Integrated Modelling System for Sustainable Water Allocation Planning

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Abstract: Efficient water resource allocation for irrigation is very important for the Australian economy where more than $6 billion of annual revenue is provided through irrigated agricultural production. One of the key instruments of the water reform is the introduction of water trading, including trading of water allocations and entitlements, under socio-economic, biophysical and environmental constrains. An integrated catchment management approach to water resource management is one of the major requirements of the Council of Australian Governments (COAG) 1994 water reform. This paper presents the modelling integration framework aimed at supporting the decision making process of the relevant Australian water authorities in order to provide the optimal water resource allocation planning in irrigated regions. The modelling integration framework includes a range of climatic, hydrological and socio-economic models, different sets of data and constraints. The decision making process is supported by a set of scenarios encapsulated into the integrated system, allowing stakeholders to evaluate the consequences of different managerial decisions related to changes in the catchment climate, land use, infrastructure and economic conditions.

Keywords: Modelling integration; Water allocation; Sustainability; Socio-economic evaluation; Water reform

1. INTRODUCTION

An efficient and sustainable allocation of water resources must take account of climatic, hydrological and economic factors, which are currently analysed using separate models. Given the strong interactions between these factors, an integrated approach to modelling is needed. This integrated modelling system is aimed at supporting the decision making process of water authorities in Australia in the context of the COAG water reform framework [AFFA, 2000]. This implies among other initiatives, the introduction of free-market based water trading as a major tool for increasing efficiency of water use for irrigation. This work is being implemented in Project 3.1 "Integration of Water Balance, Climatic and Economic Models" with the Cooperative Research Centre for Catchment Hydrology (CRCCH) Program 3 "Sustainable Water Allocation". The major task of the Project is to provide relevant water authorities with enhanced tools to ensure efficient and sustainable water management based on a modelling framework that:

- allows the application of new research results on climate change and land use impacts within a systematic water resource assessment;
- incorporates the factors that drive seasonal allocation decisions, including new regulatory constraints and medium-term forecasts of climatic conditions;
- simulates irrigators' behaviour affecting water demand, allowing for emerging factors such as water trading and technological change;
- assesses dynamic system behaviour in response to industry adjustments to the changing external environment;
- enhances the use of existing models as decision making tools by facilitating the development of decision making scenarios;
- makes the model results more relevant to stakeholders by translating the direct modelling results into more meaningful socio-economic and environmental performance measures.

Project 3.1 addresses two major questions. Firstly, what the expected structure of the modelling integration framework is and, secondly, what the implications for the integrating software to be developed are. This paper answers the first question examining a set of climate and hydrological models, used by Australia's major stakeholders for water allocation planning, and formulates a concept of their integration in a holistic system. The methodology of socio-economic evaluation of different water allocation policies related to different climatic, land use, infrastructural and market scenarios is also discussed.

The particular characteristic of water resource assessment and management in Australia is the different approach in hydrological modelling, including water quantity, quality, demand and allocation models, adopted by different Australian water authorities. New South Wales, Queensland and ACT use the IQQM (Integrated Quantity - Quality Model) [Ribbons and Podger, 2000] based approach in water allocation management, whereas Victoria, South Australia and Western Australia basically use REALM (REsource ALlocation Model) [Diment, 1991]. This is a condition defining a dual modelling option requirement for the integration framework under development.

The comprehensive overview of the research works devoted to the modelling integration in Australia's water resource management is beyond the scope of this conference paper, however some projects implemented in this field should be mentioned. The Integrated Water Resource Assessment and Management Project includes the modelling integration aimed at supporting the sustainable water allocation in rural communities in Northern Thailand [Scoccimarro et al., 1999]. The Integrated Catchment Modelling System [Reed et al., 1999] provides decision support for catchment land and water resource management in several Australian catchments. The IQQM system also includes the modelling integration prototype, which unifies a set of water quantity, quality, demand and allocation models.

The major stakeholders of this Project are the water authorities responsible for water allocation planning in Australia. The water authorities represented in the CRCCH are the Department of Land and Water Conservation (DLWC) in New South Wales, the Department of Natural Resources and Mines in Queensland, and the Department of Natural Resources and Environment (DRNE) and Goulburn - Murray Water in Victoria. Two specific focus catchments are considered by the Project: Murrumbidgee in New South Wales and Goulburn - Broken in Victoria.

