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A framework for developing an integrated modelling system for water policy analysis

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The irrigation industry in the Murray–Darling Basin is an important economic resource in terms of Australian agricultural production and rural employment. However, the sustainability of irrigation industries in the region is impeded by the uncertainties associated with the aging irrigation infrastructure, evolving institutional arrangements and growing resource degradation that impact on productivity. Industry reforms intended to relieve structural and behavioural impediments require wider participation of stakeholders, significant investments and commitment to change. The economic success of such policies will depend on the ability of the stakeholders to pay for those investments and the effectiveness of reforms in promoting productive innovation and market competitiveness.

A modelling system to examine the spatial and intertemporal interactions of adjustment scenarios, including the evaluation of alternative infrastructure refurbishment options for the basin, is introduced in this paper. The framework will permit the treatment of economic efficiency goals within specified environmental constraints. ABARE proposes to use this modelling framework in assessments of water resources policies, technology adoption and infrastructure replacement options.

ABARE project 1103

1 Introduction

Efficient and sustainable water use is a national goal endorsed by all current federal and state Australian governments. In pursuing this goal, the irrigation industry, being the major user of water in Australia, is undergoing significant reforms. The expected key outcomes of the reforms are greater user involvement in management, cost recovery based financial management and greater environmental responsibility by irrigation industry operators. Many of the reforms are designed to address the economic and ecological sustainability of irrigation in the basin (Working Group on Water Resource Policy Secretariat 1994). It is also generally accepted that significant structural adjustment leading to more efficient resource use systems may be necessary to achieve long term sustainability objectives (Industry Commission 1992).

Important reform issues identified by the Industry Commission (1992) include water pricing for cost recovery, institutional reforms to facilitate cost efficient service delivery and improved water rights systems to ensure that water is directed to its highest value uses. Following those discussions, in February 1994 the Council of Australian Governments (COAG) agreed on a water industry reform agenda. The endorsed policy objective is to achieve an efficient and sustainable water industry through:

- pricing reform — including full cost recovery and the removal of cross-subsidies;
- moves toward institutional and organisational reforms with greater user involvement in water administration;
- deregulation of water markets with transferable water entitlements;
- clarification of property rights to water; and
- allocation of water to the environment.

Much of the reform agenda acknowledges the inadequacy of the current water industry arrangements to promote sustainable natural resource use and to provide for the costs of refurbishing the existing infrastructure to maintain operations. Moreover, the changes associated with the water policy reforms themselves can be expected to affect both consumptive and environmental water demands, and hence demands for associated water supply infrastructure.

However, given the differences in the stage of progress in the reform process and the diversity of problems faced by the irrigators and other stakeholders in different Australian states, adoption of blanket policies and uniform measures to facilitate the reform process may be unviable. For example, water transferability has been allowed in South Australia for over a decade and there are significant differences in water use and the trading rights of irrigators between states.

Issues such as the total extent of the available water resource within the management region, likely magnitudes of competing demands and net transfers of water between competing needs are also likely to affect the implications of alternative infrastructure refurbishment options.

The cost incurred by stakeholders in the irrigation communities of meeting infrastructure refurbishment will impinge on the profitability of the enterprises using water as a productive input. Therefore, the commercial viability of irrigators and the sustainability of their operations in the face of irrigation policy reforms and emerging environmental considerations are key issues that relate to the investment merits of alternative infrastructure refurbishment options.

As Musgrave and Bryant (1993) observe, all adjustment options need to be carefully examined with their associated economic and social costs and returns. 'The scope for government(s) to influence these processes is considerable and its involvement is almost certainly desirable. Such intervention raises important issues of efficiency and equity, the definition of which would greatly aid the selection of optimal public policy (page 2).' To this end, economic modelling and analysis can provide useful information about the irrigation system and its likely performance under changing policy, technological and marketing environments.

ABARE's IMMS model (Integrated Murray–Murrumbidgee System model) (Hall, Poulter and Curtotti 1994) provides a framework to assess some on-farm and off-farm changes, including changes in rules governing trading of water allocations. However, the model is designed to represent the short to medium term and does not have the capacity to trace structural adjustment paths, given different options. ABARE's multiperiod investment model MIPMOD (Mallawaarachchi, Hall and Phillips 1992) on the other hand, provides a framework to analyse longer term investment options. The amalgamation of these two models could provide a robust modelling framework to enable examination of water industry reform options. It could also provide opportunities to explore advances in modelling techniques that can simultaneously handle both spatial and intertemporal dimensions.

