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Generic Simulation Models for Facilitating Stakeholder Involvement in Water Resources Planning and Management: A Comparison, Evaluation, and Identification of Future Needs

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Introduction

There exist today a variety of generic simulation models incorporated within interactive graphics-based interfaces that are available for studying water related planning and management issues in river basins. This workshop is devoted to a comparison and evaluation of some of these interactive database and model management systems. These include MIKE BASIN from Danish Hydraulics Institute, MODSIM from Colorado State University, RIBASIM from Delft Hydraulics, WBalMo from WASY, and WEAP from the Stockholm Environmental Institute (Tellus). They among others represent the current state of the art of river basin decision support systems. While each has its own special characteristics, they all are designed to facilitate the input, storage, retrieval, and display of data associated with watershed simulation models. Most importantly, they provide a means of involving stakeholders in reaching a shared vision of how their water resource systems works, and the possible economic, environmental, hydrologic and/or ecological impacts of alternative development and management policies.

Different generic decision support systems often vary in the detail of analyses they can perform. One of the challenges of developing such tools is in trying to satisfy the needs of those at different levels of decision making. Ideally any such decision support system should be able to:

- help stakeholders build their own models and to identify the important issues in managing particular watersheds or river basins;
- provide a preliminary understanding of the interrelationships or interdependencies among different system components;
- provide a first estimate of the relative importance of various assumptions regarding uncertain data and parameter values with respect to the values of various system performance criteria; and
- facilitate communication and understanding among all stakeholders involved, helping them reach a shared vision – a

common understanding of how their watershed or river basin function, and how it might be managed in the future.

Underlying each simulation model is the mass balance of water. Each model provides a way of keeping track of where water is, where it goes, and possibly what is in it, i.e., its quality, over space and time. If applicable, the amount of energy generated and/or consumed for pumping can also be determined. Using an ecological habitat assessment component, some models can also estimate the potential ecological impacts as well. If the watershed land use/cover and hydrologic and waste-load inputs are representative of what might occur in the future, the simulation results should be indicative of the direction and amount of change one would expect to observe, at least in a statistical and relative sense. Through multiple simulations, individuals can test, modify, and evaluate various structural designs and operating policies in a systematic search for the ones that they judge to perform best. They can also determine where more detailed and potentially more accurate data and analyses may be beneficial.

Evaluating the Sensitivity of Assumptions

The results of any computer simulation are always very dependent on the assumptions incorporated into the simulation. The assumptions incorporated into any simulation of possible future events are numerous and uncertain. These assumptions typically include future land uses in the watershed, future precipitation amounts and patterns over space and time, future

user demand and consumption rates, changing facility designs and operation, and numerous values of parameters of functions that define how the system works, e.g., the production of hydroelectric energy, the flow of groundwater, and the fate and transport of pollutants. It is not possible to know all of these assumptions with precision.

Stakeholders can differ over just which assumptions are best. It is not the purpose of any simulation model to identify which credible set of assumptions is the best. They can, however, be used to estimate what, when, and where events may happen, given any set of assumptions. Simulation models can be used to test how sensitive the performance of any particular system may be to various uncertain inputs and parameter values. Through simulation, individuals can identify which assumptions and policy decisions substantially affect the performance of the system and hence which assumptions and decisions may be worthy of additional study and examination. After numerous simulation runs under different land use, hydrologic conditions, system designs and operating policies, humans (not models) can better judge which designs and operating policies may provide the greatest expected benefits or have the lowest expected adverse risks under the most plausible set of assumptions.

User Interface

One thing that clearly distinguishes different river basin DSSs is their menu-driven graphical user interfaces (GUI). These interfaces are developed to give the user control over the operations of each of its program components. Menus provide the user with a number of model

operation options. The user can control the sequence of program operations and enter or modify data with the mouse and the keyboard. The input and display of data is done in a manner that facilitates the detection of mistakes and allows for easy modification of those data for sensitivity analyses. Users can display the simulation output data in a variety of ways, and each way is intended to improve the users level of understanding.