2. STRUCTURE OF THE INTEGRATED MODELLING SYSTEM

The CRCCH Project 3.1 target is to select appropriate modelling tools for each step of the modelling process where such possibility exists (at least for the hydrological component) and, ideally, to include the locally preferred models into the integrated system framework. The major task of the integrated catchment modelling system is to assess and evaluate different catchment management policies (scenarios) by comparison of quantitative output characteristics (evaluation functions and indicators) corresponding to these policies (scenarios).

This Section provides an inventory of models, which will be employed by Project 3.1, and their interconnections, as the algorithmic scheme for model integration. The model integration framework can be schematically represented as a system comprising a number of different single-disciplinary models, groups of input data/constraints and scenarios. This system and its internal system links are shown as a flowchart diagram in Figure 1.

The climatic time series representing the future climate scenarios will be outputs from one of two climate models. These are Global Circulation Models CSIRO9 [McGregor et al., 1993] with spatial resolution of 600 km and Division of Atmospheric Research Limited Area Model - DARLAM [McGregor, 1987] with resolution 60 km. This work will be implemented in another CRCCH project: "Modelling and Forecasting Hydroclimate Variables in Space and Time" (Project 5.1). The expected output is 1000 year daily series of rainfall and temperature, downscaled for meteorological stations in the Project's focus catchments for present and 2xCO_2 conditions simulated using CSIRO9 and DARLAM climate models.

The water resource system simulation model combines the water quantity, quality, demand and allocation modules. Here, we meet the problem of the dual approach in Australian water resource management modelling: IQQM *versus* REALM. This leads to a dual modelling option requirement for the integration framework under development. It simply means that the potential user of the integrated modelling system must have a choice, which of those modelling tools will be employed in the system.

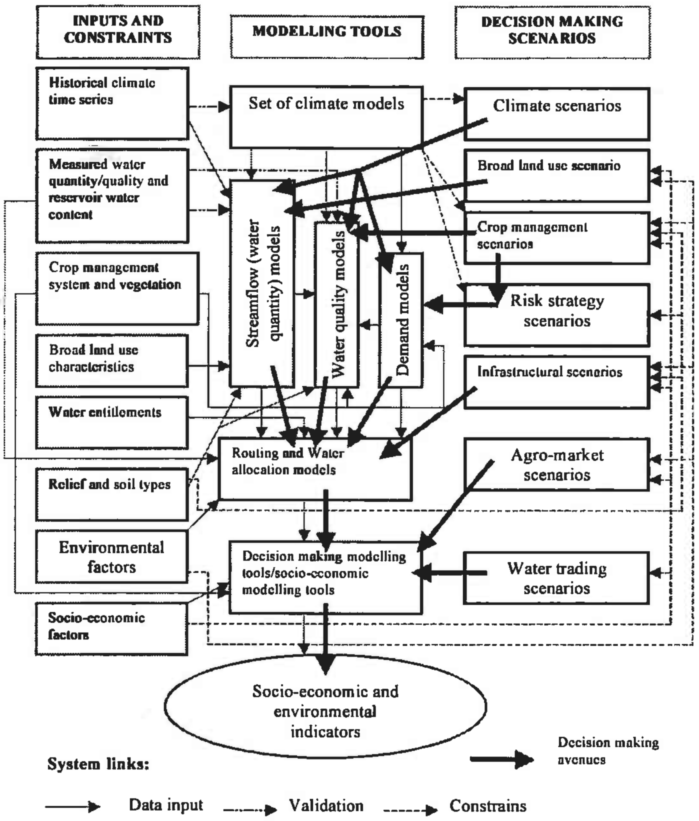

Figure 1 Model integration flowchart.

The major conceptual difference between IQQM and REALM is that IQQM is itself an integrated package including streamflow, demand, routing and allocation modelling tools. REALM deals purely with water allocation modelling. Streamflow and water demand data must be generated externally. Routing can be modelled within the REALM indirectly. Both, IQQM and REALM, include some tools for water quality modelling, which are currently being updated.