This study is one of a program of ABARE projects designed to address the wider issues of the sustainability of land and water management regimes. Existing models and the modelling systems being developed will be used to assist ABARE's land and water research. While the vision for future model developments is provided in this paper, it identifies in particular the developments earmarked over 1995 to enable the examination of infrastructure refurbishment issues. The primary focus in this study is to examine the ability of regional irrigation industries to finance various infrastructure refurbishment options, including the costs involved in maintaining the existing irrigation structures.

In this paper the issue of structural adjustment is revisited in relation to current irrigated farming structures and operating environments. This is followed by a discussion of a framework to address the investment issues related to structural adjustment options, including an assessment of the capacity of ABARE's current IMMS model to handle such analysis. Finally, proposed additions and amendments to conceptually integrate IMMS and MIPMOD models to enable multiperiod investment analysis are described.

2 Structural adjustment in the irrigation industry

The irrigation industry of the Murray–Darling Basin represents approximately three-quarters of Australia's irrigated crop land. It supports a quarter of the nation's cattle herd, half the sheep flock and half the crop land. The major irrigation developments are in the southern basin. The first of these developments were established over 100 years ago in the Murray and Murrumbidgee Valleys. At present, the southern basin has over 1 million hectares of irrigated land using, on average, nearly 8 million ML of water a year (Lyle 1994).

As identified by the Industry Commission (1992) structural adjustment in the irrigation industry may be necessary to meet economic efficiency and environmental considerations. These two objectives are embodied in the national policy agenda recently outlined by COAG (1994). Scoccimarro, Young and Collins (1994) suggest that this structural adjustment may be significant, and this is likely to have a bearing on farmers' ability to pay for new investments in infrastructure.

2.1 Technology and farm performance

There are wide disparities in farm yields and farmer incomes among irrigators. Some of this variability may be explained by differences in management practices and farm technology which can significantly change profitability by altering production costs and farm yields. Multiperiod analysis conducted with ABARE's MIPMOD indicates that choice of technology and technological investments is sensitive to the pre-development farm size, cost-savings from the new technology and the operator's ability to fund the investments. Improvements in liquidity through off-farm income offered extra flexibility to fund investments (Mallawaarachchi, Hall and Phillips 1992).

Therefore, industry's ability to restructure effectively will depend on the ability to attract capital to finance required investment, as well as the strength of available incentives for those wishing to leave the industry. Gerritsen (1992) saw this as a problem in policy sequencing, which has impeded structural adjustment. To be effective, the mix of policy instruments together must provide the necessary stimulus for reform to take place in an unhindered manner.

It is therefore important that policy analysis fully incorporates the different elements of the costs of structural adjustment in order to arrive at efficient and equitable policy outcomes.

2.2 Water charging for full cost recovery

Traditionally, charges paid by farmers for accessing water for irrigation do not reflect the cost of water to the water authorities. Also, because such charges are not reflective of the productivity of water in alternative uses, they do not represent the opportunity cost of water to society or to the irrigator.

The ongoing irrigation industry reforms embrace a policy of full cost recovery, although there are several difficulties associated with the definition of consistent full cost recovery prices. The issue of sunk capital and recurrent operating costs and the age and serviceability of the infrastructure which determines the delivery costs, and the nature of binding constraints such as farm size that determines the extent of opportunity costs to the farmer, are some such complexities.

Therefore the strength of delivery charges to impact on structural change in farms will depend on the flexibility of individual farmers to accommodate change, and their ability to improve farm performance to meet the costs of change. Given the differences in charging policies across the states at present, the development of consistent charging policies would be a prime requirement, to encourage greater levels of trading activities and the eventual development of efficient water markets.

2.3 Tradable water entitlements or allocations

Historically, rights to use irrigation water have been tied to specific parcels of land, with heavy restrictions imposed on the transfer of entitlements across areas. These restrictions, which are being progressively relaxed, may have prevented water being used in its highest value use. South Australia led the deregulation of water rights a decade ago, and currently has the largest number of market transactions of irrigation water among any of the Australian states.

Water transferability between irrigators facilitates exchange of water across a wide range of uses, including exchange between farm and non-farm uses. Thus, water use could be expected to reflect the willingness to pay, based on the marginal productivity of water in each respective use. The shifts in water use toward high value enterprises could incrementally drive the opportunity costs of water, which in turn could provide further incentives to develop more efficient water supply and use systems across the basin. However, for water transfers to become an efficient instrument for increasing water use efficiency, clarification of water rights and the associated issue of water security would be necessary.

