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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CHAPTER THIRTEEN

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13.1. Introduction

Water resources planning and management tools have been moving away from a top down (command and control) approach to a bottom up (grass-roots) approach – which emphasises the involvement of stakeholders, not only specialists, in all stages of planning – from the identification of problems and issues, the selection of potential solutions to project implementation and operation. Ideally, a participatory grassroots planning process should provide a transparent and flexible platform for all stakeholders to collectively: examine the main elements of their shared water system; understand the main issues and problems to be addressed; participate in identifying alternative policies; and select fairly balanced and broadly supported solutions. Chapter 3 discusses these issues on the broader context of decision support for environmental management.

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 and at the same time appropriate for facilitating stakeholder involvement in the planning and decision-making process. While each model has its own special characteristics, they all are designed to facilitate the input, storage, retrieval, and display of geographic, hydrologic, and – depending on the model and application – socioeconomic data associated with specific river basins or regions. The input data also include the policies defining how the water resources are to be managed over space and time. The outputs of these simulation models describe the impacts of these water management policies. Most importantly, they provide a means of involving stakeholders in reaching a shared vision of how their water resource system 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 types and 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. Water resource managers typically desire tools that provide greater detail than government agency heads or politicians, who are among those who request and often provide the money for such studies. Public stakeholder groups may differ in the detail they consider appropriate for making good decisions. Ideally, generic simulation models should be able to satisfy everyone involved in the planning and management process. In fact, that is a challenge.

As in all technological innovation the process of achieving consensus-based, sound resource and environmental management policies is often experimental; usually incremental and if managed responsibly, progressive and adaptive as new information and learning takes place. Arguably, this process can be facilitated by interactive and relatively simple water resource system simulation models suitable for preliminary planning. Such models can:

- help stakeholders develop their own models and identify the most important resource and environmental issues for sound management of particular watersheds or river basins;
- provide a preliminary understanding of the interrelationships and/or interdependencies among and between different system components;
- provide a first estimate of the relative importance of various assumptions of uncertain data and parameter values and their relationship to important system performance criteria; and
- facilitate communication among all stakeholders involved, helping them reach a common understanding of how their watershed or river basin functions and how that might lead to a shared vision of how water resources might be managed in the future.

13.2. Model Characteristics and Comparisons

A common feature of each simulation model is the computation of the mass balance of water in each time step and at each site of interest in the basin. These models provide a way of keeping track of where water is, where it goes, and possibly what is in it, i.e. its quality constituents, over space and time. If applicable, the amount of hydroelectric energy generated and/or energy consumed for pumping can also be estimated. 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 relative statistical sense. Through multiple simulations, individuals can test, modify, and evaluate various infrastructure 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 needed.

At times, the use of simulation models in trial-and-error iterative procedures could be problematic and time consuming in view of the large number of operating policies to be evaluated. As an alternative to simulation-only approach, some generic models (e.g. MODSIM, WEAP) have combined simulation and optimisation to identify and evaluate combinations of structural action and management policies that satisfy user's performance criteria. In cases where multiple conflicting objectives exist, tradeoffs among these objectives can be identified.

Five river basin simulators (MODSIM, MIKE BASIN, RIBASIM, WBalMo, and WEAP) compared below were designed for planning and management studies and are typical of many tools used for such purposes. These comparisons do not identify all the features of each model, but rather give a general impression of the capabilities built into such models. Further information is available in the operating manuals available through the cited URL addresses.

MODSIM

Description	MODSIM is a generic river basin management decision support system based on simulation of river network flow and reservoir operations. It was originally developed by Dr. John Labadie of Colorado State University (CSU) in the late 1970s. Since 1992, an ongoing joint development agreement between CSU and the U.S. Bureau of Reclamation Pacific Northwest Region has resulted in enhancements to MODSIM that allow the model to simulate physical operation of reservoirs and water demand. MODSIM uses a network flow optimisation algorithm and priority 'weights' as the mechanism to distribute the water in a river system (Labadie, 2005).
Appropriate use	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.
Key output	Time series of hydrologic volume and flow variables at selected sites.
Key input	Configuration of system and component capacities and operating policies. Seepage data, infiltration return from irrigation districts, time series of groundwater demand, initial groundwater storages, hydraulic conductance values, economic functions, inflows to surface reservoirs, surface reservoir targets, canal capacities.
Ease of use	Relatively easy to use.
Training required	Moderate training/experience in resource modelling and demand analysis required for effective use.
Documentation	Detailed documentation available through their website: http://modsim.engr.colostate.edu/download.html/.
Contacts for framework, documentation & technical assistance	Dr. John Labadie, Civil Engineering Department, Colorado State University; e-mail: labadie@engr.colostate.edu; website: http://modsim.engr.colostate.edu/download.html.
Cost	MODSIM can be downloaded free through the website.

