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An automated multi-step calibration procedure for a river system model

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A B S T R A C T

Predicted climate change impact on future water availability in the Murray–Darling Basin (MDB) has highlighted the need for a whole of basin model that incorporates various physical and management characteristics for planning and operational purposes. Modelling platforms such as eWater Source Integrated Modelling System (Source) offer a useful framework in this regard, but at present lack automated calibration techniques to parameterise river system models.

This paper presents an automated river system calibration procedure which is robust, repeatable, transparent and systematic. The procedure allows for river network calibration (as opposed to isolated reach by reach calibration), since this has more utility for basin planning and prediction. The calibration procedure routs upstream flow, estimates ungauged inputs via rainfall–runoff (RR) models, and estimates flow based split (distributary) functions and loss functions in complex river systems.

This procedure was tested in the Northern Murray–Darling Basin (MDB) and results from the Border Rivers catchment are presented. The results from the Border Rivers case study demonstrate the applicability of the procedure with median calibration and evaluation NSE values of 0.88 and 0.79, respectively. The use of this procedure in the Border Rivers region has highlighted the likelihood of changing stream channel connections at higher flows in the lower reaches of the river network.

1. Introduction

River system models are required to predict the response of a river system to various influences, be they natural (variations in climate) or human induced (reservoirs, diversions, etc.) (Vaze et al., 2011). At their best, river system models allow managers to consider many of these influences at once, and hence are a valuable management tool. Regulated river systems release water from storages and divert water from the river system to satisfy various human requirements for water (Welsh et al., 2013). Operators of regulated river systems face increasingly complex challenges trying to manage various demands and constraints on the river system, not least of which are environmental requirements, over-allocation and climate change. Such complexity obviates the need for predictive tools (Welsh et al., 2012).

In Australia, management of water resources in a river basin is the responsibility of the government of a state or territory in which the river basin is located. Different states use different river system models of varied spatial and temporal resolutions for operational and planning purposes. For example, Queensland and New South Wales (NSW) use the IQQM model (Simons et al., 1996) at daily time step where as Victoria uses REALM model (Perera et al., 2005) at monthly time step. While diversity in modelling approaches is often valuable in the general sense, it becomes problematic in trans-boundary river basins like the Murray–Darling Basin (MDB), which is shared by four states and one territory. The various models implemented by the state/territory and other water management organisations do not consider the entire basin, but portions of it, and often calculate outputs at different time steps using different modelling concepts. In an effort to implement a more holistic approach to underpin water planning and management across Australia, the Co-operative Research Centre for Catchment Hydrology and later the eWater Co-operative Research Centre (CRC) developed modelling environments capable of building river system models. The Source software package was developed by eWater CRC by encompassing (and enhancing) the key functionalities of IQQM, REALM and MSM-Bigmod (Close et al., 2004), as well as new scientific research. It has shown potential for integrating many important features of river behaviour and management (Dutta et al., 2011; Welsh et al., 2012). Source is designed to

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capture physical and regulatory processes and management rules of a regulated river system. These are conceptualised in seven major components within the Source simulation engine: i) Catchment runoff; ii) River system network; iii) Interactions between river and groundwater systems; iv) Water quality; v) River regulation and storages; vi) Demands (urban, irrigation and environmental) and vii) Complex river management rules. Each of these includes several subcomponents to comprehensively represent the underlying processes, rules and regulations. The various components and their functionalities are elaborated in Welsh et al. (2013). The authors have undertaken a project to build a simplified MDB River System Model (SMDBM) across the entire Murray–Darling Basin using Source at a daily time step. The aim of the project is to build a river system model using a consistent, transparent and defensible calibration approach, which can be used to understand and manage many environmental, economic and social processes of MDB that operate at a basin scale.

River system models are traditionally manually calibrated, relying on visual inspection of simulated and observed hydrographs (Hogue et al., 2000). However, this approach can be very inefficient, depending on how many free parameters the model has and their interrelations and may not follow a logical process because of the complexity in identifying and quantifying model performance (Madsen et al., 2002). New models are becoming more complex through integration of sub-models, data storage systems or computer technology (Grayson and Bloschl, 2001) and are now more difficult to calibrate manually due to this increased model complexity (Duan, 1996). Thus, development and implementation of automated methods for parameter calibration are important for river system models. A great deal of research has been devoted to developing auto-calibration tools for hydrological models that are able to overcome the complexity and time issues (Duan et al., 1992). Computer-based tools for auto-calibration have been developed for many hydrological models in the last decade taking advantages of advances in computer system technology (Doherty and Johnston, 2003). In particular, many research studies have focused on development of strong optimisation tools for auto-calibration that would be able to better estimate the model parameters (Kuczera, 1983; Sumner et al., 1997) such as PEST (Gallagher and Doherty, 2006) and Shuffled Complex Evolution algorithm (Duan et al., 1992; Duan, 1996). When calibrating river system models, it is not practically feasible to use the existing approaches designed for catchment scale hydrological modelling due to the complexity in the system involving water diversion and management.

