Use of the IQQM simulation model for planning and management of a regulated river system

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Abstract The Murray-Darling Basin (MDB) is Australia's largest river system. Within the MDB, rivers are generally managed as independent regulated systems. The Department of Land and Water Conservation (DLWC) is responsible for planning and management of rivers in New South Wales. To incorporate short-term variability of flows, DLWC developed a daily-time step integrated quantity quality model (IQQM) for the investigation of water-sharing issues. The increasing environmental degradation of rivers within the MDB has prompted the government to impose a policy that limits water extractions to a specified level of development. The Lachlan River Management Committee and DLWC used IQQM to develop and test new river management rules for the Lachlan River of MDB to comply with this policy. This paper introduces IQQM and demonstrates its capabilities using the Lachlan River system as an example. IQQM has proven to be a useful tool for the development, evaluation, and selection of new operational rules.

Key words Australia; catchment modelling; environmental flows; IQQM; Murray-Darling Basin; river systems; water resources planning and management

INTRODUCTION

Australia is considered to be one of the driest continents in the world. Australia's dry climate compounded by the variability of its rainfall (average annual 3200 mm in the northeastern coastal areas to less than 50 mm in central areas), means that most of its river systems are subject to considerable flow variability from year to year (McMahon et al., 1992).

The Murray-Darling Basin (MDB) is Australia's largest river system, (drainage basin area 1,057,000 km², and mean discharge 400 m³ s⁻¹) covering most of the inland southeast part of the country (Fig. 1). The Darling, Murray, Murrumbidgee, Gwydir, Namoi, Macquarie, Lachlan and Border rivers, are the major flow contributors to the basin. All the major rivers in the basin rise on the western side of the Great Dividing Range (GDR) and descend towards flat and semiarid western plains. About 14% of the drainage basin area, principally along the GDR, produces 70% of the total runoff.

The distribution of irrigated crops includes cotton in the north of the basin, and predominantly rice, horticulture, and pastures in the south. Agriculture is the major industry within the basin, with an estimated production value of 8.6 billion Australian dollars a year (ABS, 1996). This is approximately 40% of Australia's total gross value of agricultural production.

Extensive irrigation development and exploitation of the basin's resources over the past 100 years have resulted in considerable degradation of the environment. The following issues are affecting the health of the basin: (a) land degradation (soil erosion,
acid and saline soils); (b) water quality (surface and ground water pollution, including salinity); and (c) wetland degradation (declining vegetation and biodiversity).

In 1995, to ensure the long-term sustainability of the basin, the Murray Darling Basin Commission (MDBC) imposed restrictions on growth in river diversions. The diversions were not to exceed what would be made under the 1993/94-infrastructure level and operating rules, for the current climatic conditions. This restriction is widely known as the MDB Cap. In addition to the MDB Cap, the New South Wales (NSW) government introduced river flow objectives to ensure that some proportion of flow and regulated water would be available to the environment. However, the NSW rules guarantee that the impact on water users would not exceed more than 10% of the MDB Cap extraction limits.

The MDB covers about 60% of NSW. The Department of Land and Water Conservation (DLWC) is responsible for planning and management of rivers in NSW. Until the early 1990s, the department used monthly flow simulation models to investigate water-sharing issues and to evaluate alternative water resource management options for planning purposes. Many of the current water management issues are concerned with the interaction between water quality and quantity, and the restoration of natural flow variability. Monthly models cannot adequately address these issues because the modelling of the short-term variability (e.g. of flows within the month) is important. DLWC recognized that it would need a model that could take into account both the short-term variability and integration of water quantity and quality issues, and be able to run on any river system. The generic model that was developed is called the Integrated Quantity Quality Model (IQQM).
This paper introduces the quantity module of IQQM and demonstrates its capabilities using the Lachlan River system as an example. The methodology and results of the IQQM calibration process, and subsequent model application for the evaluation of various operational rules, are also described.