MIKE BASIN

Description	For addressing water allocation, conjunctive use, reservoir operation, or water quality issues, MIKE BASIN uses ArcView GIS with comprehensive hydrologic modelling to provide basin-scale solutions.

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	The MIKE BASIN philosophy is to keep modelling simple and intuitive, yet provide in-depth insight for planning and management, making it suitable 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 modelled. The groundwater description uses the linear reservoir equation (DHI, 2003).
Appropriate use	Water availability analysis: conjunctive surface and groundwater use, optimisation thereof. Infrastructure planning: irrigation potential, reservoir performance, water supply capacity, wastewater treatment requirements. Analysis of multisectoral demands: domestic, industry, agriculture, hydropower, navigation, recreation, ecological, finding equitable tradeoffs. Ecosystem studies: water quality, minimum discharge requirements, sustainable yield, effects of global change. Regulation: water rights, priorities, water quality compliance.
Key output	Hydrologic volume and flow descriptions throughout the water system, water diversions, hydropower generation, hydropower tradeoffs to other operating objectives. Water quality descriptions of dissolved solids and water temperature.
Key input	Overall system: digitised river system layout, withdrawal and reservoir locations. Water demand: time series of water demand, percentage of ground abstraction, return flow ratio, linear routing coefficient (irrigation only). Water supply: unit naturalised runoff (time series), initial groundwater elevation, linear reservoir time constant, and groundwater recharge time series. Hydropower: time series of withdrawal for hydropower, installed effect, tail water level, machine efficiency. Reservoir: initial water level, operational rule curves, stage-area-volume curve, time series of rainfall and evaporation, linkages to users, priority of delivery, linkages to upstream nodes. Water quality: rate parameters, temperature, non-point loads, weir constant for re-aeration, transport time and water depth or Q–h relationship, concentrations in effluent.
Ease of use	Relatively easy to use if user is familiar with ArcView software. Requires significant data for detailed analysis.
Training required	Moderate training/experience in resource modelling required for effective use. Also requires working knowledge of ESRI's ArcView software.

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Training available	MIKE BASIN courses are arranged both regularly and upon request (see http://www.dhisoftware.com/mikebasin/Courses/).
Documentation	Detailed documentation including on-line tours of the model available through their website: http://www.dhisoftware.com/mikebasin/Download/.
Contacts for framework, documentation & technical assistance	DHI's Software Support Centre; Tel.: +45 45 16 93 33; Fax: +45 45 16 92 92; e-mail: software@dhi.dk; website: http://www.dhisoftware.com/mikebasin/.
Cost	Licensed software cost US $3000 per class set, US $300 to update each set. In addition Arc View software is required.

RIBASIM

Description	RIBASIM is a generic model package for simulating river basins under various hydrological conditions. The model package 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 and operational and demand management, and to see the results in terms of water quantity and flow composition. RIBASIM can also generate flow patterns that provide a basis for detailed water quality and sedimentation analyses in river reaches and reservoirs. Demands for irrigation, public water supply, hydropower, aquaculture, and reservoir operation can be taken into account. Irrigation demand can be calculated based on cropping patterns, irrigation practices and meteorological data. Surface and groundwater resources can be allocated. Minimum flow requirements and flow composition can be assessed (WL/Delft Hydraulics, 2007).
Appropriate use	Evaluation of the options and potential for development of water resources in a river basin. Water allocation issues. Assessment of infrastructure, and operational and demand management measures.
Key output	Water balance providing the basic information on the available quantity of water as well as the flow at every location and any time in the river basin. This takes into account drainage from agriculture, discharges from industry and the downstream re-use of water in the basin. Produced hydropower and crop production and/or crop damage due to water shortages.