It must be noted that when calibrating complex models a “good fit” does not necessarily mean that the model structure and parameter set are simulating real processes. This is related to the problem of equifinality in prediction (Beven, 1989; Beven and Freer, 2001; Jakeman and Hornberger, 1993), i.e., many differing parameter sets and model structures can give similar outputs. Given this, reasonable agreement between simulated and observed does not mean the internal processes in the model are a reflection of reality.

Elmahdi et al. (2007) proposed a network simulation model with single and multiple objective auto-calibration algorithms for river system modelling, but it was designed to operate at a monthly time scale and tested in few selected river reaches with irrigation supply. Multi-step automatic calibration schemes have been suggested in other studies, for example Hogue et al. (2000), however these have been tested and applied in headwater basins only. Large river basins, like MDB, require models that can aggregate flow from headwater basins and rout this water downstream, while accounting for losses and gains in each reach. Estimates of flow are required at various points (spatially) within the river network. The MDB covers a diverse range of climatic zones with average annual rainfall varying from 1000 mm in the south-eastern parts to <300 mm in the western plains. Most of the runoff is produced in the humid eastern portion of the basin, while most of the land area is comprised of semi-arid floodplains. To add to the natural complexity, extractions for irrigation occur in many reaches on the floodplains. Successful conceptualisation and parameterisation of such an MDB river system model has to confront three important and interacting issues; system complexity, unaccounted losses, and calibration.

Unaccounted losses and gains are common in water balance analysis in MDB. For example, van Dijk et al. (2009) estimated that 31% of the overall water balance could not be accounted for by either hydrometric data (river gauging) or attributed losses and gains (estimated by less direct measurements such as remote sensing) in the basin. In more arid floodplains, maximum stream flow losses may vary from 79% (CSIRO, 2007b), up to 98% (Costelloe et al., 2003) for large flood events in the Lake Eyre Basin. Given this, many reaches will have an apparent mass imbalance. This must be factored into the river system modelling by considering explicit and undefined gains and losses to avoid propagation of mass balance error in simulated flow. This requires the use of a loss/gain function if predictions are required for any reach or river system. The use of a loss function within an automatic calibration routine is problematic since a loss/gain function on its own has the potential to make the simulated hydrograph match the observed data quite well. The presence of large unaccounted losses or gains compel the need for a cascading, stepwise calibration approach, followed by estimation of a suitable loss function. Additionally, river networks in flatter alluvial plains diverge, and functions that can rout flows to either channel downstream of a split need to be estimated within the calibration procedure. In some areas of the MDB, the floodplains area is characterised by complex patterns of anastomosing flow paths. The stream channel network in the floodplains is a complex arrangement of tributaries, anabranches and distributaries, usually with limited data with which to calibrate. Hence the model structure and calibration routine need to be flexible enough to cope with such complexity.

An auto-calibration procedure has been developed for river system modelling as part of the SMDBM and implemented in different regions of MDB. This paper describes the auto-calibration procedure and presents its performance in calibration and evaluation in the Border Rivers systems in MDB. The aim of the auto-calibration process outlined here is to account for losses and gains explicitly where possible, thereby reducing the reliance on a loss/gain function to obtain an adequate model fit. Additionally, the use of such a modelling approach allows more careful assessment of the nature of unaccounted gains and losses.

1.1. *Study area*

The Border Rivers region is located in southern Queensland and north-eastern New South Wales in the northern part of the MDB covering an area of 45,675 km^2 or 4.4% of the total area of the MDB (Fig. 1). Major water resources in the Border Rivers region include Macintyre Brook, Dumaresq River and the Macintyre River, which continues to become the Barwon River, the Great Artesian Basin, alluvial aquifers, wetlands and water storages. The region is bounded to the east by the Great Dividing Range, the north by the Condamine-Balonne and Moonie regions, the south by the Gwydir region and to the west by the Barwon-Darling region. The steeper part of the basin lies to the east of Boggabilla and is characterised by undulating country with numerous permanent and semi-permanent billabongs. The flatter region is downstream of Boggabilla where the terrain is undulating to flat. Floodplains stretch west towards Mungindi. The Border river system in this study terminates