The detachment of the water right from the land and increased transferability of water rights can enhance the property value of the water right currently embodied in the land value. In a well developed market, with clearly defined property rights, water rights may be traded, or offered as collateral to secure finance for farm investment. Any gains in this way, however, will be discounted to the extent to which the land value itself is diminished due to the separation of the water right.

2.4 Environmental considerations

Environmental considerations are increasingly being incorporated into national policy goals. For example, COAG (1994) agreed 'to provide a better balance in water resource use including appropriate allocations to the environment in order to enhance/restore the health of the river systems'.

If implementation of this policy leads to a net transfer of water from irrigation to environmental uses, then this may have implications for the optimal irrigation infrastructure. In addition, salinity and water logging problems are becoming increasingly apparent at a regional level. Consequently, future likely land degradation trends will also have a bearing on regional water use and the associated infrastructure requirements.

2.5 Investment in infrastructure

Pursuance of economically efficient water use systems and infrastructure investments to support efficient service delivery requires careful planning consistent with the intertemporal nature of the options involved. Net economic returns from infrastructure investment decisions can be enhanced by analyses and assessment of costs and benefits of alternative options, including the implications of long term water delivery charges, and any external costs to the environment or other industries.

Water pricing, trading regulations and project designs together must address externalities and other developmental implications to achieve a socially optimal outcome. Project planning techniques taking account of economic, environmental and social concerns not addressed in individual commercial or local decisions are required to ensure a balance between economic efficiency, equity and environmental objectives.

3 A proposed modelling framework

Economic models designed for policy analysis are generally used to assess the effectiveness of policies through an examination of target group response to policies. This could be achieved through simulation, forecasting or scenario evaluation, depending on the modelling technique employed and the nature of data, resources and personnel available.

Modelling involving long term policy and investment options, such as the one being addressed in this paper, involves a complex configuration of issues. The issues facing policy makers include a choice among a set of alternative options, meeting constraints on resources, environmental concerns, time frames and cost effectiveness. On the response side, it is primarily a question of forecasting likely target group (producers) responses to the proposed policies.

Important policy feedback therefore would include how the policies could influence farm incomes, investment, environmental needs and the overall costs to government. Much of these can be incorporated in a mathematical programming structure.

The modelling framework described in this paper is focused on developing a framework to undertake economic analysis of alternative irrigation adjustment scenarios, including the evaluation of possible infrastructure refurbishment options for the basin. It is planned to use this framework in a case study of the Murrumbidgee Irrigation Area.

The proposed framework incorporates features from two current ABARE models, IMMS (Hall et al. 1994) and MIPMOD (Mallawaarachchi et al. 1992), that will be updated, revised and reformulated into a single modelling structure in GAMS (Brooke et al. 1992).

The irrigation areas included in the IMMS model contain much of the irrigation farming in Australia. The main types of production, which are exclusively irrigated, are: rice, wine grapes, dried vine fruits, citrus, apples and pears and stone fruit. Irrigation of pastures is also undertaken to support prime lamb and milk production. The model represents the major irrigation areas as 18 regions, using data averaged over each region. This is a considerable simplification as the regional averages may obscure major differences within regions, including the distributions of farm cost structures, capital and debt.

The production options for each region include both cropping and livestock activities. Different levels of irrigation, dryland options in regions where this is feasible, and a range of cropping options are included in the IMMS model. Environmental and resource considerations such as shallow water tables, salinity and soil conditions are also represented separately for irrigated and dryland areas within each region. There are rotational constraints that affect the allowable combinations of cropping activities. There are also regional feed pools that link feed from pastures to livestock activities. The amount of feed is a constraint on livestock activities; the feed pools determine the level of this constraint. Water flows, and the level and cost of salinity in the river system are also represented in the model.

The IMMS model is static and the unit of time is a full year. Disaggregating the time frame to represent seasonality in the use of irrigation water, and the flexibility to alter prices and water flow patterns would allow examination of issues such as the effects of water security and irrigation scheduling on farm performance, between year changes in water availability, effects of changes in water use on water tables and salinisation, and the affordability of alternative infrastructure refurbishment options.