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Key input	Configuration of system (can use GIS layers for background) and component capacities and operating policies. Water demand: spatially explicit demographic, economic, cropping patterns or crop water requirements; current and future water demands and pollution generation. Economic data: water use rates, capital costs, discount rate estimates. Water supply: historical inflows at a monthly time step; groundwater sources. Scenarios: reservoir operating rule modifications, pollution changes and reduction goals, socioeconomic projections, water supply projections.
Ease of use	Relatively easy to use. Requires significant data for detailed analysis.
Training required	Moderate training/experience in resource modelling required for effective use.
Training available	Contact Delft Hydraulics for details regarding available training (see Contacts below).
Documentation	Documentation available from Delft Hydraulics (see Contacts below).
Contacts for framework, documentation & technical assistance	Delft Hydraulics Rotterdamseweg 185, PO Box 177, 2600 MH Delft, The Netherlands; Tel.: +31 0 15 285 8585; Fax: +31 0 15 285 8582; e-mail: ribasim.info@wldelft.nl; website: http://www.wldelft.nl/soft/ribasim/int/index.html.
Cost	Relatively low cost to obtain model and documentation. Limited version available free of charge.

WBalMo

Description	River basin's water resource system can be examined with the WBalMo simulation system under various hydrologic and system design and operating conditions. The management model, which forms the basis of the WBalMo simulation system, relies on the Monte Carlo Technique to generate scenario runs. River basins water utilisation processes can be reproduced, covering any space of time in time-steps of one month. The registration of relevant system states allows a statistical analysis of registered events after completion of the simulation. As a result, approximate probability distributions for factors such as reservoir storage levels, individual water user water supply deficiencies or discharges at selected river profiles, are produced. WBalMo assists user specific model descriptions and coupling with external models by the help of internal programming of Fortran statements as well as executing functions of binary DLL-files. So the states of objects of the water management model can be altered depending on other process states, described in external models.

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	The WBalMo simulation system is the ArcView desktop implementation of the GRM management model. Since the late 1970s this simulation model has been designed to provide a user-friendly interface appropriate for simulating long-term river basin management (Kaden et al., 2006).
Appropriate use	Management and general regulation for river basins in accordance with guidelines; operation plans for water resource plants and for supplying water users; provision of reports for investment projects; proceedings concerning water rights.
Key output	Reservoir storage levels, evaporation losses, water utilisation demands, withdrawal demands, return flows, discharges.
Key input	Configuration of system (can use GIS layers for background) and component capacities and operating policies. Water demands: withdrawal of water at power stations, at industrial plants, at irrigation sites, and return flow ratios. Reservoirs: reservoir capacities, initial reservoir storage levels, evaporation rates, mandatory releases, reservoir management policy.
Ease of use	Relatively easy to use if user is familiar with ArcView software.
Training required	Moderate training/experience in resource modelling required for effective use. Also requires working knowledge of ESRI's ArcView software.
Training available	Contact WASY for details regarding available training (see contacts below).
Documentation	Contact WASY for detailed document; http://www.wasy.de/english/produkte/wbalmo/index.html.
Contacts for framework, documentation & technical assistance	Stefan Kaden, Michael Kaltofen WASY Gesellschaft für wasserwirtschaftliche Planung und Systemforschung mbH, Waltersdorfer Straße 105, 12526 Berlin; Tel.: +030 67 99 98-0; Fax: +030 67 99 98-0; e-mail: support@wasy.de; website: http://www.wasy.de.
Cost	Contact WASY. In addition ArcView is required.

Water evaluation and planning system (WEAP)

Description	This is a PC-based surface and groundwater resource simulation tool, reliant on water balance accounting principles, which can test alternative sets of supply and demand conditions. The user can project changes in water demand, supply, and pollution over a long-term planning horizon to develop adaptive management strategies.

