality of the overall model.

For the *basic model version* (no interpolation between the 15 discrete demand curve cases, no trader behavioural factors), the main objective for the testing was to establish if the basic modelling principles were workable and the model was able to broadly reproduce the expected trends in water prices and volumes traded over the range of climate conditions reflected in the historic data. For this purpose the model was applied with only the 11 main irrigation nodes participating in trading. This testing confirmed the basic functionality of the model but also indicated that a discrete representation of the effects of climate variability on economic demand for water was inadequate, and that inclusion of additional demand nodes was desirable.

The initial test applied for the *enhanced model version* developed by SKM was to ensure that this model was able to correctly reproduce the results of the basic version. Once this test was satisfied, the additional model functionalities were progressively tested and the model was applied with 14, 20 and eventually 22 trading nodes (including on urban demand node and two 'dummy' demand nodes to deal with the trading of unused allocations).

The various test applications confirmed the functionality of all components of the integrated WRAM-REALM modelling system. As part of these tests, it was also established that WRAM-R was able to accurately reproduce the equilibrium prices predicted by the DPI model for the given climate scenarios.

8. Model Application

8.1 Aims

The principal aim of the model application to a case study example is to establish if the integrated modelling approach developed in this project is able to satisfy the basic utility requirements of potential users. Specifically, it needs to be assessed to what extent WRAM-R can reflect the drivers of temporary water trading and the resulting reallocation of water entitlements between nodes, and if the integration of WRAM-R within the REALM modelling framework has been successful. Satisfactory model validation is a prerequisite for broader application of the model by industry parties.

Data on traded volumes and water prices is available for five water years, covering the period from July 1999 to June 2004, so the direct comparison with actual trade data is limited to this period. However, as this five-year period provides only a limited indication of the impacts of climate variability on water trading, the results of simulations over an extended period of historic climate data (July 1891 to June 2004) are also of interest.

The assessment of the model performance in this case study example should also provide an indication of the current limitations of the model and point the direction towards future model enhancements.

8.2 Case Study Area

The integrated model has been applied to model the impacts of temporary water trading on the Goulburn System, as represented by the nodes in the Goulburn System Model (GSM). Figure 7 shows a diagrammatic representation of the key features of this system.

The following Irrigation Districts are modelled as participating in trading (total of 11 irrigation nodes):

- Shepparton (divided into the 'Shepparton 0.8' and 'Shepparton 0.2' demand nodes)
- Central Goulburn (made up of 'Rodney', 'Tongala' and 'Deakin' nodes)
- Rochester (made up of Rochester East and Rochester West nodes)
- Pyramid-Boort (made up of Tandarra, Dingee and Boort nodes)
- Campaspe

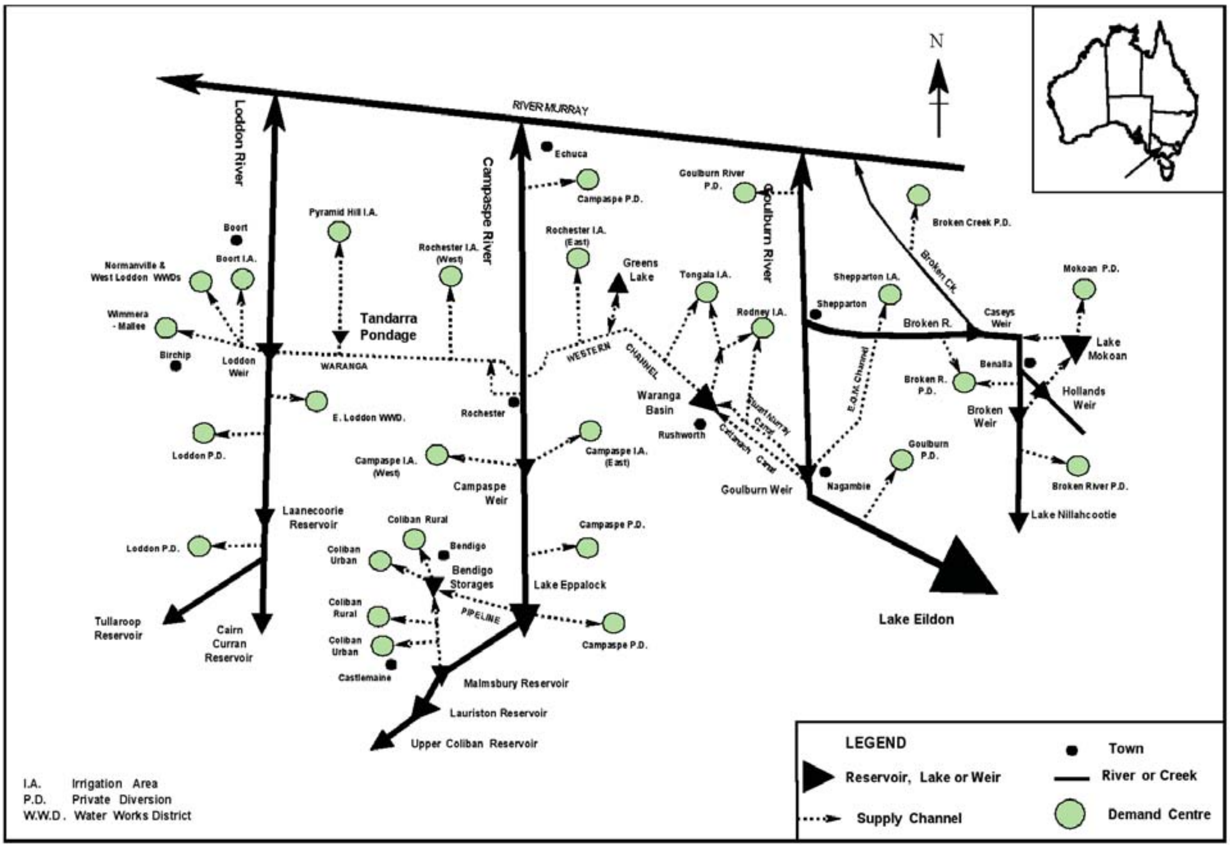


Figure 7. Goulburn System as Represented in GSM (from Perera and James, 2003)

In addition, the following Private Diversion areas are modelled as participating in trading (total of 8 private diverter nodes plus two 'dummy' nodes):

- Goulburn River (divided into Upper and Lower Goulburn nodes – there are also two 'dummy' demand nodes to model the trading of unused allocations at these nodes)
- Campaspe River (divided into Campaspe PD1, Campaspe PD2 and Campaspe PD3 nodes)
- Loddon River (divided into Cairn Curran-Laanecoorie, Tullaroop-Laanecoorie and Laanecoorie-Loddon Weir nodes)

The GSM includes one node for the major urban demands supplied from the Lower Goulburn River (mainly Shepparton/Mooroopna). The trading of the currently unused allocations held by the urban water authority is modelled using an additional 'dummy' demand node with an entitlement equal to the current unused allocation volume. The model thus includes a total of 22 trading nodes.

The demand areas in the Broken River and Upper Campaspe River catchments are not included in the model as potential participants in temporary water trading. (Trade out of the Broken system is currently prohibited.) While significant volumes are traded between the Goulburn System and the Murray System, these two systems are currently modelled as independent systems the simulation of trade between models is outside the scope of this project.

Data describing the distribution of agricultural industries, crop areas and water entitlements over the modelled part of the Goulburn System have been included in Appendix E.

8.3 Scenarios Modelled

The basis for modelling water allocation in the Goulburn System and the impacts of various scenarios is the calibration run undertaken by DSE for the system under Cap conditions. This run reflects 1993/94 conditions of development without any water trading. All the following scenarios are based on the REALM system files and GSM data files for these benchmark conditions.

The *Base Case* for modelling water reallocation in the Goulburn System reflects the economic drivers of water trading as represented in the demand curves derived from the DLP RWLP model, without any additional constraints or modifying factors. The additional scenarios introduce progressively a number of refinements or modifications which have the potential to improve the modelling results.

Scenario A1 introduces *perceived capacity constraints* for supply to the following nodes which regularly experience shortfalls in supply due to limited capacity of the delivery system (in order of decreasing frequency of shortfalls): Tandarra, Tongala, Boort, Rochester East and Rochester West. If the total annual demand at any of these nodes (including water traded in) exceeds a value at which farmers could expect about 20% shortfall in supply relative to unrestricted demand, WRAM-R assumes that no additional water will be bought by this node.

Scenario A2 retains the perceived capacity constraints of Scenario 1 and introduces two dummy nodes to allow *trading of unused allocations* at the two Goulburn Private Diverter nodes. These unused allocations typically amount to between 3000 and 7000 ML/year.

Scenario A3 builds on Scenario A2 by replacing the actual volume of water allocation with an *expected volume of seasonal allocation* at the time when farmers make water trading decisions. The expected volume of allocation for this scenario is calculated as the average of the August and February allocation levels.

Scenario A4 modifies Scenario A3 by applying a *'supply hedging factor'* to the excess supply curves at the Pyramid-Boort nodes for which the model had consistently overestimated the volumes of water sold. A very low value of 0.2 for the supply hedging factor was adopted to test the sensitivity of results to this factor.

Scenario A5 represents an alternative to Scenario A4 in which trade from the Pyramid-Boort nodes is restricted by specifying the following *trade-out constraints:* Tandarra 12000 ML, Boort 5000 ML, Dingee 5000 ML.

Scenario A7 is based on the findings from running the other scenarios, which indicated that some nodes were buying significant volumes of water that could either not be delivered to the node or not used by existing crop areas. This scenario thus includes trade-in constraints for the following four nodes: Shepparton 0.2, Shepparton 0.8, Deakin and Dingee.

8.4 Results

The results of the integrated modelling system can be divided into: (i) direct indicators of water trading (trading price of water, net volumes of water bought or sold) and (ii) impacts of water trading (volumes supplied to nodes, total system yield, seasonal allocation levels, reliabilities of supply, total gross margins).

The direct indicators of water trading are available from WRAM-R outputs and can be compared with actual trade data for the limited number of years for which trading data for the Goulburn system are available (1999-2004). Results from relatively short runs (starting say in 1990) can be expected to give an adequate indication of trading in the years of direct interest, as long as the GSM modelling provides an accurate reproduction of the seasonal allocation levels in these years.

The impacts of water trading on other performance characteristics of the Goulburn system can be best assessed by comparing the modelling results for a given water trading scenario with the results of a 'no trade' scenario (the benchmark conditions). Such comparisons are based on running the model over the extended period of record from July 1891 to June 2004. The results are presented either in the form of time series plots (e.g. for seasonal allocation levels or gross margins) or probability plots (e.g. supply reliabilities).

Trading Price of Water

As all the nodes in the Goulburn System are assumed to be part of the same pool for temporary water trading, one trading price of water applies over the whole region. Actual water prices fluctuate from week to week over a season; typically the minimum price is about 20 to 30% and the maximum price about 150 to 200% of the average price over the season. The WRAM-R model output is equivalent to a weighted average price over the season.

Figure 8 shows the variation of the modelled trading price of water over the period of simulation, based on Scenario A7. The price varied from a minimum of $24 in 1951/52 to a maximum of $265 in 2002/03. The average price was $40.80. Table 2 compares the modelled and actual average water prices for the period from 1999/2000 to 2003/04. The results indicate that the model is able to correctly reproduce the variation of actual water prices with seasonal climate factors, but the modelled water price is quite sensitive to the assumptions made in formulating different scenarios.