Models for Planning and Management

There are many kinds of models that can be used to study various water resources planning and management issues. Some of these models are designed to examine, in considerable detail, the hydrologic or hydraulic processes that take place in watersheds, in water bodies, or in facilities built to remove wastes from water or wastewater. Other models are designed to identify and evaluate potentially attractive facility and management alternatives prior to their detailed design. The computer simulation programs reviewed in this workshop are designed to assist those responsible for planning and management. Using continually updated information, they could also be used in real time for forecasting possible outcomes of current operations, but this is not their intended purpose.

The DSSs reviewed and discussed in this workshop are relatively simple. They are not suitable for detailed hydraulic design. Their simplicity reduces the input data required for simulation as well as the detail and precision that can be found in the results. Simulations are based on mass balances of quantity and quality constituents, taking into account

flow routing, seepage, evaporation, and consumption, as applicable and as implemented by the user. They are one-dimensional. Each natural lake, reservoir, aquifer and wetland-area component (or sub-component) is modeled as a storage unit - a simple bathtub, but one whose longitudinal distribution of quantity and quality is not necessarily uniform. Within the accuracy provided by these simplifying assumptions, these DSSs attempt to address problems involving the interactions among watershed land uses, the quantity of ground and surface waters, the quality of surface waters, and the health of impacted ecosystems. These processes typically involve quite different time and space scales.

Brief Descriptions of River Basin DSSs

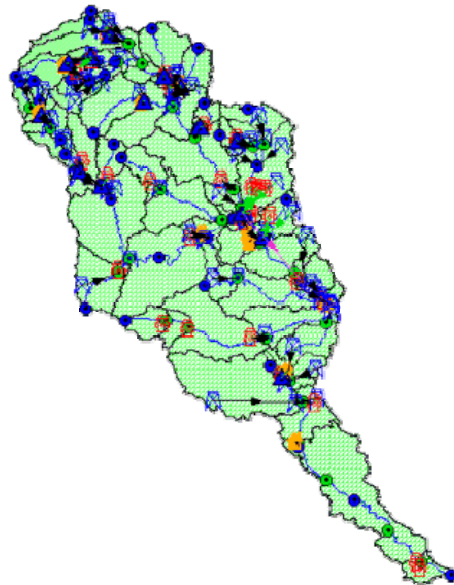


Figure 1. All the generic river basin models discussed in this workshop are based on a node-link representation of the system.

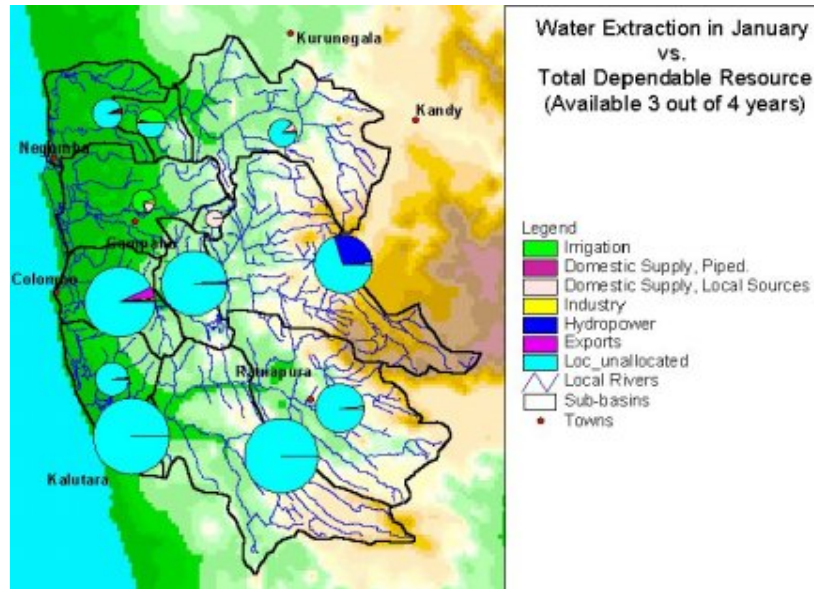


Figure 2. Various options are available for the user for displaying the outputs of these river basin simulations

In the paragraphs below each of the selected river basin simulation DSSs are briefly described. Users will note many similarities yet each has its unique features. Much more detail is available on the web sites for each model, as listed below. This workshop will focus on these differences and the motivations that caused them, i.e., why they were implemented, as well as what issues they are not able to handle or simulate as well as we would like.