The IQQM uses the Sacramento rainfall-runoff model for simulating catchment headwaters' streamflow. It is a conceptual lumped parameter rainfall-runoff model. In future the Sacramento model [Burnash et al., 1973] will be replaced with the more advanced hydrological model CATSALT (DLWC personal communication) which models the irrigation salinity as well as the streamflow and land use impacts. Selection of a streamflow generating model for the REALM hasn't been made at the present stage of the Project development. It could be one of the CRCCH products, whether the streamflow model developed within Project 2.3 or the stochastically generated streamflow from Project 5.1. Water demand models exist for both (IQQM and REALM based) water allocation modelling approaches. IQQM includes CROP MODEL 2 as a part of its integrated structure whereas REALM employs the external demand model PRIDE developed by the Rural Water Corporation of Victoria. Water allocation modules exist in both the IQQM and REALM systems.

The function of the modelling tools referred to in Figure 1 as 'decision making and socio-economic modelling tools' is to transform the direct water resource system simulation model outputs (usually expressed in terms of volumes supplied to different demand groups, frequencies of different levels of restrictions etc.) into more meaningful indicators of system performance. These may relate to economic, social and environmental benefits and costs to different stakeholder communities, and form the basis for performance evaluation and/or optimisation.

3. IMPLICIT AND EXPLICIT APPROACHES IN CATCHMENT INTEGRATED ASSESSMENT AND MANAGEMENT

The intended application of the modelling framework is to support decision making in relation to sustainable water allocation and water resource management. In this context, sustainability can have a number of different interpretations, depending on how broadly or narrowly the term is interpreted. Traditionally, economic modelling of rural water supply systems has focused on economic sustainability of farming enterprises.

The most commonly adopted assumption in this approach is that farmers follow the economic motivations in planning their use of land and water resources [Greiner, 1996]. Considered precisely as it was formulated, this assumption became a major behavioural principle for modelling of resource planning by farmers and other natural resource users. The applicability of this assumption became wider, and it started being interpreted as the only motivation for resource management. This assumption has been used in a number of research works devoted to the integrated catchment assessment and management in different regions of the world representing different levels of free-market economic developments. The common component of these integrated assessment systems is the presence of an economic optimisation algorithm, which represents a model for irrigators' behaviour. The most popular economic optimisation algorithm usually employs the Linear Programming (LP) technique [Hengsdijk et al., 1995]. Some researchers use more sophisticated algorithms such a dynamic programming [Letcher et al., 2000] or game theory [Eichberger, 1993].

The economic optimisation approach in integrated catchment assessment and management allows stakeholders to formulate optimal developmental strategies, related to land use, water allocation and economy, for maximising the economic revenue of the catchment's agricultural production. This approach allows one to simulate the catchment development over several irrigation seasons, while the economic optimisation defines an inter-seasonal system feedback: the optimal land use and water allocation structure can be used as an initial condition for the next irrigation season optimisation iteration. The economic optimisation model allows users to rely on the mathematically formal selection of the best catchment development strategy. For each irrigation season it corresponds to the maximum value of one (or several) objective function(s).

However, the integrated assessment based on built-in economic optimisation (we call it *implicit* approach) has to make many simplifying assumptions and leaves some of the aspects of land and water resource management out of direct control and influence of stakeholders. The optimisation algorithm formulates the optimal strategies itself, without direct dialog with stakeholders. The stakeholder analysis and review of existing DSS for integrated assessment and management [Schreider and Mostovaia, 2001] showed that large groups of stakeholders, especially water authority organisations, prefer to have more control over the integrated catchment management system. Regarding the preferences of the *explicit* approach in the decision making processes DIMA [2000] states:

> "...The user occupies control space, observes the situation in machine space (through the computer model outputs) and makes decisions about the setting of the control variables. The user is therefore an integral part of the feed back loop, acting as a proxy for society and its political and economic agents, and is in a position to learn a great deal about the system behaviour."

Furthermore, the statutory obligations and business imperatives of the state water authorities, the primary stakeholders of CRCCH Project 3.1, require them to manage their water systems with a broader view of 'sustainability'. This includes not only their own economic sustainability and that of the farming enterprises they serve, but also the ecological sustainability of the catchment and stream system and the sustainability of the existing social systems. Evaluation of system performance therefore involves assessment in relation to a number of socio-economic and environmental indicators produced by the integrated model. The complex array of performance measures makes it difficult to define a meaningful set of objective functions for automatic optimisation within the model. An explicit approach, external to the model, is thus considered to be more appropriate.

