Available online at www.sciencedirect.com
ScienceDirect
Environmental Modelling & Software 22 (2007) 733–742
Environmental Modelling & Software
www.elsevier.com/locate/envsoft

Integrated assessment modelling for water resource allocation and management: A generalised conceptual framework

R.A. Letcher [a,b,*], B.F.W. Croke [a,b], A.J. Jakeman [a,c]

[a] Integrated Catchment Assessment and Management Centre, SRES, The Australian National University, Building 48a, Canberra ACT 0200, Australia
[b] Department of Mathematics, The Australian National University, Canberra ACT 0200, Australia
[c] Centre for Resource and Environmental Studies, The Australian National University, Canberra ACT 0200, Australia

Received 20 October 2005; received in revised form 15 November 2005; accepted 15 December 2005
Available online 17 April 2006

Abstract

Nodal network approaches are a common framework for considering water allocation in river basins. In this type of model framework, a river basin is represented as a series of nodes, where nodes generally represent key points of extraction or instream use. When considering water allocation, agricultural production and other water use decisions generally interact with the stream system in two ways: they can affect the generation of runoff and thus the volume of water reaching the stream; or, they may involve direct extraction or use of water once it has reached the stream. Models are generally required to consider the influence of these decisions on flows and downstream water availability, as well as the influence of flows on the productive, passive use and environmental values of water. This paper provides a generalised conceptual framework for considering these types of interactions and their representation in integrated water allocation models. Applications of this framework to three very different case studies are outlined.

Keywords: Water allocation; Conceptual framework; Integrated assessment; Integrated water resources management; Rainfall-runoff; Socioeconomic; Decision making

1. Introduction

Nodal network approaches are a common framework for considering water allocation problems (see for example McKinney et al., 1999; Rosegrant et al., 2000; Merritt et al., 2004; Letcher et al., 2004; Letcher and Jakeman, 2003; Jakeman and Letcher, 2003; ESS, 1999; Fedra and Jamieson, 1996; Jamieson and Fedra, 1996a,b). In this type of model framework, a river basin is represented as a series of nodes. Nodes represent points where extraction and other activities impacting on the stream are aggregated for a region and modelled. Regions refer to land or users attached to a node. These may be defined by physical boundaries (e.g. subcatchment areas) or by social, economic, technical or political boundaries, depending on the problem being addressed by the model. An example of this type of boundary may be the property areas of irrigators extracting along a reach of the stream between two nodes. Flows are generally routed from upstream nodes to downstream nodes and thus impacts of upstream land and water use activities on downstream users are modelled.

Three recent projects conducted at the Australian National University have developed nodal network models for considering very different land activities, scales and management issues (see Jakeman and Letcher, 2003; Letcher et al., 2004; Letcher and Jakeman, 2003; Gilmour et al., 2005). Experiences gained in these projects have led to the development of a general framework for integrated assessment modelling of water allocation issues. This paper develops this framework and outlines several examples of the way in which it can be used to consider various production activities and water-related management options. A brief outline of the application

* Corresponding author. Integrated Catchment Assessment and Management Centre, SRES, The Australian National University, Builiding 48a, Canberra ACT 0200, Australia. Tel.: +61 2 6125 8132; fax: +61 2 6125 8395.
E-mail address: rebecca.letcher@anu.edu.au (R.A. Letcher).

1364-8152/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.envsoft.2005.12.014

of the framework in each of the previous projects is given before limitations of the current framework and avenues for future development are discussed.

2. Integrated assessment

Integrated assessment is a holistic approach for assessing the impacts and trade-offs related to various land and water related management options. The need for integrated assessment of such issues has been well documented (see for example Letcher and Jakeman, 2003; Jakeman and Letcher, 2003; Pahl-Wostl, 2003).