MIKE BASIN

<http://www.dhisoftware.com/mikebasin/Description/>

MIKE BASIN addresses water allocation, conjunctive use, reservoir operation, or water quality issues. It couples ArcGIS with hydrologic modeling to provide basin-scale solutions. The MIKE BASIN philosophy is to keep modeling simple and intuitive, yet provide in-depth insight for planning and management. In MIKE BASIN, the emphasis is on both simulation and visualization in both space and time, making it appropriate for building understanding and consensus.

For hydrologic simulations, MIKE BASIN builds on a network model in which branches represent individual stream sections and the nodes represent confluences, diversions, reservoirs, or water users. The network elements can be edited by simple right-clicking. MIKE BASIN is a quasi-steady-state mass balance model, however allowing for routed river flows. The water quality solution assumes purely advective

transport; decay during transport can be modeled. The groundwater description uses the linear reservoir equation.

Typical areas of application include water availability analysis, conjunctive surface and groundwater use, infrastructure planning, assessing irrigation potential and reservoir performance, estimating water supply capacity, determining waste water treatment requirements. The model has also been used to analyze multisectoral domestic, industry, agriculture, hydropower, navigation, recreation, ecological demands and find equitable trade-offs among them. It has analyzed ecosystems and water quality, minimum discharge requirements, sustainable yield, effects of global change, regulation and water rights and priorities.

MODSIM

<http://modsim. engr.colostate.edu/>

MODSIM is a generalized river basin Decision Support System and network flow model developed at Colorado State University designed specifically to meet the growing demands and pressures on river basin managers today.

MODSIM's graphical user interface (GUI) allows users to create any river basin system topology by simply clicking on various icons and placing system objects in any desired configuration on the display. Data structures embodied in each model object are controlled by a data base management system, which is also queried by simple mouse activation.

Formatted data files are prepared interactively and an efficient network flow optimization model is automatically

executed from the interface without requiring any direct intervention by the user. Results of the network optimization are presented in useful graphical plots. MODSIM can also be used with geographic information systems for managing the intensive spatial data base requirements of river basin management.

MODSIM data sets can be developed for daily, weekly, and monthly time steps. Streamflow routing can be handled through the use of lag coefficients. There is considerable flexibility in representing consumptive use demands and flow requirements and their associated water rights, including exchanges. Reservoir operations include target storage, hydropower, tailwater effects, evaporation, and seepage.

MODSIM can simulate reservoir storage contract arrangements such as accrual rights, ownership contracts, water service contracts, and rental pool or water banking. Prioritized reservoir balancing allows the user to control the distribution of system storage throughout the simulation season. MODSIM has a Glover equation groundwater model built in the model's code that has been used in systems with fairly simple unconfined aquifer / river streamflow interactions. MODSIM has been linked with stream-aquifer models for analysis of the conjunctive use of groundwater and surface water resources, as well as water quality simulation models for assessing the effectiveness of pollution control strategies. .

The network solution algorithm along with the iteration convergence sequence for return flows and watch logic gives the model user flexibility to simulate operations of complex river systems. Watch logic is a term to describe the

model's ability to define operational parameter limits for a simulated feature based on simulated results of another feature in the network. Perl scripts that tailor operation parameters while the model is running go a step further to allow for the simulation of detailed basin specific conditions. Perl scripts can also be used to customize model input and output.

RIBASIM

<http://www.wldelft.nl/soft/ribasim/int/index.html>

RIBASIM (River Basin Simulation Model) is a generic model package for analyzing the behavior of river basins under various hydrological conditions. The model package is a comprehensive and flexible tool which links the hydrological water inputs at various locations with the specific water-users in the basin.

RIBASIM enables the user to evaluate a variety of measures related to infrastructure, operational and demand management and the results in terms of water quantity and water quality. RIBASIM generates water distribution patterns and provides a basis for more detailed water quality and sedimentation analyses in river reaches and reservoirs. It provides a source analysis, giving insight in the water's origin at any location of the basin.