The MIPMOD is a multiperiod optimisation model designed to reflect the horticultural industry in the Murrumbidgee Irrigation Area. MIPMOD has been used to evaluate the effects of changes in water charges and output prices on horticultural farmer investment in farm development through replanting and irrigation system improvements from flood to drip irrigation (Mallawaarachchi et al. 1992). MIPMOD incorporates separate capital and recurrent cash flow activities with explicit handling of income tax, debt repayment and purchase and sale of land for farm adjustment. This model will be redeveloped with wider enterprise options to form the basis of the farm level intertemporal segment of the modelling system.

3.1 Model description

The amalgamated model will be built around a spatial equilibrium model designed to represent the main irrigation areas and river pumpers of the southern Murray–Darling Basin. Each irrigation region will be modelled using a linear program. The regional models will be linked by a model of the river system and a model of product supply and demand. Water trading, changes in water use in each region, their effect on the salinity of the Murray River and the cost of this salinity to the economy will also be modelled.

Technically the model variables will include crop and livestock production, crop mixes and rotations, irrigation development, river pumping, water trading, water table depth management, salinity management and river flow management. The model constraints will relate to the land, labour, machinery, seasonal water and input usage, water balance, taxation and environment use limits. The objective will be to maximise the expected regional welfare as measured by regional net farm income subject to also meeting the constraints designed to represent environmental objectives and urban water consumers' requirements.

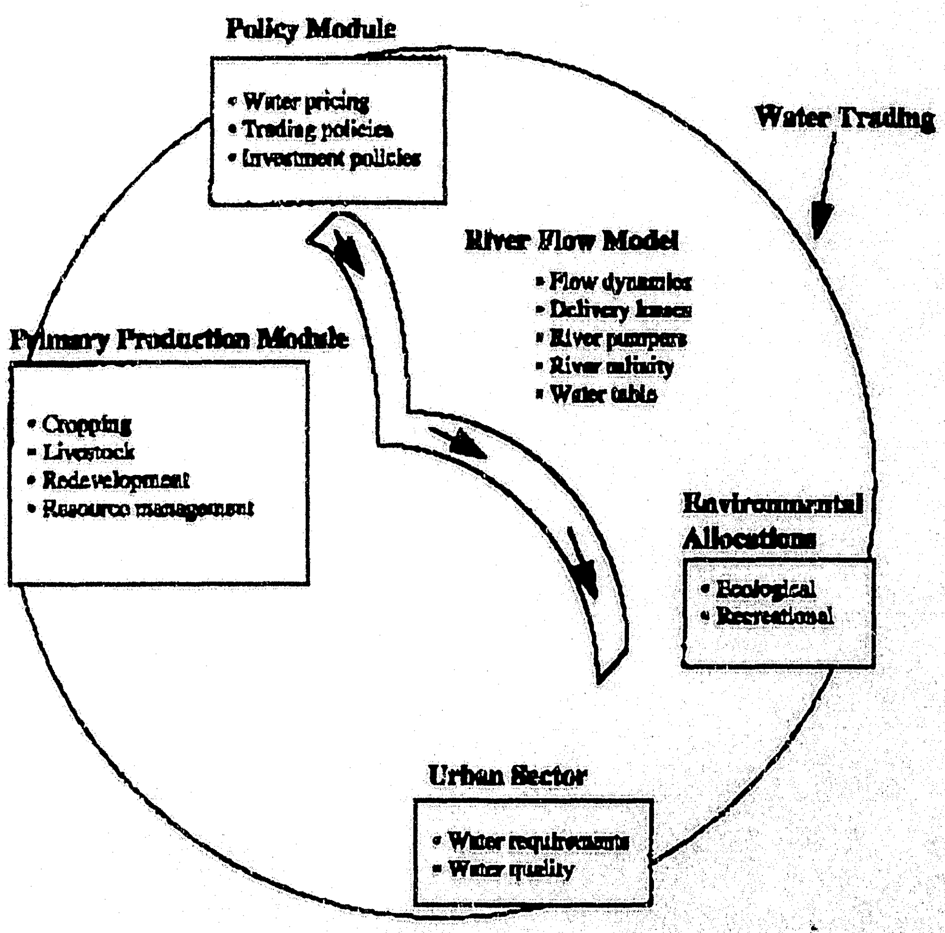
3.2 Model structure

The proposed model structure will incorporate all the modules illustrated in figure 1. The principal venue of interaction is a farm unit, where a mix of enterprises are managed in an economic environment within a set of constraints designed to represent alternative resource, institutional, environmental and other relevant policy constraints. Technological and price coefficients that relate to alternative production techniques, investment options and development possibilities will be represented in the model.