Risbey et al. (1996) stress that integrated assessment is more than just a model building exercise, it is also a 'methodology that can be used for gaining insight over an array of environmental problems spanning a wide variety of spatial and temporal scales.' Rotmans and Van Asselt (1996) stress the importance of integrated assessment models as frameworks to organise recent disciplinary research. They argue that the new feature of IA is the use of integrated frameworks such as conceptual frameworks or computer-based simulation models. The literature on IA is increasingly focused on generalising observations and lessons from conducting IA applications to advance the field of IA and to develop robust and defendable approaches to integrated assessment modelling (see for example Rotmans and Van Asselt, 1996; Jakeman and Letcher, 2003; Dowlatabadi, 1995; CIESIN, 1995; Janssen and Goldworthy, 1996; Mendelsohn and Rosenbeg, 1994; Park and Seaton, 1996; Ravetz, 1997; Risbey et al., 1996; Rothman and Robinson, 1997; Timmermunn and Munn, 1997; Weyant et al., 1995; Hagmann et al., 2002; Benbasat and Gass, 2002; Hare et al., 2003). Overall this literature has been broadly focused, highlighting issues relating to participation in IA, uncertainty, data and issues of scale. Given the importance on conceptual frameworks in IA as highlighted by Rotmans and Van Asselt (1996), there has been relatively little emphasis on generalising conceptual frameworks used for developing IA models for addressing different issues. This paper generalises the conceptual framework required to consider water allocation issues, building on a broad set of water allocation applications. A key feature of this generalisation is that the conceptual framework used for integration is independent of the specific details of component models and software considerations relating to the coupling of such models. Essentially the same conceptual framework can be 'instantiated' in many different ways depending on the needs of the project, the models and data available, and the preferences of researchers and stakeholders involved in the project. The lesson from these applications has been the transferability of the conceptual framework itself and the relative unimportance of specific details relating to its implementation when considering the integrative approach.

A key consideration when developing integrated models is the issue of uncertainty, particularly when several component models are being coupled or integrated to produce a complex integrated output. Sensitivity assessment (SA) is normally used to investigate how uncertainties in a model or its inputs affect critical outputs, and which combinations of model and input parameters are most crucial in determining the outputs (Norton et al., 2003; Babendreier and Castleton, 2005; Merritt et al., 2005; Pastres and Ciavatta, 2005). Norton (2005) states that existing SA techniques have not kept pace with the development of complex, integrated simulation models for environmental management. He argues that one difficulty is that such models produce multiple outputs of widely differing types: continuous-valued streamflows and salinity, spatio-temporally isolated incidents such as overbank flows or salinity hotspots; rank-ordered economic outcomes; discrete-valued outcomes such as low/medium/high salinity and zero/non-zero flows, acceptable/unacceptable outcomes or credible/implausible results. Overparameterisation is also common in complex models, leading to ill conditioned computation and unreliable fitting to data. Existing SA methods for complex models tend to be computationally heavy and to produce very limited information. He states that new methods are required to address these issues. Substantial research effort is currently being applied to these issues internationally (see for example HarmoniRiB, 2005; Norton, 2005) and new methods are in the process of being developed to rigorously define and understand uncertainty and its implications in integrated models. As such, issues of uncertainty are not addressed specifically in this paper given that they would be better addressed by these experts as they lie outside the scope of this work.

In terms of water allocation, integrated assessment models must be able to consider a wide range of land use and management activities that impact on catchment yields. Models must be able to consider the impact of changes in flows on extractive and non-extractive water use, as well as the influence of land and water use decisions on water availability. For example, large-scale changes in land cover, such as reafforestation or clear felling large areas of a catchment, will change recharge, surface runoff and baseflow in streams. Changes in water capture and extraction will also affect the timing and magnitude of flows in the stream network. Aspects of the catchment system that may need to be represented in an integrated assessment focusing on water allocation include agricultural and other types of decision making that affect water use or rainfall-runoff generation (socioeconomic decision making), the impacts of changed vegetation cover including forest area, farm dam capture and extractive use on the stream, issues of water availability and its impact on crop and livestock production, and the impacts of changed water and land management policy on households, farms and regional communities. The detail with which these system components are considered and represented will depend on the scale at which the management questions are to be answered, the types of land and water use activities present in the catchment and the types of management options to be considered. However several common component models can be considered.

2.1. Socioeconomic decision and impact components

For the socioeconomic sub system, two main components must be considered by the model. These are the decision-making component and the socioeconomic impact component.