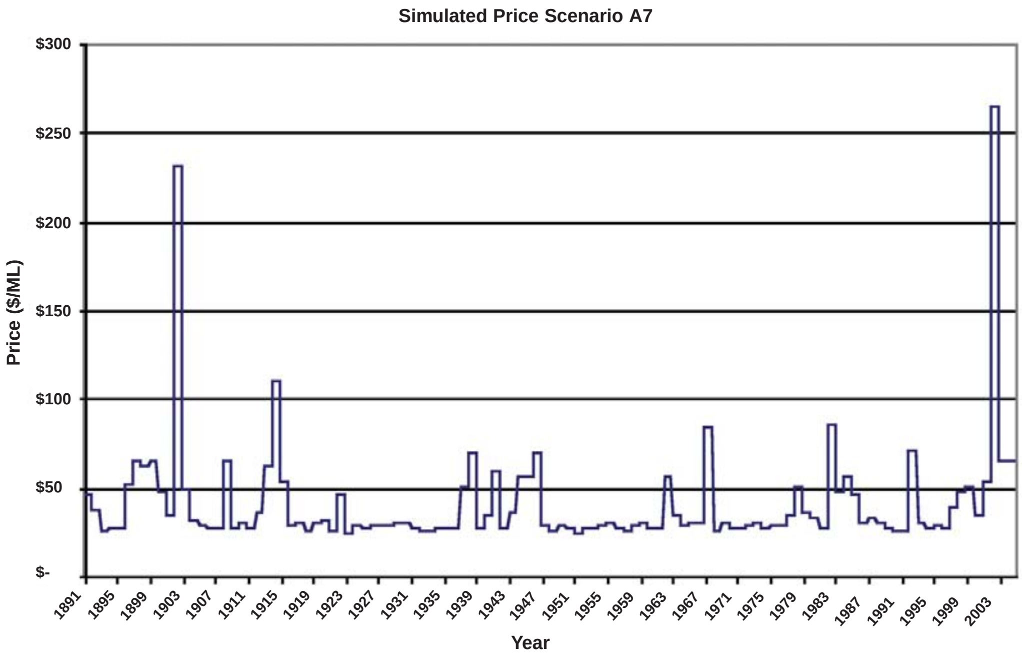


Figure 8. Variation of Simulated Water Trading Price Over Period of Simulation.

Table 2. Comparison of Simulated Water Trading Prices with Actual Prices.

Water Year	Actual Trading Price (W. Ave. for Season)	Simulated Trading Price			
		Scenario A2	Scenario A3	Scenario A4	Scenario A7
1999/2000	$56	$51	$108	$132	$50
2000/2001	$34	$34	$79	$98	$34
2001/2002	$100	$54	$101	$129	$53
2002/2003	$364	$262	$294	$328	$265
2003/2004	$67	$66	$136	$179	$65

Net volumes of water traded (reallocated)

The model results for the full simulation period show that the net volumes of water traded vary over a very wide range, depending on the seasonal conditions and the availability of supply (i.e. the seasonal allocation level). Figure 9 presents the simulated net trade volume for the Shepparton Irrigation District, based on Scenario A2. The volume traded varies from 7000 ML sold in 1999/2000 to 167,000 ML bought in 1894/95.

For a comparison of modelled with actual net volumes of water traded, the reallocated volumes of water have been summarised at the level of the four major irrigation districts in the Goulburn System: Shepparton, Central Goulburn, Rochester and Pyramid-Boort. Total net trade by the 12 minor nodes is summarised as 'Other'. Figure 10 shows a comparison of the simulated net volumes of temporary trade for Scenarios A1 to A5 with actual net trade over the period from 1999/2000 to 2003/04.

The main observation from these results is that WRAM-R is able to correctly reproduce the general direction of trade between 'seller' and 'buyer' nodes, but the accuracy of the simulated volumes is variable and depends on the assumptions and parameters used in the different scenarios. However, examination of the long term simulation results in Figure 8 also indicates clearly that the few years of actual trade data used in this comparison are not representative of the range of variation of trade that can be expected over a longer time span.

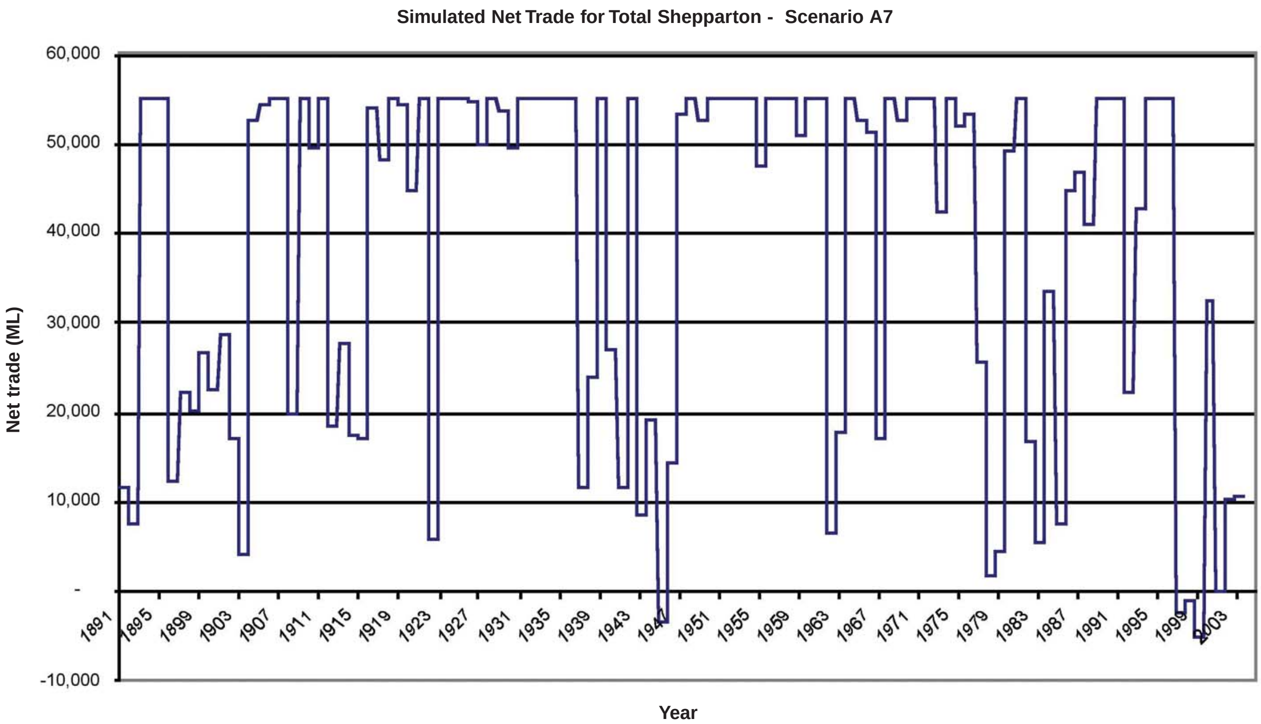
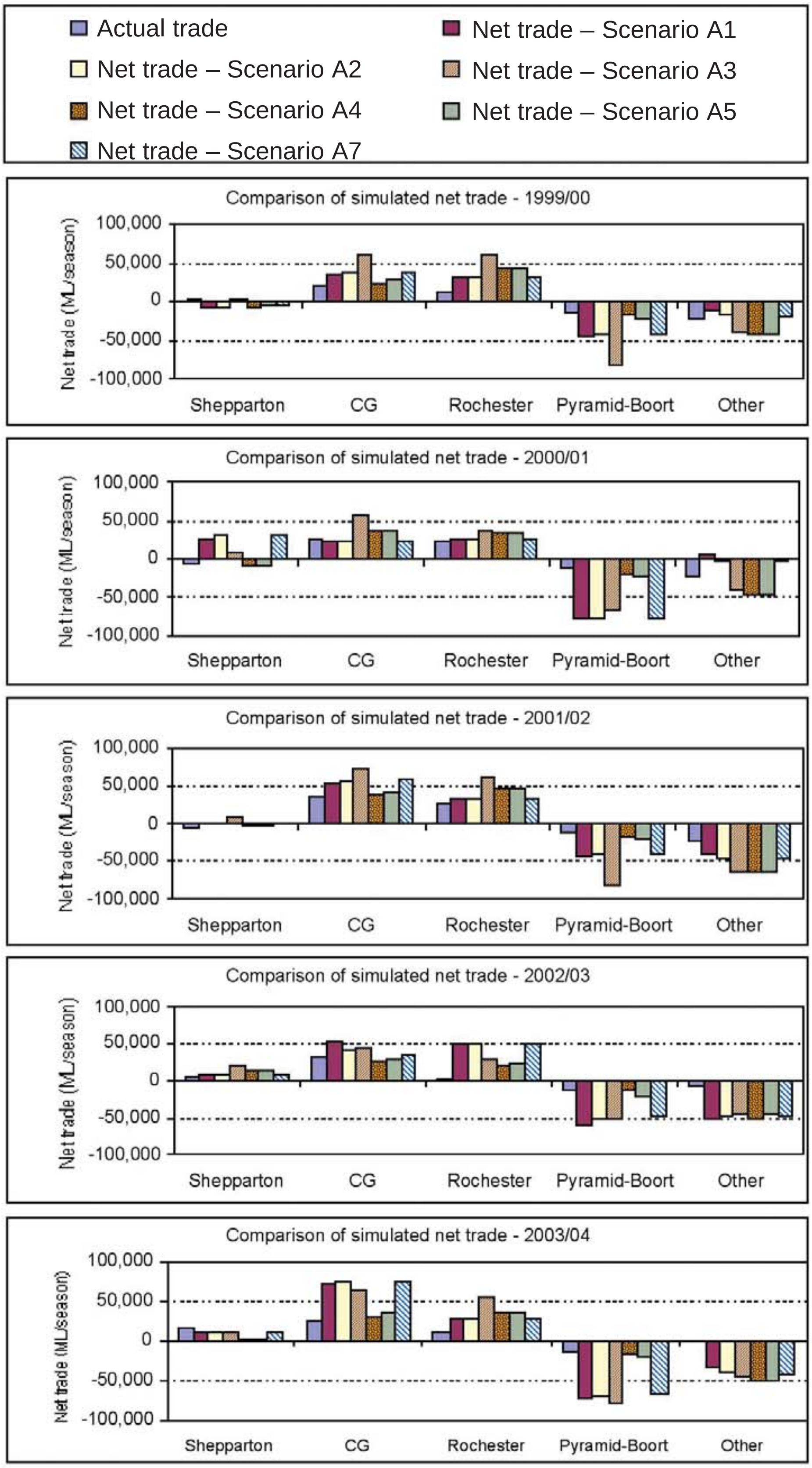


Figure 9. Variation over Period of Simulation of Volumes Traded in Shepparton District.



Note: Actual trade data for 'Other' trading nodes in Goulburn System not available for 2003/2004

Figure 10. Net Trade between Major Irrigation Districts in the Goulburn System.

Volumes Supplied

With trade, the volumes supplied to individual irrigation nodes may increase or decrease, depending on the direction of trade. The change in volume supplied to the different nodes generally directly reflects the computed volume of reallocated water entitlement resulting from temporary water trading, as discussed above. However, in years where supply is constrained by demand or limited delivery capacity rather than available allocation, only part of the additional water bought by a node will be supplied to it. This is illustrated in Figure 11 which compares for Scenario A7 the WRAM-R computed volumes of trade with the difference in supply between the Trade and No-trade cases.

As an example, in the 1992/93 water year (indicated by red circle) the modelled reallocation of water to the Rochester West node is about 18,600 ML but the supply to this node remains unchanged by this trade. This is explained by the fact that, for this water year, the unrestricted demand at the node is less than the allocation volume without trade. The additional volume bought is thus not required to supply existing demands. Furthermore, for both the Trade and No-Trade cases, in the month of highest demand (March), supply to the node is constrained by limited delivery capacity.

Figure 12 shows the simulated total volumes supplied to the Goulburn System over the period 1891/92 to 2003/04 for the No-Trade and Trade (Scenario A7) cases. The total volume of supply across all nodes changes relatively little from the 'No-Trade' case, as the model generally just reallocates supply between nodes. A small increase in total supply occurs in those years when trading allows increased utilisation of allocations. Conversely, in a few drought sequences there are carry-over effects, with increased utilisation in previous years resulting in reduced allocations and supply in a subsequent year. However, in many high allocation years, the WRAM-R predicted reallocations to buying nodes cannot be fully utilised, and in those years the total supply with trade is less than without trade.

System Yield

The water supply system yield is a measure of the nominal volume of supply that the system is able to deliver to various demands under a given set of system operation and water allocation rules. In the case of the Goulburn System, the system yield is expressed as the average volume of diversion over the entire simulation period. In this definition yield relates to water used for consumptive demands only; water supplied to satisfy environmental demands is excluded.