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	WEAP is designed as a comparative analysis tool. A base case is developed, and then alternative scenarios are created and compared to this base case. Incremental costs of water sector investments, changes in operating policies, and implications of changing supplies and demands can be economically evaluated (Yates et al., 2005).
Appropriate use	What-if analysis of various policy scenarios and long-range planning studies. Adaptive agriculture practices such as changes in crop mix, crop water requirements, canal linings; changes in reservoir operations; water conservation strategies; water use efficiency programs; changes in instream flow requirements; implications of new infrastructure development. Strengths include detailed demand modelling.
Key output	Mass balances, water diversions, water use; benefit/cost scenario comparisons; pollution generation and pollution loads.
Key input	Configuration of system (can use GIS layers for background) and component capacities and operating policies. Water demand: spatially explicit demographic, economic, crop water requirements; current and future water demands and pollution generation. Economic data: water use rates, capital costs, discount rate estimates. Water supply: historical inflows at a monthly time step; groundwater sources. Scenarios: reservoir operating rule modifications, pollution changes and reduction goals, socioeconomic projections, water supply projections.
Ease of use	Relatively easy to use. Requires significant data for detailed analysis.
Training required	Moderate training/experience in resource modelling required for effective use.
Training available	On-line tutorial available at http://www.weap21.org/. Contact SEI for details regarding available training (see below).
Documentation	WEAP21 User Guide; available online at http://www.weap21.org/ as pdf file.
Contacts for framework, documentation & technical assistance	Jack Sieber, Senior Software Scientist, Stockholm Environment Institute (SEI), Jack Sieber, Stockholm Environment Institute. Tufts University, 11 Curtis Avenue, Somerville, MA 02144-1224, USA; website: http://www.weap21.org/.
Cost	US $2000 for commercial users includes free upgrades and technical support; discounts available for government, universities, and not-for-profit organisations; free to developing countries.

13.3. Stakeholder Involvement

Traditionally, modelling tools have played a crucial role in supporting and revitalising the water resources planning and management profession. Water resources models have grown in sophistication from simple single mathematical procedures to physically-based and highly graphical, full-blown software applications. The adoption of a participatory approach by leading planning agencies, e.g. US Army Corps of Engineers, has created the opportunity for using modelling (among other technologies) to facilitate the involvement of stakeholders at all stages of decision making. Stakeholders should be involved in the modelling steps of

- 'drawing in' the basin configuration,
- identifying the sites of interest,
- inputting the data relevant to the particular site or reach,
- testing various assumptions if there are stakeholder disagreements to determine how important those different assumptions are to the decisions that need to be made, and
- continuing on to full simulations with alternative hydrologic and water quality data sets, as appropriate.

This will give stakeholders a sense that it is not just someone else's model, it is their model, and they will better understand its strengths and weaknesses.

In essence, the challenge lies in enabling non-experts to achieve familiarity with the water resource system, its components and interactions and to help them understand the main issues and problems from a variety of perspectives. This approach helps the involved stakeholders appreciate the potential impact of alternative policies and management options on their interests, and the interests of other stakeholders such as providing estimates of both direct and indirect impacts on environmental and economic resources.

13.4. Enhancing Non-expert Modelling Accessibility

Improvements in information technology, coupled with the development of information analysis and processing capabilities, have made system modelling more accessible to non-experts. The following is a non-exhaustive list of some of these achievements, with some continuing challenges, that provide a glimpse into future research needs:

- GIS technology is being used in the design of user interface, data processing, analysis and visualisation. All the DSSs reviewed in this paper incorporate, at different levels, map or picture display capabilities. Increasingly DSSs are incorporating the use of GIS technology, especially the mainstream business and engineering communities, exemplified by the advent of highly powerful, intuitive and widely available GIS products such as ArcView, ArcGIS or MapWindow. In the future data available from Google Earth Pro (Google, 2007) will surely be a resource users will want to incorporate into their interfaces.

- A remaining major challenge in the use of models in water resources planning is the clear communication of model results and model uncertainties, especially with respect to developing measures and constructs that clearly and fairly address the often conflicting interests of stakeholders (see also Chapters 5 and 6).
- At the core of simulation-based water resources planning is the concept of scenarios (see also Chapter 9). This approach considers a set of statistically independent scenarios about the uncertain future in the search for a "robust" decision policy that minimises the risk of making the wrong decision. In the majority of DSSs – scenario formulation and their simulation within models is conducted externally and generally depends on the skill and experience of the analysts. Sulis (2006) provides an example of this in his WARGI-DSS. More focused efforts are needed to develop more realistic conceptual frameworks and procedures for developing and analysing scenarios in the discipline of water resources planning and management.
- Some of the innovations that have increased the user base of water resources models and involved greater numbers of non-experts in the water resources modelling process are the improvement of high level modelling and analysis capabilities through automation, the click-drop-and-add and other highly visual simulation environments and interactive visualisation tools. This is similar to the trend in programming and software applications, e.g. Visual Basic and Excel. Water resources modellers can benefit from the experience in developing science and technology educational packages, such as the NASA's EdGCM (Chandler et al., 2005).
- Virtual Reality (VR) or real world-like simulations and user interactions can incite interest and facilitate more intimate understanding of the water resources system. For example, VR methods have been used in the Life Safety Model (LSM) to produce dynamic and visual simulations of people reacting to a dam breach flood by escaping via vehicles and on foot (Assaf and Hartford, 2002).
- Free and Open Source Software (FOSS), which includes the freely-shared Linux operating system, offers the potential of facilitating model development and use especially in developing countries. Several open-source geospatial software including Quantum GIS (Quantum GIS, 2007), PostGIS (PostGIS, 2007), MapServer (MapServer, 2007), and GRASS (GRASS, 2007) are freely available for a wide array of tasks and can be easily linked to or incorporated within simulation models. Despite their availability at no cost, ownership costs of FOSS including technical support and training can be significant. (For more discussion of this topic, see Chapter 10.)