The model will incorporate a suite of modules nested around two decision agents, the water authority and the primary producers (figure 1). The policy module is the platform for specifying alternative policy settings for water pricing, water trading and infrastructure redevelopment.

The primary producer/consumer response module will incorporate the current and potential irrigators, who operate under the policy settings coming from the policy module. Their domain of activities will also be restricted by their resource endowment, prior commitments such as debt, and the availability and access to capital from their own savings and through borrowing from the capital market.

Figure 1: Components of the multi-level programming model



The modelling system includes several different components or modules that are linked through a water trading and allocation model. While hierarchically the Policy module sets the directions for adjustment, the Primary Production module determines the adjustment path also subject to the constraints imposed by other modules.

A separate module formulated as a structural model will represent the river flows. This will include flow dynamics, delivery losses, river pumpers and also environmental considerations such as river salinity and environmental and urban allocations. Two separate simple modules will represent the urban water demand and environmental allocations. They will all be linked to other models through built-in interactions, including water trading.

The modelling system will follow the hierarchical decision making framework. Since the models would be nested through interactive activities they will also represent a multi-level programming formulation (Candler and Norton, 1977). The model which will be developed initially as a recursive nested model, will permit examination of the influence of resource endowments on changes in technology and institutional set up over time. Initially the model will be developed as deterministic, although attempts will be made to incorporate the elements of financial risk on alternative paths of adjustment and refurbishment options.

The production response possibility set in the Primary Production module will reflect input substitution between activities based on scarcity and efficiency of input use. Spatial variation in agricultural production is incorporated together with the differences in resource characteristics including natural and physical constraints. Variables are also specified for factor acquisition and disposal possibilities such as hired labour, machinery, irrigation water and purchasing or selling land.

3.2.1 Temporal interactions

The complexities involved in the adjustment process relate largely to the existence of dynamic interactions between economic agents and events.

Two options are primarily available for the treatment of intertemporal variability in programming models. The most widely used option is the multiperiod formulation. While it is the most appropriate way of formulating the model to incorporate two-way interaction between static and dynamic variables across time periods to reflect rational expectations assumptions of adjustment, for reasons of practicality and simplicity it is less attractive for models with several dynamic variables.

An alternative way of accommodating intertemporal variability is to formulate a recursive model which limits the intertemporal treatment to a set of key variables. Here the problem is modelled essentially as a static formulation, covering a single time period. However, the adjustment path of a set of variables (prices) is traced through repeated runs of the static model with successive substitution of values for the selected variables from the previous run.

While the technique reasonably reflects the behaviour of economic agents with adaptive expectations (in a myopic manner) and 'simplifies the process of considering the dynamics effects of policy changes on farm production patterns, and hence farm income' (Batterham and MacAulay 1994), it does not permit exploration of all the possible adjustment paths given the knowledge about likely behaviour of variables as embodied in the technological and economic coefficients used in the model.

The option chosen for this model development is to first work with the assumption of adaptive expectations, where major variables (both price and behavioural) that drive the intertemporal adjustment paths are identified and their movements through successive time periods are traced using a recursive formulation. Movement toward a dynamic formulation may be possible once the basic model structure is developed.

3.2.2 Spatial interactions

Differences in resource attributes between regions could have a significant bearing on the viability of investment as the expected profitability of enterprises can be affected by the quality and availability of resources. For example, the level of river salinity increases as it passes through irrigation regions and with that raises the costs to irrigators, other water users and the environment. Moreover, differences in farm attributes such as soil characteristics, the depth of the water table, proximity to the markets and location of the farm in relation to the distribution network also affects the homogeneity assumptions used in LP models.

The standard practice in modelling regional responses is to ignore spatial variability and to use a set of representative farm models to jointly reflect the components of regional production relevant to the study. Alternatively, accounting for spatial variation in programming models is possible through disaggregation. A greater level of disaggregation, however, could lead to aggregation errors when model results are added up over the modelling regions (Day 1963; Önal and McCarl 1991). Therefore, ways to minimise the level of disaggregation while still reflecting the variation in regional resource attributes are required. An approach incorporating the weighted distribution of farms based on multivariate analysis of farm attributes will be used in this model development. While it will not fully meet the criteria for exact aggregation (Önal and McCarl 1991), it will nevertheless improve regional representation over the use of a single representative model for a region. The selection of the distribution weights will be based on multivariate analysis of ABARE survey farms in the basin.