OVERVIEW OF IQQM

IQQM operates on a continuous time basis and can be used to simulate river system behaviour for periods ranging up to hundreds of years (DLWC, 1995). It is designed to examine long-term behaviour under various management regimes, which include environmental flow requirements. IQQM is based on a node-link concept. Each important feature of a river system is represented by one of thirteen node types. The movement and routing of water between nodes is carried out in the links. Normally the model is run on a daily time step but for adequate representation of certain water quality and routing processes, the model can run down to an hourly step. In a regulated river system, IQQM makes three passes of the river system. The first pass starts from the bottom of the system and totals water demands along the river up to the supply reservoirs. These orders take into account the water requirement of the different users along the river, and consider transmission and evaporation losses as well as tributary flow contributions. The second pass determines water user shares of surplus unregulated flow and how this is to be distributed within the system. The order pass and unregulated flow sharing is carried out with a daily time step. The final pass routes the reservoir releases and tributary inflows down the system at a user defined time step, between one hour and a day. The extractions from the system also take place in the final pass.

The water quantity module of IQQM simulates all the processes and rules associated with the movement of water through the river system. The major processes include: (a) flow routing; (b) on and off river reservoir modelling; (c) harmony rules for reservoir operation; (d) town water and other demands; (e) hydropower modelling; (f) effluent and irrigation channels; (g) crop water demands, orders and diversions; (h) wetland demands and storage characteristics; (i) water sharing rules among regulated and unregulated river systems; (j) resource assessment and water accounting; and (k) interstate water sharing agreements. The model applies hydrological flow routing for the simulation of the different ranges of low and high flow conditions.

There are a variety of options available to model the different operating procedures of both on and off river storages. The options include Puls' routing (IE Australia, 1987), gated storage operation and target rule curves for flood mitigation and water conservation. IQQM can be configured for systems operating single or multiple reservoirs and multiple reservoirs can operate in series or parallel.

In NSW, water access from streams is based on a system of entitlement volumes. In each water year, the available resources are continuously assessed. This estimates the water available at various times during the water year, based on current storage conditions, expected inflows, and losses. Based on this resource assessment, each user in a river system is allocated a percentage allocation based on their entitlement volume. Frequently, because of the conservative nature of the resource assessment process, an allocation of less than 100% at the beginning of a water year, can increase
during the year depending on rainfall and inflows to the system. IQQM models this resource assessment process in a detailed fashion.

The irrigation module in IQQM includes features for soil moisture accounting, simulating decisions of farmers regarding area of crop to plant and irrigate, water ordering and usage, taking into account on-farm storage operation where appropriate, and accounting for water use in relation to water license and access rules conditions.

The model can also simulate fixed demands (e.g., urban water supplies and power stations), riparian and minimum flow requirements, flood plain storage behaviour, wetland and environmental flow requirements, distribution of flows to effluent streams, and transmission losses. It is also capable of simulating water quality processes such as salinity, temperature, and other constituents (Simons et al., 1996). In addition, the Sacramento rainfall–runoff (Burnash et al., 1972) and climate generation models are available as separate modules within IQQM.

STUDY AREA

Basin overview

The Lachlan River Valley located in central western NSW occupies around 85,000 km$^2$, that is about 10% of NSW (Fig. 2). The eastern part of the drainage basin has higher elevations of 1000–1400 m and contributes most of the flow to the river. About 75% of the valley is flat, having slopes of less than 3°. Average rainfall varies from 1200 mm along the elevated eastern part of the drainage basin to 250 mm in the lower western reaches. Potential average annual evaporation exceeds average annual rainfall over the entire drainage basin with 1210 mm year$^{-1}$ evaporation in the east and up to 1750 mm year$^{-1}$ in the west.

Since the early 1960s, irrigation activities have increased rapidly and according to recent data, some 90,000 ha is used for planting crops such as cereals, lucerne (alfalfa), and cotton. Most of the summer crops need irrigation, whereas the winter crops are generally rain fed.