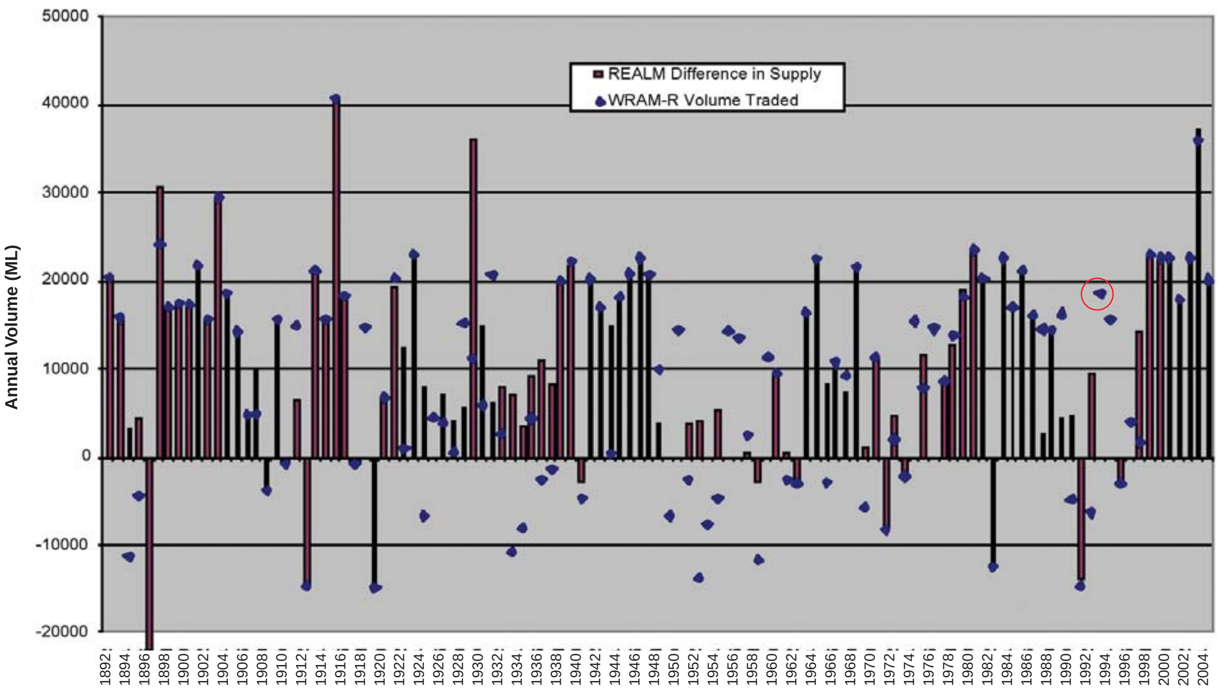


Figure 11. Comparison of Differences in Annual Volumes Supplied by REALM With and Without Trade and WRAM-R Computed Annual Volumes of Trade (Rochester West Node)

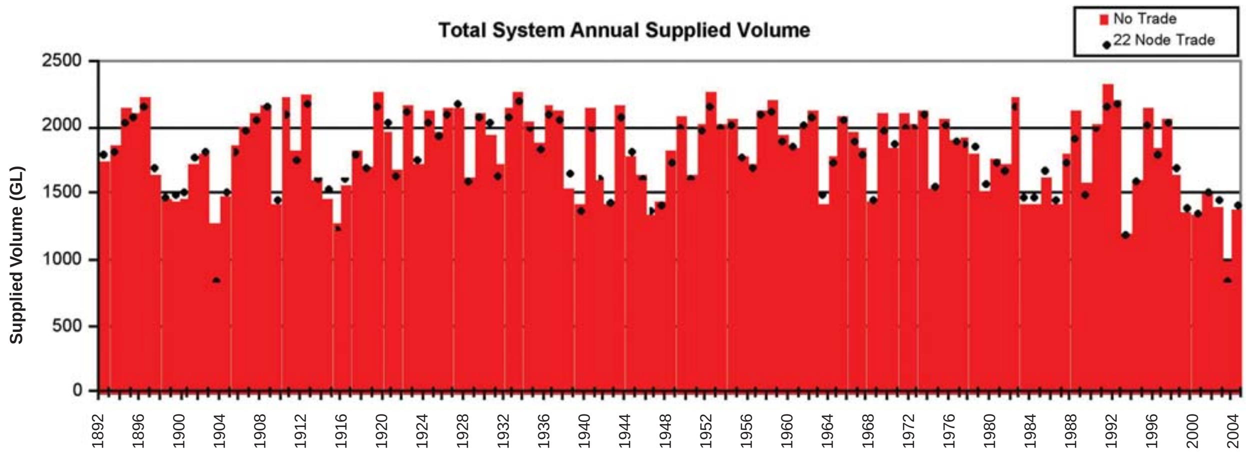


Figure 12. Comparison of Total Annual Volumes Supplied With and Without Trade.

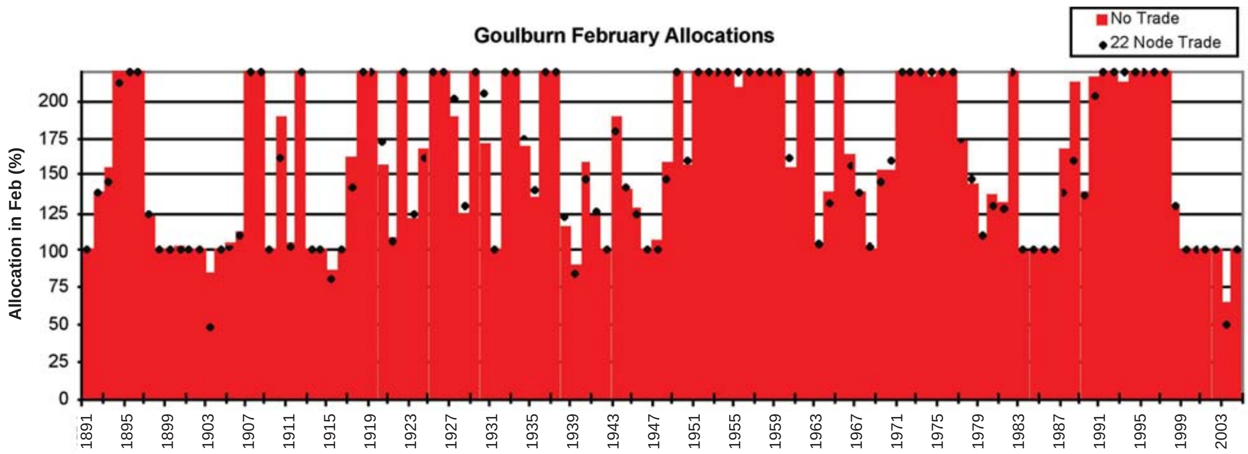


Figure 13. February Seasonal Allocations for Goulburn System With and Without Trade.

The system yield for the 'No Trade' case is 1820 GL/annum; for Trading Scenario A7 the equivalent figure is 1800 GL, representing a reduction of about 1%. This indicates that temporary trading of water has a relatively minor impact on system yield but the lower degree of water utilisation following temporary trading is somewhat counterintuitive. To the extent that water is being bought to increase security of supply, trade can be expected to reduce the degree of utilisation, but the WRAM-REALM simulation results also reflect another factor. Water that was previously used on low value crops is being reallocated for use at nodes with higher value crops, but some of this water remains unused, because WRAM-REALM does not allow for any increase in crop areas or crop water demands at nodes buying water.

Seasonal Allocations

The impact of temporary water trading on overall utilisation of water can be assessed by comparing the seasonal allocation levels with and without trading. Figure 13 shows a plot of February seasonal allocations over the whole simulation period for Scenario A7. It can be seen that the overall impact of trading on allocations is relatively small, but trading reduces the available resources in two of the worst drought years. This is probably due to increased utilisation of allocations at the start of the drought which produces lower storage levels in the worst year of the drought. The simulated increase in allocations in some years can be explained by carry-over effect of lower utilisation in some high allocation years, as discussed above, which results in higher storage levels and increased allocations in a subsequent year.

Supply Reliabilities

The percentage of time for which the seasonal allocations reach a nominated value can be used as a performance measure for the supply system. Figure 14 compares the supply performance of the Goulburn system with and without temporary trading. The percentage of time for which 100% water right can be supplied is used as an indicator of the systems 'reliability of supply'. The figure shows that the impact of trading on reliability of supply is relatively minor, with reliability of supply for both cases being

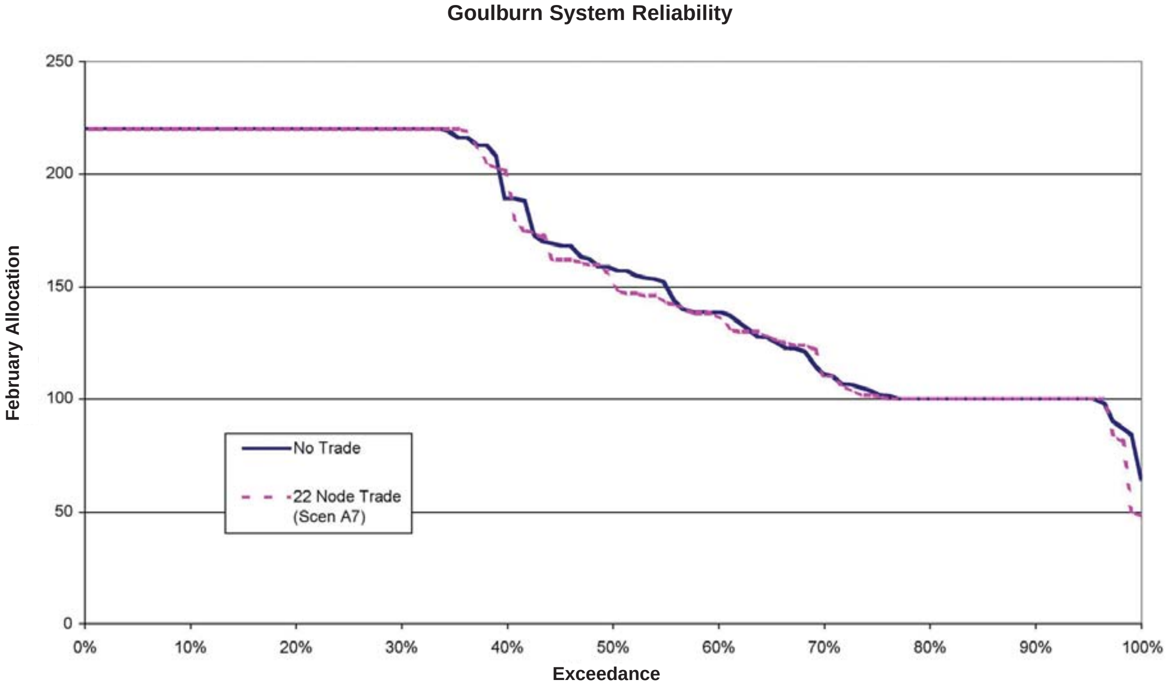


Figure 14. Probabilities of February Seasonal Allocations for Goulburn System.

Table 3. Comparison of Gross Margins for Different Scenarios.

Water Year	Allocation (%)	Gross Margin ($x1,000,000)						
		No Trade(*)	Scen. A1	Scen. A2	Scen. A3	Scen. A4	Scen. A5	Scen. A7
1999/2000	100	*384*	391	393	375	381	382	393
2000/2001	100	*398*	402	402	382	388	388	402
2001/2002	100	*386*	393	394	379	385	386	395
2002/2003	57	*340*	356	356	370	373	375	363
2003/2004	100	*385*	391	392	374	379	380	393

(*) The gross margins for the No-Trade case are approximate only

about 97%. However, the modelling indicates that allocations are likely to be lower in the 3% of years when full water right cannot be provided.

Gross Margins

The total gross margin for the irrigation nodes in the Goulburn System participating in water trading is an indicator of the farm returns gained from the use of irrigation water. Table 3 compares the calculated gross margins for the 'No Trade' case with those for a number of modelled trading scenarios. It can be seen that over the five water years analysed, temporary water trading results in a significant increase in total gross margins. It is also evident that the trading behaviour factors or trading constraints modelled in Scenarios A3 to A5, sub-optimal behaviour results in reduced gross margins compared with Scenarios A1 and A2. The slight increase in gross margins between Scenarios A1 and A2 reflects the value of unused allocations allowed to be traded.

8.5 Discussion

The initial application of the WRAM-REALM modelling system in a practical example has served to establish the basic functionality of all the modelling features. It has shown that the representation in the model of a number of constraints and trader behaviour factors has the potential to produce a better match between modelled and observed trading behaviour.