4 Model implementation

The modelling framework introduced in this paper offers a means to incorporate strategic and sectoral concerns into a policy model in a simple and direct way. Relating water sector developments to the overall development goals of the basin allows the assessment of the effectiveness of alternative policies in a meaningful manner. This is being achieved through incorporation of linkages and interactions between different policy goals within the modelling framework. Analysing all the issues mentioned in the paper, however, is an onerous task, which is beyond the limits of resources available for this project.

The model implementation would therefore concentrate on the infrastructure renewal in the basin through the development of a case study of the MIA. Modelling work currently being undertaken will be used in this case study which is expected to be completed within the next 12 months. The primary objective of the case study is to analyse the ability of MIA irrigators to finance the refurbishment of the existing irrigation structure and to develop and examine the viability of alternative infrastructure refurbishment options under various policy scenarios.

Mathematical model

The basic quadratic programming model is a modified version of the one used in Hall et al. (1994) and closely follows Duloy and Norton (1975). Assuming the competitive market environment, where producers act as price takers and equate marginal costs to the prices of products, and a linear demand function of the form

(1) $p = a + Bq.$

The objective function for the static formulation is of the form:

(2) $\text{Max } \Pi = q'(a + 0.5\, Bq) - c(q)$

subject to

(3) $Aq \leq b,$

where a is an $N \times 1$ vector of constants, B is an $N \times N$ matrix of demand coeffic ients and $c(q)$ is an $N \times 1$ vector of total cost functions and $q \leq 0$. A is an $M \times N$ matrix of resource coefficients and b is an $M \times 1$ vector of resource availability levels.

The Kuhn-Tucker necessary conditions for this constraint optimisation problem includes (3) plus,

(4) $p - c'(q) - \lambda A \leq 0,$

(5) $[p - c'(q) - \lambda A]q = 0,$ and

(6) $\lambda[Aq - b] = 0,$

where λ is the vector of dual variables to the LP.

Equation (4) states that the profits must be non-negative. Unit profits are defined as prices less marginal costs, where costs have two components; the explicit (market) costs of inputs as subsumed in the vector of cost functions $c(q)$ and the economic rents which accrue to the use of the fixed factors (land and water, for example) represented by the vector b. Equations (5) and (6), respectively, are the complementary slackness conditions for activities and the constraints.

Representation of water trade, investment and land buying and selling activities can be incorporated into the model structure in the usual way, through the definition of additional

Table 1: **LP Tableau with separable demands**

	Production activities		Selling activities				RHS
	Good 1	Good 2					
Objective function	$-c_{1j}$	$-c_{2j}$	w_{11}	w_{12}	w_{21}	w_{22}	(max)
Income constraint	$-c_{1j}$	$-c_{2j}$	r_{11}	r_{12}	r_{21}	r_{22}	≥ 0
Commodity balance 1	y_{1j}		$-q_{11}$	$-q_{12}$			≥ 0
Commodity balance 2		y_{2j}			$-q_{21}$	$-q_{22}$	≥ 0
Demand constraint 1			1	1			≤ 1
Demand constraint 2					1	1	≤ 1

activities analogous to 'production' and 'selling' activities as outlined in table 1 for an illustrative case of two commodities with separable demands (Duloy and Norton 1975).

The modelling system thus becomes a predictive tool also suitable for scenario analysis for examining the producer reactions to policy changes. Some of the output of the Primary Production Module will recursively be used in the Policy Module to examine alternative policy options.

5 Concluding comments

The modelling framework introduced in this paper offers a means to incorporate strategic and sectoral concerns into a policy model in a simple and direct way. The model, for example, will be able to be used to provide guidance for collective investment decisions in the basin by irrigators, water authorities and government agencies.

The modelling advances address the issues of concurrently incorporating spatial and intertemporal dimensions as well as economic and environmental considerations. In particular, the framework has the capacity to simultaneously address the complex issues of efficiency and interdependence of water resource investments and the structural adjustment of the irrigation industry driven by the water policy reforms. Competing demands for water, such as from urban and environmental uses, will also be modelled to examine the implications for the rest of the system. The possibility of developing the model within a multi-criteria decision analysis framework will be investigated once the primary model development objectives have been met.

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