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A computationally efficient open-source water resource system simulator – Application to London and the Thames Basin

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ABSTRACT

Interactive River-Aquifer Simulation-2010 (IRAS-2010) is a generalized water resource system simulation model. IRAS-2010 is a new release of IRAS previously released by Cornell University in 1995. Given hydrological inflows, evaporation rates, water allocation rules, reservoir release rules, consumptive water demands and minimum environmental flows, IRAS-2010 estimates flows, surface water and groundwater storage, water use, energy use, and operating costs throughout the water resource network at each user-defined time-step. Multi-reservoir release rule curves, streamflow routing, regional groundwater flow, ecological flows, hydropower, pumping, desalination, and other features can be represented. The IRAS-2010 model is linked to a generic user-interface called HydroPlatform; both model and user-interface are open-source. We present an IRAS-2010 model of London's conjunctive use water resource system that satisfactorily emulates a more sophisticated model currently used by regulators. Results from daily and weekly time-step models are compared. IRAS-2010's fast run times make it appropriate for workshop settings and advanced planning methods that require many model evaluations. Model limitations, benefits, project organization and future plans are outlined.

Software availability

Name of software: IRAS-2010
Developers and Contact Address: Evgenii Matrosov and Julien Harou, University College London. Gower Street, London, UK WC1E 6BT, Pete Loucks, Cornell University. Ithaca, NY 14853
Year first available: March, 2011
Hardware Required: Windows, Linux or Apple computer
Software required: a Fortran compiler to modify source code
Program Language: Fortran 77 and 90
Program Size: 450 Kb
Availability: www.hydroplatform.org
Cost: free under general public license (GPL)

1. Introduction

Water resource simulation models help water managers plan, design and operate water systems (Loucks et al., 1981; Loucks and van Beek, 2005). Such models use user-defined operating and allocation rules to predict flow and storage of water throughout the water resource node-link network (Letcher et al., 2007; Maass et al., 1962) over time. They help predict how different management rules and infrastructure configurations react to adverse conditions such as droughts, flooding or long-term change. Simulation models are frequently used in integrated assessments (Jakeman and Letcher, 2003) and can be embedded in decision support systems (e.g. Lautenbach et al., 2009) or linked to optimization models (e.g. Ahrends et al., 2008).

This paper describes the generalized IRAS-2010 water resource management simulation model and its application to the Thames basin water system in south east England. The first parts of this paper describe IRAS-2010's history, functionality, equations and simulation procedure. Next an IRAS-2010 model of the Thames water resource system is described. Results of the IRAS-2010 Thames model are compared to those of a calibrated planning model of similar resolution maintained by the Environment Agency (EA) of England and Wales. Finally, limitations and advantages of IRAS-2010 and future development are discussed. Before describing IRAS-2010 we summarize below the main approaches to simulating water resource systems.

1.1. Approaches to water management simulation

Two main computational approaches exist for simulating water resource management: 'rule-based' and 'optimization-driven'

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simulation. Rule-based models use procedural or object-oriented computer code where programming instructions sequentially define how water is managed using for example “if then else” statements and iterative instructions (‘loops’). Iterative solution procedures are used to represent the interconnections between water requirements and management rules at different locations, often moving from upstream to downstream to route flows and track storage throughout the system. Such ‘ad hoc’ algorithms are challenging to build but have the potential to reproduce management mechanisms with high fidelity. Examples of generalized rule-based models available with user-interfaces include RIBASIM (WL Deflt Hydraulics, 2004), WRAP (Wurbs, 2005b), HEC-ResSim (Klipsch and Hurst, 2007), WaterWare (Cetinkaya et al., 2008), AQUATOR (Oxford Scientific Software, 2008) and WARGI-SIM (Sechi and Sulis, 2009). IRAS-2010 and AQUATOR, the models considered in this paper, are both rule-based simulation models. Table 1 summarizes selected defining features of a representative set of rule-based simulators including whether they allow scripting and whether their time-steps are fixed or user-selected. Scripting allows customizing actions of particular nodes or links in a network using a generalized programming language rather than modifying source code. Scripting increases flexibility but requires more skillful users.