13.5. Reaching Out to Younger Generations

The water resources modelling community can benefit from the experience of other modelling groups in making highly advanced models accessible to the public and younger generations in particular. This can bring about two main advantages in reaching out to stakeholders and the public at large:

- The technology used in customising and adapting models to cater to novice users such as students can be readily applicable and transferable to those of stakeholders. The two groups have similarities with respect to their lack of expertise in modelling and their curiosity and, one hopes, interest in model applications. Educational software packages can provide a less risky testing ground for novel ideas.
- Early introduction of modelling concepts and issues to younger generations is a valuable investment since it will foster the formation of well informed future stakeholders who will be more receptive and understanding of the role of science and technology in addressing critical issues.

13.6. The Current State of the Art – Results of Workshop Discussion

How well have generic river basin simulation models performed? To address this question we focused mostly on the five models described above, with participants of the workshop commenting on their experiences with these and other models designed to serve similar purposes. Workshop participants were familiar with the models. Some had experience with one or more of the software codes and routinely appreciated their utility.

13.6.1 On detail and complexity

All of the models discussed in this chapter are one-dimensional node-link representations of water resource systems. Each model application is formulated through a graphics-based interface. First the system configuration is defined (drawn in). This typically defines the model application data requirements. These data may be entered interactively or, especially for time-series data, as flat files or tables that can be cut and pasted from spreadsheets. The software performs hydrologic mass balances – some consider flow hydraulics and permit water routing, a necessary feature if short model time step durations relative to the time flow would take to travel through the entire basin are chosen. None of these models are fully-fledged hydraulic models and they do not consider flow hydrodynamics. Their relative simplicity reduces the input data, and therefore the cost, required for simulation as well as the detail and precision that can be found in the results.

Some of the models include water quality, but most water quality modelling components are relatively simple compared to the state of the art in water quality modelling. Some of the models can be linked to more detailed higher-dimensional models (e.g. MODFLOW for groundwater-surface water interactions or more complex water quality models). Within the accuracy provided by their simplifying assumptions, these decision support systems (DSSs) attempt to address problems involving, for example, 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 and this presents a challenge in constructing models that are designed to address issues characterised by these quite different temporal and spatial scales.

Each of the five models presented in this chapter have been applied in various basins in numerous countries. Occasionally there are cultural issues associated with their use. In some basins, especially where the flow in rivers is largely base flow from groundwater accretions, surface-groundwater interactions can be very important if one is to simulate the water resource system realistically. The stream-groundwater interaction has posed a challenge to many water basin models mostly because of the process time scale differences but also because of the difficulty in obtaining good groundwater accretion (or depletion) data. MODSIM can link to 3D models (like MODFLOW) to capture the dynamics of this interaction between surface and groundwater. WBalMo can link to groundwater models (like FEFLOW) as well.

While there is a definite place for simple, less data demanding, models, there is a danger that they can be too simple. There is also a danger that over time they can become too complex. We need good models with sufficient detail to adequately address the issues of concern. Can we build a model for planning that also works for operations? Can we provide adequate precision in any generic model that by definition is not built to fit the particular details of specific basins?

In the era of shared vision modelling, the interface can make or break a model. The model interface has to be intuitive, clean and efficient. It must satisfy a highly versatile audience with a wide spectrum of knowledge, background and interests. Borrowing from the GIS technology, WEAP allows users to zoom up and down geographically but it is harder to zoom up and down with respect to modelled spatial and temporal resolutions. Can we learn from other technologies that are successful in reaching out to the public at large? Can we make our models as intuitive as Google Earth is to operate?

Conclusion: Model complexity is an issue. It is always a temptation to make a relatively simple model more complex to address certain new problems or issues. There are advantages to both simple and complex models, and somehow our generic general purpose simulation models need to address the needs of those who want things simple and those who want things more realistic or detailed without detracting from the advantages of both.