RIBASIM has been applied for river basin planning and management in a number of countries in a variety of projects. Water management organizations use it to support their management and planning activities. Large and complex river basins have been modeled and simulated with

RIBASIM. Separately modeled sub-basins can be combined into one main-basin. A recent application of RIBASIM is the use of the model as flow routing component within a Flood Early Warning System (FEWS).

RIBASIM has links to other Delft Hydraulics software programs. It can link with the HYMOS hydrological database and modeling system. For detailed water quality process RIBASIM can link with the DELWAQ water quality model.

Various hydrologic routing methods are available in RIBASIM e.g. Manning formula, Flow-level relation, 2-layered multi segmented Muskingum formula, Puls method and Laurenson non-linear "lag and route" method. The flow routing is executed on daily basis starting at any selected day for any number of days ahead.

The structure of RIBASIM is based on an integrated framework with a user-friendly, graphically, GIS-oriented interface. Working with RIBASIM means applying a structured approach to river basin planning and management. Various tools from the Delft Tools library are used.

WBalMo

<http://www.wasy.de/english/produkte/wbalmo/index.html>

WBalMo (Water Balance Model) is an interactive simulation system for river-basin management. WaBalMo has been used to identify management guidelines for river basins, design reservoir systems and their operating policies, and perform environmental-impact studies for

development projects. Using an ArcView user interface, a representation of the river basin ("system sketch") is constructed or derived from an existing digital stream network. Model data can subsequently be modified in various scenarios.

The natural processes of runoff and precipitation are stochastically (Monte-Carlo) simulated and the respective time series are balanced with monthly water use requirements and reservoir storage changes.

By recording of relevant system characteristics during the simulation, probability estimates can be provided for water deficits, maintaining minimum runoff levels, or reservoir levels. Simulations can be performed both for stationary and transient (e.g., changes in climate) conditions. By comparing various plausible scenarios an approximately optimal water resources management can be obtained.

A river basin is modeled in WBalMo by input of the following data:

- Stream network with desired balance profiles for accurate accounting of water uses, reservoirs, water transfer, etc.
- Catchment areas and their respective simulated runoff time series
- Location of water uses and their requirements (discharge and uptake rates, minimum runoff) Reservoirs and their management regime
- Desired system characteristics such as mean and extreme values, frequencies and threshold values.

Units for input and output are user-defined.

WBalMo can be coupled with other algorithms or models to supplement the provided routines. This may be useful, for instance, for specific types of resources management, to implement a flood control, or when addressing water-quality issues. Two alternatives exist for extending the capabilities of WBalMo:

- New algorithms are implemented directly in WBalMo using FORTRAN syntax
- Dynamic-link libraries (*.dll) provide the new algorithms in compiled form and are accessed by WBalMo.

In addition, the attributes of model elements can be freely extended.

Additional system components include:

- Automatic labeling of the river-basin representation
- Presentation of all data using adjustable report generators
- Comparison of scenarios with listing of differences found
- Integration of DIGITAL-Visual-Fortran
- Display of user-selected system variables during the simulation

WEAP <http://www.weap21.org/>

WEAP ("Water Evaluation And Planning" system) is a user-friendly software tool that takes an integrated approach to water resources planning. Freshwater management challenges are increasingly common. Allocation of limited water resources between agricultural, municipal and environmental uses now requires the full

WEAP Highlights

Integrated Approach	Unique approach for conducting integrated water resources planning assessments
Stakeholder Process	Transparent structure facilitates engagement of diverse stakeholders in an open process
Water Balance	A database maintains water demand and supply information to drive mass balance model on a link-node architecture
Simulation Based	Calculates water demand, supply, runoff, infiltration, crop requirements, flows, and storage, and pollution generation, treatment, discharge and instream water quality under varying hydrologic and policy scenarios
Policy Scenarios	Evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems
User-friendly Interface	Graphical drag-and-drop GIS-based interface with flexible model output as maps, charts and tables

integration of supply, demand, water quality and ecological considerations. The Water Evaluation and Planning system, or WEAP, aims to incorporate

these issues into a practical yet robust tool for integrated water resources planning. WEAP is developed by the [Stockholm Environment Institute's Boston Center](#) at the [Tellus Institute](#).