Fig. 2 Lachlan River system.
The Lachlan is a complex regulated river system having numerous anabranches, several headwater and re-regulating storages, wetlands, major irrigation developments, and various environmental needs. There are two headwater storages, the Wyangala and Carcoar dams. Two mid-river storages, Lake Cargelligo and Lake Brewster, are used to capture and re-regulate excess water coming from the tributaries located downstream of the headwater storages. In addition, various weirs provide the necessary head for water diversion. River regulation is further complicated by the long travel times for water released from the headwater storages to the furthest water user (approximately four weeks). The standard DLWC resource assessment procedure is applied in the Lachlan for a July–June water accounting year.

River management issues

Large diversions of water for irrigation and other consumptive purposes have impacted severely on river health and wetlands. DLWC (1997) has identified major issues confronting the Lachlan Valley. Some of the major problems are: (a) land clearing and subsequent soil erosion; (b) fewer medium floods as a result of extensive river regulation; (c) reduced river flow to wetlands; (d) decline of native fish and increased proliferation of introduced species; and (e) increased salinity and poor water quality.

IQQM implementation

The Lachlan Valley has experienced a steady growth since the 1970s. To meet the River Flow Objectives and the MDB Cap obligations (1993/94 conditions), the Lachlan River system required new operational rules to reduce diversions from the river and to restore some natural flow to the environment. It was recognized that the best way to achieve this was to restore some critical medium flow events by allowing these to pass through the river system.

IQQM was configured to assess the effect of various operational rules. The model was set up with more than 200 nodes to describe the dominant processes within the Lachlan River system. The calibration process required extensive data collection, validation, and processing. These data were subsequently used in a staged process to calibrate the model. Each stage of the calibration focused on calibrating a sub-set of parameters with the other parameters being fixed to observed data. The objectives of the calibration were to match the relevant observed data. The various stages of calibration are: (a) flow routing parameters, losses and effluent flow; (b) crops and irrigation demand; (c) unregulated flow usage; and (d) storage behaviour. The quality of calibration is shown in Figs 3 and 4. The model was then set up for the specific valley operational rules and resource assessment. The model was initially configured for two benchmark cases: Natural and 1993/94 MDB Cap Case. This was done so that future options could be measured against these benchmarks. The model was run over a climatic period from 1894 to 1997.

Various operational rules were trialed to meet the environmental objectives. It became clear that rules related to passing particular inflow events through storages achieved the best compromise near the end of the system (Brewster). The model was
Fig. 3 Wyangala Dam storage calibration.

Fig. 4 End of system flows.

Fig. 5 Comparison of various cases.
used to determine the size of events that would be useful. This set both a lower and an upper limit of events that would be passed through the river system, including storages. Trade-offs between event size, losses, and localized flooding determined the upper limit. The model also identified critical times within a year to make these releases for the environment. It also identified critical water resource constrained years where this release should not be made.

After more than 100 combinations of various flow rules had been considered, the option was agreed upon that maximized the environmental benefits while limiting the impact on consumptive users. In the agreed option, flow events are to be released through Wyangala Dam from 1 June to 31 October, up to a maximum of 350 GI total volume released. Specified mid-river flows at Brewster are to be achieved subject to the Wyangala storage volume conditions shown in Table 1. As compared to the Baseline (MDB Cap) Case, the annual average diversions in the agreed option were reduced by 3.7%. A comparison of three cases is shown in Fig. 5.

<table>
<thead>
<tr>
<th>Storage volume (%)</th>
<th>Lower window (m$^3$ s$^{-1}$)</th>
<th>Upper window (m$^3$ s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td>80</td>
<td>40</td>
<td>70</td>
</tr>
<tr>
<td>100</td>
<td>40</td>
<td>90</td>
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</tbody>
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**CONCLUSIONS**

IQQM has demonstrated the usefulness of a daily water balance simulation model in developing water management rules within a river system. The model allowed government bodies, irrigators, environmentalists, and others to have a clear understanding of the impacts of the various rules. This allowed these groups to reach agreement on an option that would benefit river health while minimizing the impact on consumptive users. It also made these groups aware of how all water users within the valley interact with each other.

**REFERENCES**