Using the explicit approach, stakeholders evaluate the system implementation for a selected scenario directly, via a set of performance indicators. Stakeholders themselves formulate the developmental scenarios, which reflect system feedback between irrigation seasons. The disadvantage of the explicit approach is that system simulation for a future optimum situation cannot be performed so rigorously as in the case of economic optimisation, when a formal criterion for selection of the best strategy is specified. On the other hand, the considerable benefit of the explicit approach is the possibility of direct stakeholders inputs to the scenario definition and model parameter selection, thus ensuring that the assumptions used in the model are in tune with current stakeholder and community views and aspirations. In practice, the explicit approach requires a degree of iteration, as initial model results are used to educate stakeholders about likely system outputs for a given scenario, allowing them to refine their feedback, based on an improved understanding of system behaviour and constraints.

4 SYSTEM SCENARIOS

The decision making or, in other words, system evaluation process will be implemented via scenario formulation and comparison of these scenarios using a set of socio-economic and environmental indicators. The comparative analysis of different strategies for agricultural development and related water allocation policies is the core of the methodology of sustainable water allocation planning accepted in the Project.

All scenarios employed in the modelling system can be classified into the following groups:

Climate scenarios:

- Mid-term climate scenarios, which are related to climate variations associated with El Niño/La Niña cycle. Forecasts of seasonal climate conditions can be incorporated into these scenarios.
- Long-term scenarios will be based on the climate model outputs employed by the Project.

These scenarios affect all models receiving their inputs from the modelled climate series. These are water quality, quantity, demand and allocation models.

Broad land use scenarios:

- This type of scenarios is related to the possible changes of forested area in the catchments considered.
- If broad land use classification is more complicated than just forest *versus* grassland, some other broad land use scenarios could be considered.

This type of scenarios affects an integrated system via the streamflow generation models.

Crop management scenarios include:

- Areas under different crops,
- New crops introduced in the area,
- Irrigation salinity caused by inefficient water use and poor drainage, and
- Amount of chemicals introduced to the soil for different types of crops (fertilisers, pesticides and herbicides).

This group of scenarios is closely related to the risk strategy scenarios applicable to different groups of farmers, which could be subdivided into classes of high, medium and minimal risk strategies. The particular definitions of these terms must be given in accordance to the risk levels defined by the appropriate water demand models encapsulated in the integration framework. The crop management and risk types of scenarios are linked with the integrated system via water quality and water demand models.

Infrastructural scenarios include:

- Changes of number of catchment reservoirs, their volumes and on-farm storages,
- Changes in catchment water delivery system (new pipes and canals),
- Changes in the water carriers' operational cost, and
- Changes in farm irrigation technology.

These scenarios are linked with the integrated system through the water allocation models.

Agricultural market (agro-market) scenarios include:

- Changes to the prices of crops grown in the catchment,
- Variation of credit interest rate,
- Changes to the prices of chemicals,
- Variation of transport/fuel prices, and
- Labour market variations (availability and salary rates).

These scenarios are connected to the integrated system through the economic modelling tools. Some link could also connect these scenarios with water allocation models (fuel price can affect the water pumping, and then water delivery prices) but we assume these links to be insignificant.

Water trading scenarios:
Strictly speaking, these scenarios are a subset of the scenario group above (i.e. agro-market). They are separated in a special group because of the Project emphasis on water trading as an especially effective tool of water allocation optimisation. These scenarios can be formulated as:

- Water prices for different years, seasons and locations, and
- Water quality/quantity exchange rates.

The scenarios listed above are evaluated via the application of the integrated modelling system and represent the major decision support tool in the modelling integration framework. On the other hand, the socio-economic models generate the scenario formulation feedback allowing stakeholders to draw up the plausible multidisciplinary and, hence, integrated scenarios supporting the operational decision making.

5. CONCLUSIONS

The paper describes the modelling integration framework for sustainable water allocation planning in catchments under intensive irrigated agriculture. The integrated framework unifies the climatic, hydrological, including water quantity, quality, demand and allocation, models and economic optimisation and/or evaluation procedure. The inventory of models constituting the modelling integration framework has been presented.

Two approaches in catchment economic modelling have been compared. The first one, implicit, based on economic optimisation and an alternative approach based on the explicit economic evaluation of catchment development by stakeholders. The explicit economic evaluation approach was selected as a major strategy for the catchment integrated assessment and water resource allocation and planning. The implicit approach is preferable when stakeholders are farmers or local administrations interested in maximising farmers' incomes and, consequently, local taxes. The explicit way of stakeholders' decision support is preferable when primary system's stakeholders represent water authorities as it is established for the CRCCH Project 3.1.

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