However, there are also a number of clear discrepancies between simulated and historic trade. In the following, some of the key factors which may contribute to these discrepancies are discussed in more detail.

Effect of DataLimitations

The following data limitations may introduce errors into the simulated water trading results:

(i) Some of the basic data used to derive the demand curves was not available for individual GSM irrigation nodes and had to be estimated by disaggregation or scaling of other data. Any errors introduced in this process can be expected to impact on the simulation results.

(ii) The crop areas and water entitlement data used to derive the demand curves represent the situation that existed in 1993/94, the conditions for which the current version of the GSM has been calibrated. However, it is known that since then there has been a general trend towards higher value crops and significant permanent transfer of water entitlements to areas where such crops predominate.

(iii) While a comparison of actual and simulated net trade for individual GSM irrigation nodes would give a better indication of potential sources of discrepancy, such a comparison was not possible, as data on actual volumes of net trade is only readily available at the level of irrigation districts.

Effect of Model Time Step

The representation in WRAM-R of the drivers and modifying factors of temporary water trading involves a number of simplifications. The principal simplification is that water trading, which in reality happens at weekly time intervals, is only modelled as total net trade over the whole season, and assumes that total irrigation water requirements for the season are known. In reality, at any point of time during the irrigation season, irrigators face a range of uncertainties about water requirement and supply availability over the remainder of the season, as well as uncertainties about the price of water and agricultural commodities. These uncertainties result in speculative sales and purchases of water, and fluctuations of water prices that are difficult to predict, even if a shorter time interval is used in the modelling. These fluctuations may bias the average annual water price and the net volumes traded compared to the values estimated from annual modelling. [It is likely that a mature and well informed market would be subject to smaller fluctuations than experienced in the early years of trading.]

Effect of Model Assumptions

The WRAM-REALM modelling approach adopts the basic assumption that, in northern Victorian irrigation systems, temporary water trading results in a reallocation of supply to irrigation demands that remain essentially unchanged from the ‘No Trade’ situation. This basic assumption restricts the maximum volume of water that can be reallocated (sold) from a node to the volume that would have been supplied without trade. This limited supply volume reflects the following factors modelled in REALM/GSM:

(i) less than full utilisation of allocation volumes in years of average to high seasonal allocations (at least 130% of water right) – this reflects a relatively high security of supply and is modelled in GSM through a ’limit curve’ which constrains the maximum volume of supply to the highest historic level of utilisation;

(ii) current level of unrestricted demand being lower than the assumed maximum level of utilisation reflected in the limit curve;

(iii) reduced supply due to delivery capacity constraints in years when, without trade, there are shortfalls in supply to a node due to the limited capacity of the channel system.

The first two factors combine to produce a significant volume of unused allocation in the Goulburn Private Diverter nodes. This has been allowed for in Scenarios A2 to A7 through the inclusion of ‘dummy’ nodes to allow trading of this unused allocation volume.

However, factor (i) also restricts the amount of water sold from other irrigation nodes. Without modification of the limit curves from those used in the GSM calibration and allowance for trading of unused entitlement in the WRAM-R algorithms, in years of high water allocation the total potential volume of temporary trade and simulated water usage may be overly constrained, and total water usage underestimated. As a consequence, the potential impact of trading on the total utilisation of water from the Goulburn Systems could be significantly underestimated.

Factor (iii) may act to constrain the water that can be sold from a node to a volume significantly less than the total allocation volume for the season. This constraint in the model ignores the fact that the sale of water from capacity constrained parts of the system would be beneficial and should thus not be restricted. The constraint also impacts on the trading price of water, resulting in an increased price for a given volume of water sold compared to an unconstrained supply.

The results from the initial model application to the Goulburn System have indicated that the practical impact of the artificial trade-out constraints introduced by the model assumptions is not severe. Even in high allocation years, WRAM-R tends to overestimate rather than underestimate the volumes traded out, as limited ability to use traded water at the ‘buyer’ nodes seems to be what limits trade, as discussed below.

The modelling of the economic drivers of temporary water trading in WRAM-R assumes that the water reallocated to buying nodes will be supplied and used productively. The results of the initial model application have also shown that this assumption is not satisfied at some nodes in many of the high allocation years. Water that before trade was used on low value crops has been reallocated for use at nodes with higher value crops, but some of this water remains now unused, because WRAM-REALM does not allow for any extra demand at nodes buying water through additional crop areas or increased crop water demand. Extra water usage at some nodes may also be restricted because of delivery capacity constraints.

Discussion of Specific Discrepancies

The major discrepancy between modelled and actual trade over the water years from 1999/2000 to 2003/2004 is that the net volume of water traded out of the Pyramid-Boort District has been severely overestimated. The full reasons for this are not clear, but unrepresentative crop and entitlement data may play an important part. Scenarios A4 and A5 constrain this trade, either by use of a hedging factor or by a trade-out constraint. The results presented in Figure 10 indicate that this also improves the prediction of trade to the Central Goulburn District.

The simulated lower degree of water utilisation in the Goulburn System following temporary trading, as indicated in Figure 12, is somewhat counterintuitive. To the extent that water is being bought to increase security of supply for high value crops, trade can be expected to reduce the degree of utilisation, but the discussion of model factors above indicates that the modelling assumptions in WRAM-REALM may have biased this result. Further model refinement will be required to allow a more definitive assessment of the impact of temporary trading on the degree of water utilisation in the Goulburn System.

9. Summary and Conclusion

The initial scoping work within the CRC for Catchment Hydrology's research program on Sustainable Water Allocation identified an important gap in current water system simulation capabilities using the REALM modelling package: the reallocation of water from temporary water trading in rural water supply systems could not be satisfactorily modelled. On this background, the project team for Activity 3 within the CRC Catchment Hydrology Project 3A developed the WRAM-REALM integrated modelling system described in this report. The Goulburn System in northern Victoria, as represented in the Goulburn System Model (GSM), was used as a case study example for this project.

The project used and enhanced the existing features of REALM which allow calling of other programs during a simulation run to link it to a newly developed water reallocation module called WRAM-R. Rather than developing a new economic optimisation model to represent the economic drivers of water trading, the project team decided to build on the substantial development work that had previously been undertaken by the Department of Primary Industries and which resulted in the DPI Regional Water LP model. This model was thus used to determine for each of the irrigation nodes participating in temporary trading a relationship between the trading price of water and the annual demand for water. These total demand curves were determined in a pre-processing step for 15 cases of crop water demand and supply availability, selected to represent the typical range of climate variability, and then made available to WRAM-R as data files.

Recognising that, in the northern Victorian irrigation systems, temporary water trading mainly results in modifying the availability of supply to given irrigation demands, rather than changing the demands themselves, WRAM-R simulates the effects of temporary trade as a reallocation of supply between irrigation demand nodes. Apart from the economic drivers of trading reflected in the demand curves, WRAM-R also includes features to reflect the effects of trading rules and effects of delivery capacity constraints, as well as a number of trader behavioural factors, which may vary between the different demand nodes.

WRAM-R also allows the trading behaviour of urban authorities to be represented through appropriately specified economic demand curves, trading rules and behavioural factors. Application of similar concepts to include trade by entitlement holders for environmental supplies is possible in principle, as long as these environmental flow entitlements are specified as exclusive rights and modelled in REALM as separate demands.

The WRAM-REALM output routines facilitate tabular or graphical presentation of simulation results and performance measures at the level of individual nodes or for the overall system. The water supply impacts of different trading scenarios can then be evaluated by comparing the results from different model runs.

The WRAM-REALM modelling system also outputs total gross margins for each of the irrigation demand nodes participating in trading, as an indicator of economic returns from irrigated agriculture, and to assess the direct impacts of water trading on these returns. Furthermore, the model outputs can provide water account information for use in an input-output model of the system, allowing the assessment of the broader economic impacts of different water trading scenarios.

The testing and initial application of the integrated WRAM-REALM modelling system to the Goulburn System has confirmed the feasibility of modelling in an integrated fashion the hydrologic and economic factors that affect the allocation and supply of water in complex rural water supply systems. It has also established the functionality of all the features in WRAM-R to simulate the reallocation of water that results from temporary water trading.

The comparison of simulated and actual trading prices and net volumes of water traded for the limited period for which data are available indicates that the modelling system is only partly successful in simulating the actual trading results over these drought years, which include the year of lowest seasonal allocation in a 113-year simulation period. Among the factors thought to be responsible for discrepancies between simulated and actual trade results is the fact that the crop area and entitlement data incorporated in the GSM do not reflect some of the trends since the 1993/94 water year, which defines the benchmark conditions used for modelling. The use of historical utilisation factors in the GSM has been found to act as a significant constraint on utilisation of water following trading, but future model adaptations to reflect the Victorian Government's White Paper reforms (DSE, 2005) are expected to overcome this limitation. Other limiting factors relate more directly to the modelling approach adopted in the WRAM-REALM system, including the limitations imposed by modelling water trading only at the annual level.

There is clear scope for further improvements to this modelling approach, based on the results of further exploratory applications and research. Some postgraduate research is already progressing to explore the potential of other economic modelling approaches using seasonal or monthly time steps to simulate trading behaviour (Zaman *et al.,* 2004; Griffith *pers. comm.*, 2005). However the full benefits of any further developments of the water trading component of an integrated modelling system will only be realised if these developments are accompanied by efforts to obtain more comprehensive and current data on irrigated agriculture in the water supply systems to be modelled, and recalibration of the REALM model using these updated datasets.

10. References

AFFA (2004), Australian Government, Department of Agriculture, Fisheries and Forestry, http://www.affa.gov.au/

DNRE (2001). The value of water – a guide to water trading in Victoria. Department of Natural Resources and Environment (in conjunction with rural water authorities), 109pp.

DSE (2005). Our Water Our Future – securing our water future together. Victorian Government White Paper, Department of Sustainability and Environment, http://www.dse.vic.gov.au.

Eigenraam, M., Stoneham, G. *et al.,* (1996). Water policy reform in Victoria: a spatial equilibrium approach. 40th Annual Conference of the Australian Agricultural and Resource Economics Society, University of Melbourne, Melbourne.

Eigenraam, M. (1999). Economic assessment of water market reform using the Water Policy Model, Department of Natural Resources and the Environment.

Erlanger, P.D., Poulton, D.C. and Weinmann, P.E. (1992). Development and application of an irrigation demand model based on crop factors. IEAust, Proc. Conference on Engineering in Agriculture, Albury, NSW, 293-298.

Malano, H and Wijedasa, A. (2003). Integrating trading into water allocation and economic modelling for the Goulburn-Broken Catchment. Article in ‘Catchword’ No. 118, July 2003, CRC for Catchment Hydrology.

Perera, B.J.C. and James, B. (1999) REALM – REsource ALlocation Model. Civil and Environmental Engineering Conference: New Frontiers and Challenges, 8-12 Nov., Bangkok, Thailand, pp. V~187-196.

Perera, B.J.C. and James, B. (2000) Advance Use of REALM in Water Supply System Simulation. Xth World Water Congress, Melbourne, 12-16 March, Paper No. 0347 (CD-ROM).

Perera, B.J.C., James, B. and Kularathna, M.D.U. (2003). Computer software tool for sustainable water allocation and management – REALM. MODSIM03

Perera, B.J.C. and James, B. (2003) A Generalised Water Supply Simulation Computer Software package – REALM, Indian Journal of Hydrology.

SKM, (2003). REALM Macro Development. Sinclair Knight Merz.

Victoria University of Technology and Department of Natural Resources and Environment, Victoria, (2001) REALM User’s Manual, June, http://www.nre.vic.gov.au/vro/water.

Wijedasa A, (2003). Notes for presentation to Project Team meeting of 28 January 2003.

Wijedasa A, (2004). Implication of water trading on system management and environmental flow: the case of the Goulburn-Murray Irrigation Scheme, Victoria. PhD Thesis, University of Melbourne.

Yu, B., Tisdell, J., Podger, G. and Salbe, I. (2003). A hydrologic and economic model for water trading and reallocation using linear programming techniques. MODSIM03

Zaman, A.M., Davidson, B. and Malano, M. (2004) What is driving temporary water trading in the Goulburn-Broken Catchment? AARES Conference, Melbourne.