Optimization-driven simulation models solve a distinct optimization model at each simulated time-step to route flows, track storages and allocate water through the network. This method is popular because of its relative ease of use and flexibility; optimization-driven allocation takes some of the burden off the programmer whose code no longer has to consider every conceivable system state or outcome. However, some complex rules may be difficult to represent using optimization and model results may not be easy to replicate in practice. Examples of such models with user-interfaces include WATHNET (Kuczera, 1992), AQUATOOL (Andreu et al., 1996), OASIS (Randall et al., 1997), MISER (Fowler et al., 1999), MODSIM (Labadie and Baldo, 2000), RIVERWARE (Zagona et al., 2001), MIKE BASIN (Jha and Das Gupta, 2003), CALSIM (Draper et al., 2004), REALM (Perera et al., 2005) and WEAP (Yates et al., 2005). Further information on the optimization-driven simulation approach is given by Labadie (2004) and descriptions of modeling systems that use it can be found in Wurbs (2005a).

Since each approach has advantages and limitations, the institutional and water management context often determines which modeling type is most suitable for a particular application. For example a model seeking to predict water trading will benefit from an optimization engine, whereas rule-based models are well-suited for modeling actual system operating procedures (e.g. reservoir release tables) and predicting their performance under certain conditions.

1.2. IRAS-2010 history

The original IRAS (Interactive River-Aquifer Simulation) program (Loucks et al., 1995) was developed at Cornell University and the International Institute for Applied Systems Analysis and released in 1995. IRAS was used in several published and unpublished studies around the world as a tool for addressing regional, national and international water basin management (Loucks and Bain, 2002; Loucks et al., 1995; Salewicz and Nakayama, 2004). Using IRAS Brandgo and Rodrigues (2000) conducted a study of the downstream effects in Portugal of reservoir storage capacity increases on Spain’s Guadiana river.

IRAS-2010 is a new code based on the 1995 version. Improvements include (1) an improved calculation algorithm for water deficits, (2) the ability to associate demand link diversions to any demand node, (3) more flexible reservoir group balance rules, (4) demand restrictions during water supply shortfalls, (5) long-term water demand changes, (6) energy costs and hydropower revenues, (7) more detailed aquifer interactions, (8) calculation of channel dimensions and flow velocity, (9) performance measure output, (10) support for batch runs (e.g. for stochastic climate change studies), (11) addition of text-based input and output files and leap year support. More information on these changes is found in section 4 and Table 3.

IRAS-2010’s Fortran source code was optimized for speed by reducing file manipulation, caching data, and transforming input data into a structured binary format. Using data structures gives users the possibility to modify network parameters without having to re-read input files, increasing the efficiency of multiple run simulations for stochastic simulations. The resulting modeling system produces fast models; for example the London water resource system model described below runs in 1 second on a 3.5 GHz computer when using a weekly time-step over an 85-year time horizon.

1.3. IRAS-2010 functionality

IRAS-2010 is a rule-based water resource management simulator that models water flows and storages, single and joint reservoir releases, time-varying water consumption, hydropower production and pumping energy use. Salient IRAS-2010 features include computational speed, the ability to realistically represent a wide range of water management actions and conditions, and a customizable user-interface and online open-source code management (www.hydroplatform.org).

An IRAS-2010 model represents the system as a network composed of nodes and links of various types. Nodes can be natural lakes, reservoirs, aquifers, wetlands, gauge sites with time-series of inflows, demand sites, consumption sites, and confluence or

Table 1
Selected benefits and limitations of a representative group of rule-based water resource simulation modeling systems.

Model	Selected characteristic features
IRAS-2010	Free and open-source; Computationally efficient; Multi-reservoir operating rules; Flow routing; Geographic interface implemented in a separate customizable open-source model platform named ‘HydroPlatform’; Time-step is user-selected between 1 and 365 days
AQUATOR	Flexible generalized scripting at nodes and links using the VBA language; Simplified modeling of groundwater flow or storage not included; Time-step is daily
RIBASIM	Wide variety of features (lay-out, demand and control nodes) and several link types; Links to DELWAQ water quality model and HYMOS hydrological model; Geographic interface; Many international case-studies; Time-step is user-selected between monthly and daily
WRAP	Represents priority-based water allocation; Calculates supply reliability performance measures; Time-step is user-selected between monthly and daily
HEC-ResSim	Includes generalized scripting using the Jython language for reservoir rules allowing complex rules including flood control operations; Operational focus rather than long-term planning; Multiple routing methods; Geographic interface; Incorporates time-series generated by sister hydrologic model HEC-HMS; Public domain (free); Time-step is user-selected between daily and 15-mimute intervals
WaterWare	Includes native rainfall runoff, water quality, and irrigation demand models; Web-interface with user-management which allows running models on servers and clusters; Link to heuristic optimization procedures for calibration and management; Time-step is daily
WARGI-SIM	Links with WARGI-OPT, an optimization model; Time-step is user-selected between seasons and hours