Environmental Modelling & Software 40 (2013) 214–225

Contents lists available at SciVerse ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Comparison of generic simulation models for water resource systems

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ARTICLE INFO

Article history:
Received 12 December 2011
Received in revised form
9 May 2012
Accepted 7 September 2012
Available online 10 November 2012

Keywords:
Decision support systems
Water resources management
Simulation
Optimization

ABSTRACT

In water resource systems that frequently experience severe droughts, generic simulation models can provide useful information for developing drought mitigation measures. This paper is about modeling in practice rather than in theory. The emphasis is on the application of generic simulation models to a multi-reservoir and multi-use water system in Southern Italy where frequent droughts over the last two decades have necessitated the use of temporary and unsustainable user-supply restrictions. In particular, AQUATOOL (Valencia Polytechnic University), MODSIM (Colorado State University), RIBASIM (DELTARES), WARGI-SIM (University of Cagliari) and WEAP (Stockholm Environmental Institute) models are considered in a preliminary analysis, which considers series and parallel simple schemes and also evaluates the possibility of alternative plans and operating policies in complex real water system. Each model has its own characteristics and uses different approaches to define resources releases from reservoirs and allocation to demand centers. The proposed model comparison and application does not identify in detail all the features of each model, rather it provides insights as to how these generic simulation models implement and evaluate different operating rules.

1. Introduction

Generic simulation models provide information and insight that can help improve water system management and planning processes. In conditions of drought, simulation models provide an efficient way to reproduce source–demand interactions and to predict the impacts of rule modifications, over time and space. This helps set more appropriate drought mitigation measures. Appropriate measures can mitigate the economic, social and environmental impacts of drought. Currently, interventions are largely crisis driven. There is an urgent need (Rossi et al., 2007; Sechi and Sulis, 2009) for more risk-based management approaches to drought planning. Determination of appropriate drought mitigation measures is becoming the primary goal in managing water systems that frequently experience severe droughts. In this context, generic simulation models provide an efficient way to predict the effectiveness and efficiency of alternative mitigation measures. Frequently, generic simulation models are the core of complex decision support systems (DSS). The DSS can assist at different levels of detail, ranging from simple screening models for guiding data collection activities to more complex tools requiring high levels of expertise. These computer-based prediction models can be combined in a mixed optimization–simulation approach to anticipate the occurrence of drought considering different hydrological scenarios (Pallottino et al., 2005; Sechi and Sulis, 2009). Despite the potential of using scenario optimization in the search for efficient alternatives, full integration between simulation and optimization has not yet been achieved, and real-world applications are frequently applications of generic simulation models.

Despite the large number of simulation models available and the perceived value of those models with regard to inform water resource management authorities, there are many improvements that could be made to the work of planners, managers, modelers and analysts in this important area (Assaf et al., 2008). Two decades ago, Loucks (1992) and Simonovic (1992) described the gap between theory and practice in water resources planning and management, and still, models are often not adopted by the intended end users (McIntosh et al., 2011). All models produce simplified representations of real-world systems. What features are incorporated into the model depend in part on what the modelers believe is important. Improving the usefulness, as well as establishing trust and credibility, is important if the models are to be fully understood and accepted by the intended end users.

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http://dx.doi.org/10.1016/j.envsoft.2012.09.012

This paper is about modeling in practice rather than in theory. An extended state-of-the-art review on simulation and optimization modeling approaches in reservoir system operation problems is given by Rani and Moreira (2010). The main objective is to illustrate application performances of five generic models for simulating multi-reservoir and multi-use water resource systems: AQUATOOL-SimWin (referred to as AQUATOOL in this paper) (Valencia Polytechnic University) (Andreu et al., 1996), MODSIM (Colorado State University) (Labadie et al., 2000), RIBASIM (DELTARES) (Delft Hydraulics, 2006), WARGI-SIM (University of Cagliari) (Sechi and Sulis, 2009) and WEAP (Stockholm Environmental Institute) (SEI, 2005). Presented models have been applied in the 2009 release version.

These models are representative of simulation models used for preliminary analysis of alternative plans and policies on water resources systems. These popular generic simulation models have been implemented world-wide in a large number of water systems. They incorporate most of the desirable attributes of a simulation model.

After a short presentation and comparison of the main characteristics and features of each simulation model, we emphasize the application of these simulation models to single-purpose reservoirs in series and in parallel, as well as to a complex multi-reservoir and multi-use real water system in Southern Italy, where frequent droughts over the last two decades have necessitated adoption of temporary and unsustainable user-supply restrictions.