APPENDIX A – GSM (REALM) Modelling in the Context of Project 3A

Introduction

The general features of REALM and GSM are described in a number of papers (e.g. Perera and James, 1999, 2000, 2004; Perera *et al.,* 2003). The purpose of this appendix is to provide some more detailed information on those modelling steps in REALM/GSM which are particularly relevant to the integration of water allocation modelling and economic optimisation modelling to reflect the impacts of temporary water trading.

The most common application of REALM models is for *scenario analysis and evaluation.* This scenario modelling process starts with the model set up phase, the definition of the model characteristics for a particular set of conditions (past, current or future). As part of this the model structure and the parameters defining the physical and operational system characteristics, irrigation entitlements etc are set and the climate and demand time series are provided as input files. These predefined system and climate characteristics remain *fixed during each simulation run,* but may be changed between runs undertaken for *different scenarios.*

Overview of Modelling Steps

The overall objective of water allocation modelling is to simulate the various physical, regulatory and operational factors which affect the balance of demand and supply in the water resource system being modelled. The modelling process to achieve this aim can be divided into a number of major steps. The order in which the steps are listed here indicates their logical sequence in the simulation.

For each month of the simulation period, the REALM/GSM modelling involves the following steps:

1. define the *level of basic (unrestricted) irrigation demand* at each demand node
2. determine the limits on supply imposed by *entitlements,* current level of *seasonal allocation* and assumed *utilisation*
3. apply restrictions to progressive supplies (deliveries) during an irrigation season
4. determine the optimum sources of supply and delivery routes
5. distribute *shortfalls in supply* at demand nodes in accordance with specified priorities of supply

Based on the monthly results from the modelling, a number of post-processing steps follow (for an irrigation season or the whole simulation period):

6. summarise and output the key system performance characteristics (e.g. volumes supplied, shortfalls, levels of restrictions)
7. prepare special outputs for system performance assessment, economic impact analysis and environmental compliance assessment

In the following, these steps are described in more detail.

Description of Individual Modelling Steps

1. Basic (Unrestricted) Irrigation Demands

The basic irrigation demand is pre-calculated using the PRIDE model, and the resulting monthly values for different demand nodes supplied to GSM in the form of input files. The irrigation demand computations are based on *fixed areas* planted to a *fixed mix* of crop types (for current or future scenarios), the crop water requirement of each crop type, and the climatic conditions as reflected by rainfall and evaporation for the month. While PRIDE computes the demands for different crop types at a demand node separately, they are then aggregated into total demand for the node, as REALM does not currently have the capability to separately model the demand of and supply to different crop types at a node.

While some of the assumptions and algorithms in the PRIDE model may warrant review in the light of more recent data and research results, this has not been attempted as part of this project. However, significant efforts have been made to ensure consistency in the crop area data used in PRIDE and in the pre-processing model that determines the demand-price relationship for irrigation water.

Longer term changes to crop types and crop areas could be modelled through scenarios, using information from long run economic modelling. The effects of changes to irrigation techniques and practices could be allowed for by changing relevant parameter values in PRIDE. Similarly, impacts of climate change scenarios on irrigation demands could be allowed for through changes of the rainfall and evaporation time series used in PRIDE.

2. Limits on Annual Supply: Entitlements, Seasonal Allocation, Utilisation

A number of features incorporated in REALM/GSM define the maximum annual supply that can be made available to a specific demand node. Individual water entitlements held by irrigators at a node are added to give the *total entitlement volume* of the node. This total entitlement volume for a year is kept fixed in a scenario but the impacts of *permanent water trading* can be reflected through scenarios which include modified total water entitlements for demand nodes with significant volumes of permanent trade.

At a particular time within the irrigation season, the expected *total allocation volume* for the year, i.e. the total volume of water that is expected to be supplied to a node over the whole season, is calculated as the product of the total entitlement volume and the current *seasonal allocation level.* This total allocation volume acts as absolute upper limit on annual supplies to the node.

The modelling of seasonal allocations in the GSM closely reflects the process used by G-MW to set actual seasonal allocation levels. An updated estimate of the *seasonal allocation level* for the next month is computed at the end of each month of simulation, based on a *'water budget'* over the period to the end of the planning horizon (end of current season or end of next season). The water budget accounts for water currently in storage, expected seasonal inflows (from low flow frequency analysis, without the use of any forecasting information), expected environmental releases, supplies to various demands, evaporation and transfer losses, as well as delivery efficiencies. The seasonal allocation level is set such as to preserve an agreed volume of reserve storage at the end of the planning horizon. [It should be noted that the determination of seasonal allocations in the current GSM does not fully reflect G-MW practice over the last few years, when total system resources were extremely low due to extended drought conditions.]

The actual supply data for the GSM system indicates that in years of average to high seasonal allocations (130% and greater) not all of this allocation volume is actually utilised. This is reflected in the GSM by the application of an *utilisation factor* as an additional limiting factor on modelled supplies. The utilisation factor for a node is based on the analysis of historic supply data. The use of these factors in the modelling

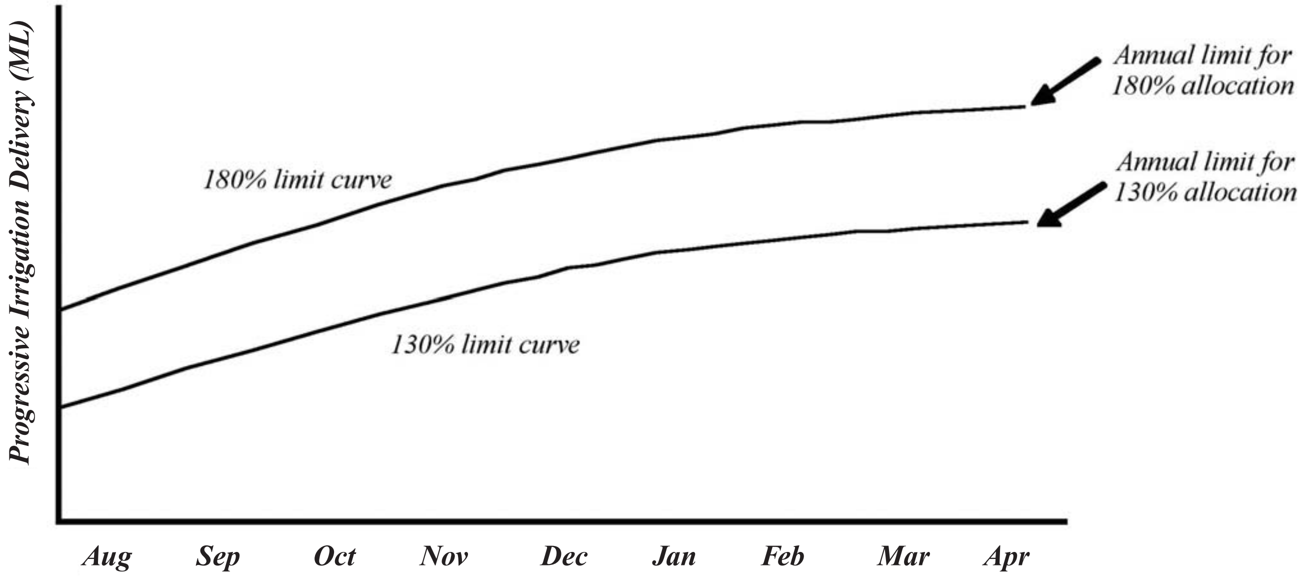


Figure A1 Limit Curves for 130% and 180% Seasonal Allocations.

of current or future supply scenarios involves the assumption that changes to agricultural industries, supply system characteristics and water allocation rules will only have a limited impact on utilisation levels. This assumption has important implications for modelling the impacts of water trade.

Combining all these factors, the limit on supply in the GSM is defined by the *limit curve* which gives for each allocation level a maximum volume of supply for the year, calculated as the product of the total allocation volume and the utilisation factor. These curves also provide upper limits to progressive supplies throughout the season (Figure A1).

The impact of temporary water trading, modelled in WRAM-R, is to increase or decrease the total entitlement volume at different demand nodes. This is reflected in GSM by a corresponding parallel upward or downward shift of the limit curves shown in Figure A1.

The GSM has a 'Capping mechanism' that can be turned on when modelling any scenario that has the potential to increase usage. The Cap mechanism applies continuous accounting to Cap overruns and Cap underruns and reduces Sales allocations when progressive overruns reach a pre-determined trigger level, which complies with the Capping requirements in the MDB Agreement (Schedule F). This Cap mechanism will need to be turned on if trade is shown to increase overall usage in the GSM.

3. Restriction of Progressive Supplies During a Season

Faced with expected shortfalls in supply in relation to basic (unrestricted) irrigation demand, an irrigator has the following options to deal with this situation:

(i) to irrigate fully a *reduced crop area*

(ii) to apply a *reduced irrigation rate* to all the initially planted crop areas

(iii) to avoid the expected shortfall by *buying additional water* through temporary trading (i.e. by increasing the total allocation volume)

(iv) to *substitute feed for irrigation water* (in the case of livestock enterprises)

or a *combination* of these options.

The current REALM/GSM modelling approach can only model options (i) and (ii) which both result in a restriction of supply in relation to unrestricted demands. The economic modelling approach adopted in WRAM-R allows choices between all the above options to be modelled.

The simplified modelling of supply restrictions in REALM/GSM assumes that the PRIDE-estimated basic (unrestricted) irrigation demands (as computed in Step 1) are modified as follows during a season. The group of farmers represented by a demand node will respond to a water shortage by progressively reducing the basic (unrestricted) irrigation demand so that progressive usage for the season to date does not

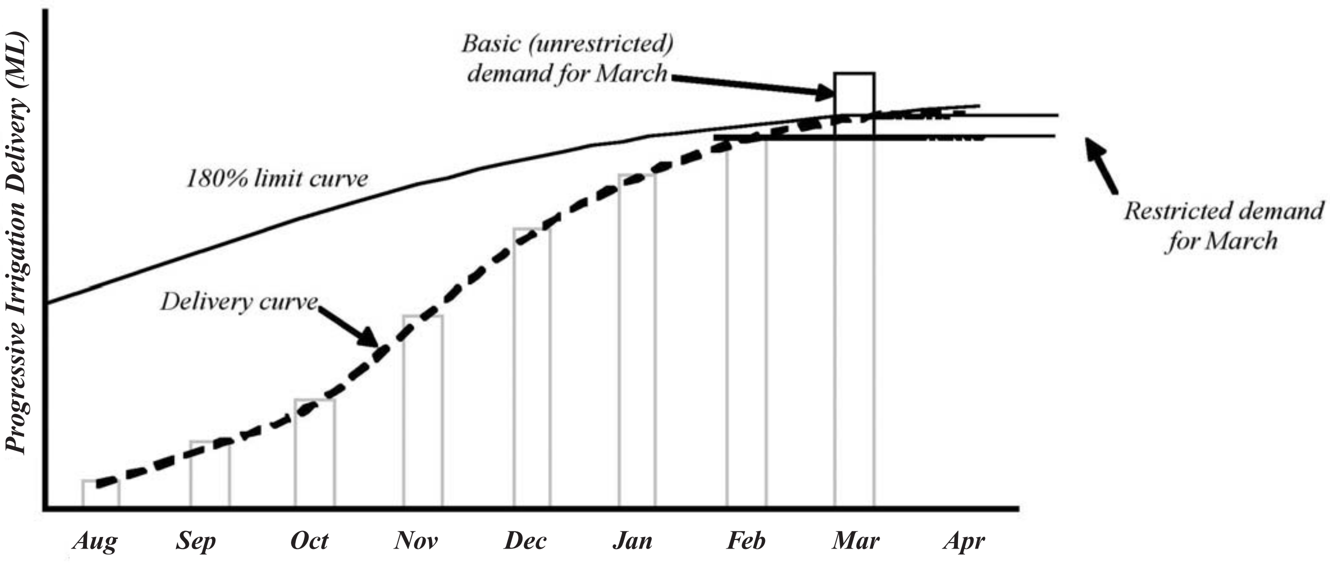


Figure A2 Impact of Limit Curves on Restricting Demands.

exceed the limit for the current month defined by a *limit curve.* The limit curves were designed to simulate how farmers control their usage during droughts while not restricting them too much early in the season when there is a high probability that allocations will increase. The limit curve is an inverted parabola with its maximum defined by the total allocation volume for the current season multiplied by the utilisation factor (as explained above). The other point that defines this parabola is a limit at the start of the season which applies the user defined "frac" parameter. [At this stage it has been assumed that the parabolic shape of the limit curves remains valid when they are adjusted for the results of temporary water trading.]