WEAP is a microcomputer tool for integrated water resources planning that attempts to assist rather than substitute for the skilled planner. It provides a comprehensive, flexible and user-friendly framework for planning and policy analysis. A growing number of water professionals are finding WEAP to be a useful addition to their toolbox of models, databases, spreadsheets and other software.

Over the last decade, an integrated approach to water development has emerged which places water supply projects in the context of demand-side management, and water quality and ecosystem preservation and protection. WEAP incorporates these values into a practical tool for water resources planning and policy analysis. WEAP places demand-side issues such as water use patterns, equipment efficiencies, reuse strategies, costs, and water allocation schemes on an equal footing with supply-side topics such as stream flow, groundwater resources, reservoirs, and water transfers.

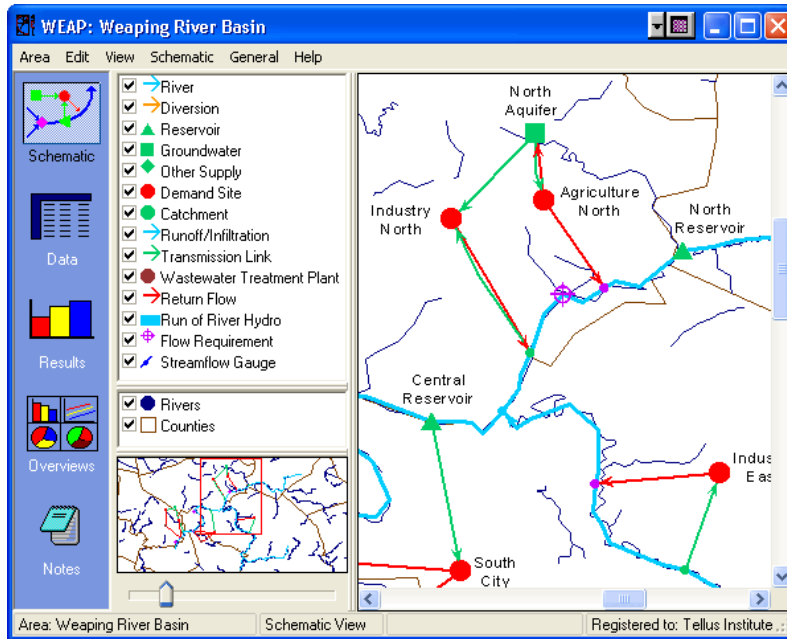


Figure 3. Main interface for the WEAP model again showing node-link network representation of river basin section.

WEAP is also distinguished by its integrated approach to simulating both the natural (e.g., evapotranspirative demands, runoff, baseflow) and engineered components (e.g., reservoirs, groundwater pumping) maintaining water demand and supply information of water systems, allowing the planner access to a more comprehensive view of the broad range of factors that must be considered in managing water resources for present and future use. The result is an effective tool for examining alternative water development and management options.

- Scenario generation tool: Scenario analysis is central to WEAP. WEAP simulates water demand, supply, runoff, streamflows, storage, pollution generation, treatment and

discharge and instream water quality.

- Policy analysis tool: WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems.

Examples of WEAP scenario analyses have included

- What if population growth and economic development patterns change?
- What if reservoir operating rules are altered?
- What if groundwater is more fully exploited?
- What if water conservation is introduced?

- What if ecosystem requirements are tightened?
- What if a conjunctive use program is established to store excess surface water in underground aquifers?
- What if a water recycling program is implemented?
- What if a more efficient irrigation technique is implemented?
- What if the mix of agricultural crops changes?
- What if climate change alters demand and supplies?
- How does pollution upstream affect downstream water quality?
- How will land use changes affect runoff?

Among the topics to be discussed in this workshop include

- DSS availability.
- DSS features and comparisons.
- DSS interfaces and ease of use. (Standards and criteria).
- DSS hardware and additional software requirements (advantages and disadvantages).
- DSS technical support and upgrades (challenges and costs).
- DSS documentation (how best to educate potential users).
- DSS use and experiences in shared vision exercises with stakeholder participation.
- DSS research needs. (Future wish list).

We encourage everyone interested to attend and participate in this workshop.

Issues of interest to River Basin DSS developers and users.