2. Model characteristics and comparison

The five generic simulation models considered in this paper were developed within interactive graphics-based interfaces by public and private organizations. They are all designed to study water related planning and management issues in water systems and to satisfy the needs of those at different levels of the planning and decision-making process (Assaf et al., 2008). Each model has its own special characteristics. However, a feature makes the main difference: AQUATOOL, MODSIM and WEAP apply optimization methods on a single time-period of the simulation, and the results are used as an efficient mechanism for performing the simulation of a single period of water allocation in the system, whereas RIBASIM and WARGI-SIM are simulation-only models based on a more conventional if-then approach. Technically speaking, in MODSIM the flow allocation problem is modeled using a minimum cost flow modeling approach in a simplified way. In WEAP, a standard linear program is used to solve the water allocation problem. This allows the model to consider more complex physical, hydrological, and institutional constraints than the min-cost flow approach. In AQUATOOL, the simulation and management of the surface system are made simultaneously by solving a conservative flow network optimization problem and trying to maximize several objectives. The application of simulation-only models, such as RIBASIM and WARGI-SIM, to complex water systems could enable lower performance system indexes (e.g., vulnerability or reliability at user-defined water supply levels). However, these simulation-only models can better reproduce the operating policies used by water authorities in the resource management of real systems.

There is a large variety of operating policies presented in the literature. For single-reservoir systems, operating policies can precisely define how much water to release from the reservoir for all possible combinations of hydrologic and reservoir storage conditions. For multi-reservoir and multi-use systems supply preference and demand priority are frequently included in the operating policies. Operating policies in AQUATOOL, RIBASIM and WARGI-SIM are fixed, whereas operating policies in MODSIM and WEAP are defined as a combination of system states and hydrologic conditions. The most recent version of MODSIM is developed under the MS .NET Framework that allows users to customize MODSIM for specialized operating rules without having to modify the original source code. While these generic simulation models vary with regards to the type and details of the operating policies that they can reproduce, they all include the concepts of priorities and preferences.

Each of the five models has a built-in capacity for water quality modeling, but most water quality modeling components and algorithms are relatively simple compared to the state of the art in water quality modeling. In addition to this capacity, MODSIM and WEAP can be linked to a more detailed higher dimensional model (e.g., the US EPA QUAL2E modeling framework, Brown and Barnwell, 1987) to provide highly detailed and comprehensive modeling of water quantity and quality conditions in the system. MODSIM and WEAP can also be linked with the MODFLOW model (Harbaugh et al., 2000), a three dimensional finite difference groundwater model, to study how changes in groundwater levels affect the overall system and vice versa. However, this tight coupling between generic simulation models and MODFLOW is not an easy task because it requires an extensive calibration phase. In AQUATOOL, the user can choose among a spectrum of models to represent groundwater realistically, ranging from a model of reservoir type to a distributed model of a heterogeneous aquifer of irregular shape.

3. Model features

3.1. AQUATOOL

3.1.1. Description

AQUATOOL is a generalized DSS developed at the Universidad Politécnica de Valencia (UPV), Valencia, Spain. The model was designed for the operational management and planning stages of decision-making in complex basins comprising multiple reservoirs, aquifers and demand centers. Implemented within the Microsoft Windows Environment, AQUATOOL has been coded in different programming languages, such as C++, Visual Basic and FORTRAN.

3.1.2. Appropriate use

The DSS has been upgraded and expanded. It currently consists of several modules including a simulation module (SimWin), a management module for a water resource system that considers the risk of drought (SimRisk) and is based in SimWin, an optimization module with a monthly passage of time (OptiWin) that is more detailed than SimWin, and a simulation module of groundwater that uses the eigenvalues method (AquiVal) to simulate groundwater distribution. The simulation in SimWin is made on a monthly basis, and it allows nonlinear processes, such as evaporation and infiltration, to be adequately shaped. SimWin distinguishes five types of oriented connections that allow the user to reproduce the losses of water, hydraulic connections between nodes, reservoirs and aquifers and flow limitations based on elevation. The optimization of the flow network attempts to minimize several target functions on reservoirs, demands and rivers subjected to the restrictions of mass conservation and to physical capacities.

3.1.3. Training required

To effectively use all of the SimWin features, a high skill level and experience in resource modeling is required.