Figure A2 illustrates how the information from the limit curve is used to restrict the maximum volume of supply (deliveries) made available to demands in a specific month.

4. Optimisation of Supply Sources and Delivery Routes

In a complex water supply system such as the one modelled in GSM, there are usually a number of options how to deliver water from alternative sources to individual demand nodes. The priority of supply from different potential sources to individual demands is determined using predefined penalties assigned to the different sources, based on the state of the reservoirs in relation to target curves. Similarly, the carriers along alternative delivery routes are assigned penalties which reflect their relative priority in accordance to a set of operating rules or the relative cost of delivery. This is the step which uses the network LP algorithm (RELAX) built into REALM to optimise how supply is matched to demand. [The actual optimisation is undertaken for a more complex equivalent system network rather than the network defined by the actual physical system components and demands.]

A more detailed explanation of this component of REALM modelling is given in Perera and James (2000).

The routing of supply along model carriers also takes account of all specified capacity limitations in transfer or delivery channels.

5. Distributing Shortfalls in Supply

If the available supply from possible sources is insufficient to meet the restricted demand of a demand node, a supply shortfall will occur. The supply shortfalls at different demand nodes and for different levels of shortfall (or shortfall zones) are also subject to priority rules, implemented through penalty functions. The optimum distribution of shortfalls between different demand nodes and shortfall zones is achieved through the REALM LP algorithm, concurrently with the optimisation in Step 5.

The penalties assigned to different shortfalls (or the priorities assigned to different demands) reflect the existing system operating rule, which is to distribute shortfalls pro-rata across all entitlements affected by the shortfall, rather than being the result of economic modelling. While it would be possible in principle to use economic demand functions to determine priorities between different demands in situations of supply shortfall, it would violate the current rule that water entitlements are equal regardless of the crop type being watered. This would also require complex code changes and has not been considered within the scope of this project.

The deliveries to nodes resulting after all the factors in Steps 2 to 5 have been allowed for represent the final supply figures and are referred to as *'volumes supplied'* to individual demands.

6. Summary and Output of Key Modelling Results

The direct results of each GSM simulation run are time series data of all flows in carriers, unrestricted and restricted demands and volumes supplied, as well as various statistics of system performance in terms of proportion of demands supplied, shortfall volumes, etc at nominated points of interest in the system. A number of post-processing options are available to present these results in user-friendly formats and as graphical outputs.

These demand and supply statistics computed for the GSM demand nodes can form the basis for various forms of system performance assessment. However, as the results are aggregated to total values for demand nodes, which may represent a number of industries, they are of limited direct use for economic impact analysis.

7. Special Outputs for Performance and Compliance Assessments

The current GSM does not output any direct indicators of economic performance or process standard outputs into convenient formats for economic impact analysis. As part of WRAM-R, total gross margins for the enterprises represented at the demand nodes are calculated, as a simple direct indicator of economic performance. These total gross margins for nodes can be disaggregated into components for the main industries and crops represented at the nodes. An option is also available to undertake this disaggregation in relation to the sectors specified by an input-output model for the region.

In the current GSM, supply to environmental demands (as defined by minimum flow requirements in bulk entitlement specifications) is modelled as having the highest priority of supply (greatest penalties). REALM includes flexible features designed to replicate quite complex environmental flow rules where these have been defined, and GSM outputs allow assessment of compliance with these specifications. Current research is aimed at establishing more meaningful indicators of environmental performance, based on ‘flow events’. For indicators based on monthly or annual flow events, it will be relatively easy to post-process REALM/GSM results into appropriate outputs for compliance assessments.

References

Perera, B.J.C. and James, B. (1999) REALM – REsource ALlocation Model. Civil and Environmental Engineering Conference: New Frontiers and Challenges, 8-12 Nov., Bangkok, Thailand, pp. V~187-196.

Perera, B.J.C. and James, B. (2000) Advance Use of REALM in Water Supply System Simulation. Xth World Water Congress, Melbourne, 12-16 March, Paper No. 0347 (CD-ROM).

Perera, B.J.C., James, B. and Kularathna, M.D.U. (2003). Computer software tool for sustainable water allocation and management – REALM. MODSIM03

Perera, B.J.C. and James, B., (2003) A Generalised Water Supply Simulation Computer Software package – REALM, Indian Journal of Hydrology.

APPENDIX B[1] – The DPI Regional Water LP Model

Regional Agricultural Models

The Regional Water LP Model (referred to as the RWLP model) used in this project to estimate demand and supply characteristics for irrigation water in each region for given levels of crop water demand and water delivery has been developed as part of the DPI's Water Policy Model (Eigenraam, 1999).

A range of methods were considered for providing information about the regional demand for irrigation water. While econometric techniques are normally preferred, this was not feasible because the irrigation sector has been highly regulated in the past and there is very little historical data available from which to estimate demand for irrigation water. A simulation approach using linear programming models was therefore used to estimate the demand for irrigation water in irrigation regions.

Existing linear programming models (LP) of irrigation farming systems in Victoria were revised for this research. This covers the major irrigation areas of the Goulburn irrigation system. The area includes the Goulburn, Campaspe and Loddon Valleys of Victoria. Irrigation in these areas of Victoria accounts for 49 per cent of total State irrigation diversions (DNRE, 2001).

Table B1. Victorian Regions Modelled

Goulburn Valley	Campaspe Valley	Loddon Valley
Shepparton 0.8	Campaspe Irrigation	Tandarra
Shepparton 0.2	Campaspe PD1	Boort
Rodney		Dingee
Tongala		Loddon L-L Weir PD
Deakin		
Rochester East		
Rochester West		
Goulburn PD's		

A list of regions modelled is provided in Table B1. The LP models were used to determine the quantity of water demanded or supplied in each region over a range of water prices.

Linear programming is one of the most commonly used mathematical programming approaches. It has been applied to a wide range of resource management problems to determine the most economically efficient allocation of resources given a range of alternatives and constraints. Linear programming techniques have been used extensively in regional planning (Land and Water Management Plans in NSW) and water related research (assessment of the impacts of changes in water availability, water pricing and trading in Victoria and NSW). NSW Agriculture, ABARE and DLWC have also combined linear programming approaches with hydrology simulation modelling to evaluate the impacts of changes in water resource availability across different seasons.

Despite its broad applicability, there is a range of well-documented deficiencies of linear programming methods (see Hardaker 1971; Dent, Harrison and Woodford 1986), including:

- the assumption of linearity;
- perfect divisibility; and
- an objective function which maximises gross margin (in this case) where other objectives such as the minimisation of risk and accumulation of wealth could be equally applicable.

The significance of these limitations depends on the nature of the problem being addressed. Many of these limitations are relevant for individual farm analyses but less relevant for more aggregated or regional analyses like the one undertaken here. The development and evolution of better policy options requires the use of methods which provide some general insights into farm behaviour, rather than presenting a course of action for an individual farm. Parametric linear programming methods have been widely used to estimate demand functions for irrigation water in the past (Gisser 1970; Gisser and Mercado 1972; Flinn 1969; Moore and Hedges 1963; Briggs-Clark, Menz, Collins and Firth 1986; Chewings and Pascoe 1988; Read Sturgess and Associates 1991).

[1] This appendix is based on reports prepared by Mark Eigenraam, Department of Primary Industries

Model Specification - Irrigation Regions

Details of the Victorian model specifications and data used for each of these regions are contained in Branson and Eigenraam (1996a) and Branson and Eigenraam (1996b). Regional gross margin is defined as gross agricultural income less the variable costs incurred in production aggregated across the relevant region. Regional gross margin is therefore a measure of the profitability of agriculture in the region and can be used to estimate the impact on the sector of changes in water supply and demand.

The LP models developed for each of the 14 regions in Victoria maximise regional gross margin (M) according to the objective:

$$M = \sum_{j=1}^{n} (c_j - a_{ij} . x_j . p_i), \qquad (j = 1,.........n)$$

where:

c_j denotes all the revenue from activities j;

x_j is the magnitude of activity j;

a_{ij} is the amount of resource i used per unit of activity j (i.e. water);

p_i is the cost of resource i; and

n is the number of *j* activities.

subject to: $\sum_{j=1}^{n} a_{ij} . x_j . \quad a_i \qquad (j = 1,.........,m)$

These models include different water use technologies, alternative crop and livestock production enterprises and allow for the inclusion of variables that reflect different levels of management. Activities represented in the models include: permanent horticulture, summer and winter crops, livestock enterprises, hay making for on-farm use or sale, water buying and selling, and pasture transfers and reconciliations. Constraints include land area available by soil type and irrigation technology (landformed, non-landformed), limits to crop and pasture areas, volumetric allocation, off-allocation supplies, livestock numbers, and various pool constraints for pasture, crops and hay sales.

Crop and livestock prices used within the models are based on averages calculated over a five year period from 1994-95 to1998-99 (ABARE, various). Key model parameters such as crop and pasture yields and variable costs are obtained from a number of sources including research and extension staff within the Victorian Department of Primary Industries, various departmental publications (Downs and Sime, 1999; Economics Branch, 1998; other technical reports, etc) and information collected during catchment based planning initiatives (e.g.. Salinity Management Planning in Victoria). Enterprise areas and other land-use data are sourced from various G-MW censuses including Douglass *et al.,* (1998).

Water use requirements of crops and pastures are based on the results of long-term simulations using the PRIDE (Program for Regional Irrigation Demand Estimation) model (Erlanger *et al.,* 1992). Although the water entitlements (or pumping licenses) are fixed for each node, the on-farm water delivery can be varied between model runs using the percentage allocation. This means both the demand for and the supply of irrigation water to a node are the major input variables to the RWLP model, when analysing changes in water availability and water trading.

The models used were specified as short run models. That is, only limited farm adjustment is possible in terms of enterprise mix, such as the production of lucerne hay, vegetables, soybeans and dairying. It could therefore be argued that the elasticity of demand for water may have been underestimated. Whether short run models are adequate for analysing these policy reforms has been investigated by Pagan *et al.,* (1997) for the MIA. It was concluded that within any plausible range of pricing or environmental flow policy reform, the short run models would not provide substantially different results to longer run models.

Estimating derived demand and supply functions for irrigation water

The derived demand and supply for irrigation water is calculated by varying the price of water in the models and recording the quantity of water either demanded or supplied by the region in question. The water price here implies the price at which water would be traded on the water market and not what it costs to an irrigator for owning and using their own water. When the trade price of water is close to zero, a node may buy water on top of their own and use all possible irrigable land. The quantity of water bought would gradually decrease as the trade price increases. Then, the node would switch from buying to selling water in the water market. The reason being it becomes more profitable for the node to sell some of its own water and receive an income than using that quantity of water to produce irrigated agricultural crops or pasture. The quantity sold would increase as the trade price increases further (see Figure 3 in section 4.1).

Past approaches used Ordinary Least Squares (OLS) regression analysis to estimate linear demand functions from the price and quantity data collected using parametric techniques. For this report further analysis of the OLS approach revealed that in some instances the OLS intercepts exceeded the raw data. For instance, the maximum price used to estimate the demand curve may have been $100 however on fitting an OLS curve the intercept for the price axis would be less than $100 resulting in an under-estimate of demand at higher prices.

Therefore, the model derived demand curve is used for the modelling work reported here, without using linear regression. The RWLP model estimated functions represent an unconstrained[2] demand function in an unregulated market. It is assumed that the resulting derived demand curve is applicable to the conditions of an unregulated water market.

The derived demand curve represents the marginal value of water for irrigation activities in that region. In this analysis, it was necessary to make a clear distinction between the costs of supplying water to irrigation districts and the traded price for water established in the irrigation water market. Traded prices are established by the water market and reflect the relative scarcity of water. Supply price reflects the costs of trapping and delivering water and is specified as one of the costs of irrigation activities in the linear programming models.

The derived demand and supply curves assume that internal trade options will be optimised simultaneously. That is, trade opportunities are exhausted within the region prior to any external trade occurring. Therefore the results from the RWLP model only estimate the trade that occurs between the regions and not that within the regions. This has important implications for structural adjustment. The derived curves assume instantaneous adjustment within the region and further the RWLP again assumes between region trade will allow regions to make up any shortfalls in water (or sell if the price is sufficiently high).

This approach to the estimation of excess demand and supply relationships is repeated for all regions considered in an analysis, and for each scenario under consideration. The derived curves are different for each region and also for each of the scenarios (for example, the 15 demand curve groups in Table C1). Excess demand and supply curves are then incorporated into a spatial modelling framework, as described in Sections 5 and 6 of the report.

References

ABARE (2002), Environmental flows and water trade. ABARE Current Issues 02.3, March 2002.

ABARE (various issues), Australian Commodities, Australian Bureau of Agricultural and Resource Economics (ABARE), Canberra.

Branson, J. and Eigenraam, M. (1996a), Northern Irrigation Region Mixed Linear Program, Technical Report, Victorian Department of Natural Resources and Environment.

Branson, J. and Eigenraam, M. (1996b), 'Water policy in Victoria - A regional perspective', Paper presented to the 40th Annual Conference of the Australian Agricultural and Resource Economic Society, Melbourne, February.

Briggs-Clark, J., Menz, K., Collins, D. and Firth, R. (1986), A Model for Determining the Short Term Demand for Irrigation Water, BAE Discussion Paper 86.4, AGPS, Canberra.

Chewings, R.A. and Pascoe, S. (1988), 'Demand for water in the Murray Valley, New South Wales: An application of linear programming', Paper presented to the 32nd Annual Conference of the Australian Agricultural Economics Society, Melbourne.

Dent, J.B., Harrison, S.R. and Woodford, K.B. (1986), Farm Planning with Linear Programming: Concept and Practice, Butterworths, Sydney.

[2] The model was solved after specifying volumetric allocation to the region. The regional model was then solved unconstrained allowing it to buy or sell water depending on the marginal return to the use of the water. Other production resources, such as land, labour and capital, remained constrained.

DNRE (2001). The value of water – a guide to water trading in Victoria. Department of Natural Resources and Environment (in conjunction with rural water authorities), 109pp.

Douglass, W., Poulton, D., Abuzar, M. and Morris, M. (1998), Results of Irrigated Farm Census 1997, Goulburn Murray Water, Tatura, Victoria.

Downs, A. and Sime, A. (1999), Loddon Murray Region Horticultural Gross Margins 1999/00, Department of Natural Resources and Environment, Echuca, Victoria.

Economics Branch (1998), Northern Irrigation Dairy Region CAB: Assumptions document, Department of Natural Resources and Environment, Agriculture Division, East Melbourne.

Eigenraam, M. (1999) Economic Assessment of Water Market Reform using the Water Policy Model, Land and Water Resources Research and Development Corporation, Working Paper, Economics Branch, Department of Natural Resources and Environment

Erlanger, P.D., Poulton, D.C. and Weinmann, P.E. (1992). Development and application of an irrigation demand model based on crop factors. IEAust, Proc. Conference on Engineering in Agriculture, Albury, NSW, 293-298.

Flinn, J.C. (1969), 'The demand for irrigation water in an intensive irrigation area', Australian Journal of Agricultural Economics 13(2), 128-43.

Gisser, M. (1970), 'Linear programming models for estimating the agricultural demand function for imported water in the Pecos River basin', Water Resources Research 6(4), 1025-32.

Gisser, M., and Mercado, M. (1972), 'Integration of the agricultural demand function for water and the hydrogeological model of the Pecos basin', Water Resources Research 8(6), 1373-84.

Hardaker, J.B. (1971), Farm Planning by Computer, Technical Bulletin 19, Ministry of Agriculture, Fisheries and Food, London.

MDBC (1999) Structural adjustment pressures in irrigated broadacre farming in the Southern Murray-Darling Basin, Natural Resource Management Strategy, Murray Darling Basin Commission I&E Project No. I6041, Final Report to the Australian Bureau of Agricultural and Resource Economics

Moore, C.V. and Hedges, T.R. (1963), 'A method for estimating the demand for irrigation water', Agricultural Economics Research Vol. 15, 131-135.

Pagan, P., Fagan, M., Crean, J. and Jones, R. (1997) Short and Long Run Approaches to Water Demand Estimation, Paper presented to the 41st Annual Conference of the Australian Agricultural and Resource Economics Society, Gold Coast, Queensland.

Read, Sturgess and Associates (1991), 'Derivation of economic demand schedules for irrigation water in Victoria: Executive Summary', Water Resource Management Report Series, State Water Resource Plan, Victorian Department of Conservation and Environment.

APPENDIX C – Notes on Demand Curve Pre-processing

Demand curves have been defined and pre-processed for each irrigation node in the GSM and for 3 groups of seasonal irrigation demand conditions and 5 groups of seasonal supply conditions. The basis for defining demand and supply groups is documented in the following tables.

Table C1. Demand Curve Groups for Node x.

	Supply Group				
Demand Group	**1**	**2**	**3**	**4**	**5**
Wet (W)	W1	W2	W3	W4	W5
Normal (N)	N1	N2	N3	N4	N5
Dry (D)	D1	D2	D3	D4	D5

Table C2. Class Definitions for Demand Groups.

Demand Group	Class Boundaries		Representative Value for Group
	Lower	**Upper**	
Wet (W)	Min Demand	Mean – 10%	Mean – 20%
Normal (N)	Mean – 10%	Mean + 10%	Mean
Dry (D)	Mean + 10%	Max Demand	Mean + 20%

Note: The 'mean' demand condition refers to the standard (long-term average) net crop water demand values used in the original version of the DPI Regional Water LP Model

Table C3. Class Definitions for Supply Groups.

Supply Group		Class Boundaries (percentile)		Representative Value for Group (percentile)
		Lower	**Upper**	
1	Very low	0	4	2
2	Low	4	20	12
3	Below Average	20	40	30
4	Normal	40	65	50
5	High	65	100	80

Note: Supply levels relate to percentile values from the distribution of annual volumes of water delivery to each irrigation node over a long period of simulation

APPENDIX D[3] – Estimation of Crop Areas for Goulburn Simulation Model

Background

The Farm Irrigation Survey is conducted as a means of providing information on irrigation farming enterprises within areas under the jurisdiction of Goulburn-Murray Water in Northern Victoria (G-MW, 1998).

Since 1992/93, the census is conducted every four years and prior to the 1992/93 season the census was conducted annually. It is important to note that until 1991/92, the culture data was collected by G-MW field staff and first time data was collected by a mail out survey in 1992/93.

The 1996/97 Farm Irrigation Survey was also conducted mainly by mail out of survey to all irrigation customers and satellite imagery was used to verify the survey returns (approximately 70% returns in the 1996/97 census).

The last census was conducted in 2000/01 (G-MW, 2004) and only gravity irrigation customers were surveyed using the interactive voice recording on the water ordering system or Irrigation Planning Module (IPM) known to customers as WaterLINE. Around 53% of services that ordered water in 2000/01 completed the survey and half of the response were outside + or – 20% expected range. The outcome of the survey was documented but not published due to poor rate of reliable returns (approximately 30% of services).

Culture Data and Trends

According to the 1996/97 census report (G-MW, 1998), the total irrigation area has increased by over 2% per year from the 1992/93 census to the 1996/97 census. During this period perennial pasture has increased by over 3% mainly due to the expansion of dairy industry and this accounts for 68% of the increase in total irrigation area. There is not any recent published information readily available to quantify the changes in the total irrigation area since the 1996/97 census.

Since the 1992/93 census, the methodology used to collect the Irrigation Farm Survey varied from season to season and the rate of census returns also varied significantly. Therefore, it is practically impossible to directly compare census results without significant effort to analyse the raw returns. As stated earlier, poor return rates in 2000/01 prevented G-MW from coming to any meaningful conclusion from the 2000/01 census results.

Goulburn Simulation Model (GSM)

In late 1998, to meet MDBC cap obligations it was decided to replace the 1990/91 level of development irrigation demand with 1993/94 data in GSM.

As stated, the Irrigation Farm Survey was not carried out in 1993/94 hence the 1992/93 and 1996/97 census results were simply linearly interpolated to estimate the 1993/94 total irrigation culture area. The comparison of 1990/91 (based on census results) with the 1993/94 data (estimated) showed that there was approximately more than 10 percentage of increase in the irrigated culture area over the three seasons. In the absence of any actual field data for verification and uncertainty of the estimated 1993/94 culture areas it was decided to adjust the estimated 1993/94 culture area using actual water usage. The estimated culture areas for the 1993/94 season were adjusted until the PRIDE demand match with the cumulative plots of actual usage over the period July 1992 to July 1995.

[3] This appendix is based on notes provided by M P Seker of Goulburn-Murray Water, October 2004

Table 1. Adjusted Crop Areas for 1993/94 Level of Development (Ha).

Region	Annual Pasture	Perennial Pasture	Winter Crop	Summer Crop	Lucerne	Orchard	Wine	Total
Shepparton	21179	28205	1480	1396	538	4737	0	57535
Rodney	25039	37694	2447	1370	1000	3526	0	71076
Tongala	16474	41537	1749	334	243	539	0	60876
Deakin	3120	2701	0	239	113	0	0	6173
Rochester East	5015	7008	64	641	724	10	0	13462
Rochester West	15279	18385	2620	1313	737	10	0	38344
Tandarra	43684	10037	4595	1555	1272	0	0	61143
Dingee	15858	5353	746	432	818	0	0	23207
Boort	13487	3332	9967	1440	5990	1	0	34217
Campaspe District	497	3493	226	209	514	1	0	4940
Campaspe PD1	409	988	55	72	364	7	0	1895
Goulburn PDs	1133	2583	116	832	704	175	0	5543
Broken River PDs	1639	1662	115	439	89	61	0	4005
CC-Laan*	5	80	9	0	149	0	5	248
Laan-L Weir*	1053	839	295	117	687	3	96	3090
Tull-Laan*	20	102	22	5	344	0	0	493

*Included in the 2003 update for the first time

Thus, the final crop area numbers used by PRIDE to calculate demands in the GSM do not directly relate to actual crop areas as they include a calibration adjustment factor. Final adjusted crop area numbers used in the Cap model are presented in the following table.

References

G-MW (1998): Results of Irrigated Farm Census 1997, Goulburn-Murray Water and Department of Natural Resources and Environment.

G-MW (2004): Farm Irrigation Survey 2000/2001, Goulburn-Murray Water, Unpublished Report.

APPENDIX E – Data for DPI Regional Water LP Model

Crop area data are required in the economic optimisation model to estimate farm water demands and gross margins for different farming enterprises. For this purpose, estimates of *actual crop* areas are required, without the adjustments introduced in the calibration process. The unadjusted crop area estimates for the 19 irrigation nodes assumed to participate in trading are shown in Table 1. These estimates are based on the irrigation census data described in Appendix D and additional information obtained from DSE.

As the reporting regions for the irrigation censuses did not correspond directly to all the GSM modelling nodes, some data processing was required to estimate crop areas for all the 19 irrigation nodes assumed to participate in trading. In the case of the two nodes making up the Shepparton irrigation district the total areas were disaggregated to the nodal level using proportions of 0.8 and 0.2 respectively. In all districts, crop areas were available for some selected crops at the nodal level, and the areas under other crops (e.g. for the breakdown of orchard crops into pome fruit, stone fruit, citrus, etc.) have been sourced from various databases of previous G-MW censuses and surveys. Crop areas for private diverter nodes lacking detailed crop data were estimated on the basis of average water deliveries to the different nodes.

Table 1. Unadjusted Crop Areas used in Economic Modelling.

Region	Annual Pasture	Perennial Pasture	Winter Crop	Summer Crop	Lucerne	Orchard	Grapes	Total
Shepparton 0.8	15257	20317	1066	1006	388	3011	259	41304
Shepparton 0.2	3814	5079	266	251	97	752	65	10324
Rodney	20521	30894	2005	1122	819	2425	22	57808
Tongala	13502	34044	1434	273	199	388	8	49848
Deakin	3571	3092	0	273	129	0	0	7065
Rochester East	5498	7684	70	703	794	11	1	14761
Rochester West	17524	21087	3005	1506	844	11	2	43979
Campaspe Irrig.	477	3357	218	201	494	1	0	4748
Tandarra	39598	9115	4146	1440	1158	0	0	55457
Boort	12810	3165	9466	1367	5690	0	0	32498
Dingee	16739	5651	787	456	863	0	0	24496
Goulburn PDs	735	1675	75	539	456	113	0	3593
Campaspe PD1	462	1118	62	82	412	8	0	2144
Campaspe PD2	*5*	*21*	*50*	*3*	*4*	*0*	*0*	*83*
Campaspe PD3	*9*	*41*	*99*	*6*	*7*	*1*	*0*	*163*
Loddon CC-L PD	*5*	*80*	*9*	*0*	*149*	*0*	*5*	*248*
Loddon Tull-L PD	*20*	*102*	*22*	*5*	*344*	*0*	*0*	*493*
Loddon L-L Weir PD	1053	839	295	117	687	3	96	3090

Note: Nodes shown in italics have not been separately modelled. 'Goulburn PDs' comprises the Upper Goulburn PD and Lower Goulburn PD nodes (50% each).

A complication in modelling the two livestock industries (dairy and mixed) was that both use perennial pasture and annual pasture. However, data in terms of the breakdown of these pastures between dairy and mixed industries is not available. This limitation was overcome by including maximum area constraints for irrigated land and dryland under the three industries (see Table 2) estimated from the results of the G-MW census 1997 (Douglass *et al.,* 1998). The maximum perennial pasture area within a dairy farm was constrained to be 70% of the total irrigated area based on survey data (Armstrong *et al.,* 1998).

Important data with regard to irrigation water include water entitlements (or pumping licences for private diverters) and fees paid by irrigators to the water supply authorities (see Table 3). These data have been sourced from Douglass *et al.,* (1998) and G-MW website (2004), respectively. The fees paid for water consists of two components, "fixed" and "variable" fees. The fixed component of the fee is paid by each irrigator for their total water entitlements irrespective of whether they use any of this water. This amount of water is equivalent to "high-security" water in New South Wales. In addition to the basic entitlements, water authorities may allocate another percentage of entitlements (ranging from 0% to 120% depending on the extra storage available) on top of it, which is referred to as "sales" water. The variable component of the fee is paid only for the amount of water supplied to the property. This amount of water supplied may comprise water entitlements, sales water and any other water bought-in.

Table 2. Irrigated and Dryland Areas Under the Three Industries.

Region	**Dairy**		**Mixed**		**Horticulture**	
	Irrigated land	**Dryland**	**Irrigated land**	**Dryland**	**Irrigated land**	**Dryland**
Shepparton 0.8	17760	5600	21600	4400	4000	1600
Shepparton 0.2	4440	1400	5400	1100	1000	400
Rodney	42840	8400	26400	10500	2760	840
Tongala	24990	4900	15400	6125	1610	490
Deakin	3570	700	2200	875	0	0
Rochester East	8289	2795	7722	5913	10	40
Rochester West	22411	7556	20878	15987	10	40
Campaspe Irrigation	2920	1000	1700	1900	0	0
Tandarra	7911	3272	50490	32994	0	0
Boort	3516	1454	22440	14664	0	0
Dingee	3223	1333	20570	13442	0	0
Goulburn PDs	385	158	5456	3400	200	100
Campaspe PD1	434	178	1997	1250	65	0
Loddon L-L Weir PD	150	62	3000	1000	100	0

Table 3. Water Entitlements Between Industries and the Fees Paid by Irrigators.

Region	Water entitlements/pumping licences			Fees for water paid by irrigators	
	Dairy	Mixed	Horticulture	Fixed	Variable
Shepparton 0.8	60520	65600	18528	35.25	6.37
Shepparton 0.2	15130	16400	4632	35.25	6.37
Rodney	145632	81738	13302	30.29	7.49
Tongala	90412	47681	2300	30.29	7.49
Deakin	13245	6812	0	30.29	7.49
Rochester East	29922	21206	40	28.32	7.08
Rochester West	80968	57334	40	28.32	7.08
Campaspe Irrig.	9928	10792	0	38.10	8.66
Tandarra	21082	103075	0	22.97	5.81
Boort	9370	45811	0	22.97	5.81
Dingee	8589	41994	0	22.97	5.81
Goulburn PDs	1769	25072	919	6.55	1.70
Campaspe PD1	2659	12234	398	6.55	1.70
Loddon L-L Weir PD	314	6288	210	6.55	1.70

Maximum numbers of dairy cows, beef cows and ewes that a region could run were estimated with due consideration of the pasture area in each industry and the average stocking rates in the region. This was due to the unavailability of data on stock numbers at the required geographical scale.

References

Armstrong, D., Knee, J., Doyle, P., Pritchard, K. and Gyles, O. (1998). A survey of water-use efficiency on irrigated dairy farms in northern Victoria and southern New South Wales. Department of Natural Resources and Environment, Tatura.

Douglass, W., Poulton, D., Abuzar, M. and Morris, M. (1998). Results of irrigated farm census 1997. Goulburn-Murray Water and Department of Natural Resources and Environment, Tatura.

G-MW website (2004). http://www.g-mwater.com.au/.

APPENDIX F – WRAM-R Input and Output Data

ASCII files are used to transfer data between the WRAM-R and REALM programs. Some of these files contain data that does not change over the whole simulation period and some files contain data that is updated annually by either WRAM-R or REALM. These files can be grouped into the following four categories which are described in more detail in the table below.

1. Inputs to WRAM-R not dependent on the REALM simulation

These files contain information needed by WRAM-R such as the demand nodes in the REALM participating in trade, the pre-processed demand curves, class boundaries for representative supply and demand levels and a number of WRAM-R adjustment factors. As the data in these files does not depend on annual variations in water supply coming from the REALM during the simulation, these files are read by WRAM-R but are not over-written.

2. Inputs to WRAM-R dependent on REALM simulation

The data in these files will vary annually during the REALM simulation. It is output by REALM as 12 monthly values at the end of each year and is subsequently read by WRAM-R. This information includes such information as the current simulation year, supply to each demand node (in the absence of trade), demand limit curves and allocation levels.

3. WRAM-R outputs needed for the REALM simulation

This file contains the demand limit curves for each demand node after WRAM-R has adjusted them to allow for trade. It is the key feedback information needed by REALM to undertake the simulation including temporary trade.

4. WRAM-R outputs not needed for REALM simulation.

These files are output by WRAM-R for analysis after the simulation is complete. They contain information such as equilibrium price, gross margins and the volume traded at each node.

WRAM-R input/output data specification

Format		Description	Filename P=PRIDE R=REALM S= .SYS* O=Other
1	**Inputs not dependent on REALM simulation**		
1A	5 **header lines** initially, then 1 or 2 header lines between each block of data **Number** of demand nodes involved in trade. List of **demand node names** with corresponding values of **behavioural factors** for water trade: *hedging factor for water sales, minimum water price and expected supply weighting factor.* Global values of supply *hedging factor and maximum extrapolation factor.* **Number** of supply and demand cases 15 demand curve **filenames** 2 **class boundaries** and 3 **mid points**, *used for defining demand scenario this year using DEMAND INDEX variable read from REXT1.dat file.* 4 **class boundaries** and 5 **mid points**, *used for defining supply scenario for each demand using annual supply obtained from monthly values in WRAMSUPP.DC file* List of demand node **names** and their annual **limit on demand** due to capacity constraints for each demand node for each of 15 scenarios List of demand node **names** and their annual **limit on trade-in** to each demand node for each demand node for each of 15 scenarios List of demand node **names** and their annual **limit on trade-out** to each demand node for each demand node for each of 15 scenarios	0001WRAM.dat	O
1B	DPI pre-processed demand and gross margin data; *one file for each scenario means 15 files are needed.*	01S1D1.DAT to 01S5D3.DAT	O

2	**Inputs dependent on REALM simulation**		
2A	Current **year** and current **month**. *WRAM-R runs on annual time step initially so month is not used.* **DEMAND INDEX** calculated from RODNEY demand node (average value is 100). *Delivery & trading **constraints** that vary annually: e.g. **volume** of Campaspe to Goulburn supplement this year and volume of trade allowed upstream of Goulburn Weir.*	REXT1.dat	O
2B	**Supplied demand** (without trade) at each node for that year. *WRAM-R reads twelve months data for each demand node and accumulates to annual total.*	WRAMSUPP.DC	R
2C	**Unrestricted demand** at each node for that year. *WRAM-R reads twelve months data for each demand node and accumulates to annual total. Currently not used.*	WRAMUNRS.DC	R
2E	**Restricted demand** at each node for that year. *WRAM-R reads twelve months data for each demand node and accumulates to annual total. Currently not used.*	WRAMREST.DC	R
2F	**Allocation level** for each node for that year. *WRAM-R reads twelve months data for each demand node.*	WRAMLVLS.DC	R
2G	Water **entitlement** before trade for that year. *WRAM-R searches file for node name match and reads entitlement/allocation relationship. Entitlement corresponding to May allocation level defines pre-trade volumetric allocation. WRAM-R may need to check that trade-out volume does not exceed this volume.*	L_curves.dat	O
3	**Outputs not needed by REALM simulation**		
3A	Trade **price** for that year. *DRIVER will append this file to a file with current run name containing previous year's output.*	WRAMPRIC.DC	R
3B	**Gross margin** at each node for that year. *Expressed as $ per ML supplied. DRIVER will append this file to a file with current run name containing previous year's output.*	WRAMGROM.DC	R
3C	**Volume traded** at each node for that year. *DRIVER will append this file to a file with current run name containing previous year's output.*	WRAMTRAD.DC	R
4	**Outputs needed by REALM simulation**		
4A	**Revised limit curves** with adjustment for volume traded at each node for that year. *WRAM-R searches file for node name match and adds traded volume to each point on limit curve.* *Note: 1) these traded volumes are same data as in 3C.* *2) at zero allocation limit volume for some demands may be negative.*	L_curves.dat	S

NOTES: * This format defined by the format used by the REALM model system file.

APPENDIX G – REALM Driver

REALMDriver.txt

```
 if (currentyear=1891) then
   if (currentseason=1) then
      doscmd : setupforwram.bat
   endif
endif
load : 1_yr.scn
if (currentseason=6) then
   Change parameters : Scen%StartYr = currentyear
   Change parameters : Scen%EndYr = currentyear + 1
   Change parameters : Scen%LogName = one1.log
   SaveAs scenario : one1.scn
   Run : one1.scn
   doscmd : wram_tjs_v17.exe
   doscmd : copy l_curves.apd+l_curves.out l_curves.apd
   append :one1stor.rv|appnstor.rv
   append :one1flow.ar|appnflow.ar
   append :one1capc.ar|appncapc.ar
   append :wramgrom.dc|appngrom.dc
   append :wramtrad.dc|appntrad.dc
   append :wrampric.dc|appnpric.dc
   append :one1supp.dc|appnsupp.dc
   append :one1lvls.dc|appnlvls.dc
   load : l001.scn
   change parameters: all_limits=l_curves.out
   saveas system : GOULt817_t.SYS
endif
```

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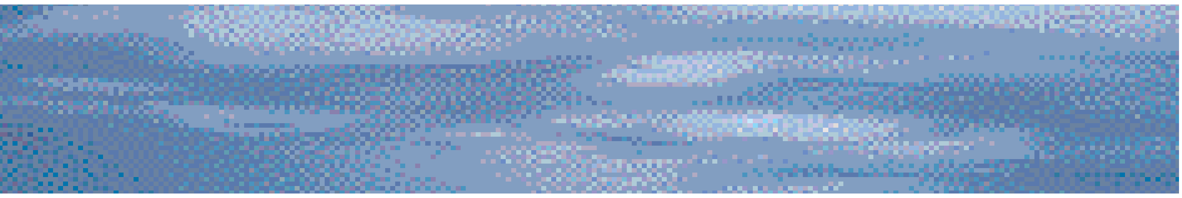

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- Bureau of Meteorology
- CSIRO Land and Water
- Department of Infrastructure, Planning and Natural Resources, NSW
- Department of Sustainability and Environment, Vic
- Goulburn-Murray Water
- Grampians Wimmera Mallee Water
- Griffith University
- Melbourne Water
- Monash University
- Murray-Darling Basin Commission
- Natural Resources and Mines, Qld
- Southern Rural Water
- The University of Melbourne

ASSOCIATE:

- Water Corporation of Western Australia

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