13.6.2 On stakeholder participation and shared vision modelling

Stakeholder participation in developing conceptual models can be very helpful in gaining support for actual actions taken in the region or basin (Palmer et al., 1999; US Army Corps of Engineers, 2007). Experience with stakeholder groups in model definition and analysis is mixed. Some participatory modelling experiences have been very successful and others not so much. Some expressed concern that stakeholder involvement could possibly degrade the scientific quality and rigour of the analysis. Others believe it may be the most effective way to ensure buy-in at the conclusion of the planning process when model results are being discussed and for the input of any socioeconomic considerations. These simulation models must address the issues of interest to all stakeholders, and delineate the tradeoffs among objectives where such tradeoffs exist.

The US Army Corps of Engineers have built a number of their river basin simulation model (called shared vision model) interfaces using Visual Basic in Excel. This interface can then link to various simulation modules that have been developed using other software.

Conclusion: Interactive, relatively simple generic simulation models or modelling platforms have been proven to be useful in facilitating stakeholder involvement and buy-in of the model results. But it takes work and patience on the part of those leading the participation process. Stakeholder involvement in model building of particular river basins or watersheds can vary from just overseeing what is being done to actual model operation and testing of alternative data sets and assumptions.

13.6.3 On applied technology

Some of these DSSs are very modular. A modular approach is often useful for addressing various levels of information needs and for linking to site-specific models. The approach also allows inclusion of client-owned models that are trusted by those clients, whether better or worse than other alternative modelling approaches. Some generic models are more modular than others. Modules can be added to WEAP but only by trained developers. MODSIM has used the PERL scripting language in the past to modify rules and provide customisation. Perl is an interpreted programming language – for rules, thus avoiding the need to recompile the whole program after modifications in interactive consensus-building situations. However, this has resulted in slow system operation in some cases. In a complex system precompiling PERL will allow it to run much faster. Currently MODSIM is shifting to Microsoft's programming language independent .NET technology, which allows a cleaner design, componentisation of software, enhanced maintainability and reusability of the code base, and faster operation in many cases.

One of the greatest advantages of the .NET Framework is providing users with the ability to customise MODSIM for any specialised operating rules, input data, output reports, and access to external models running concurrently with MODSIM, all without having to modify the original MODSIM source code. Customised code can be developed in any of the several .NET languages that are freely provided with the .NET Framework. All important PUBLIC variables and object classes in MODSIM are directly accessible to the custom code, and the .NET CLR produces executable code as opposed to other applications requiring scripts to be prepared in an interpreted language such as PERL or JAVASCRIPT with poorer runtime performance. WBalMo models can be customised with internal FORTRAN statements; functions of binary DLL-files are also supported.

Increasingly these generic simulation models are built on top of a geographic information system. MIKE-BASIN and WaBaMo require the use of ESRI's GIS software such as ArcView or ArcGIS. To some this is an advantage, to others it is a constraint and an expensive one if they do not otherwise use GIS. Everyone agrees that there is an advantage of seeing the defined water resource system on top of a map or aerial photograph of the region. This is inviting for stakeholders. They see their places of interest in the basin being modelled. WEAP has built into the code a limited vector representation of the geographic area of interest, but this requires no additional software or cost. For users with expertise in GIS and license ownership of ESRI's ArcGIS software, GEO-MODSIM is a full implementation of MODSIM that operates as a custom extension in ArcMap, allowing automatic generation of MODSIM networks from geometric networks and processing of spatial database information for MODSIM network features. GEO-MODSIM networks can be developed, edited, executed, and output results displayed completely within the ArcMap interface of ArcGIS.

Conclusion: A modular approach to generic simulation modelling allows for varying degrees of complexity and utility. Increasingly, maps and photographs are being used along with digital elevation models in some cases, for model inputs and for improved visualisation of model results. Models that provide flexibility in defining operating policies are particularly useful when simulating complex, multipurpose, water resource systems.

13.6.4 On development and continuity

All generic river basin simulation models have had their development challenges. Over time many challenges are met, and others appear when the models are applied in a new setting. The developers of RIBASIM have continuously improved their model over time, although they claim that nearly all their professional applications still require some modification and/or further extension to the existing model.

Models such as these are constantly in a state of development. It is expensive to keep models current or alive and to service (respond to the needs of) those who wish to use the model. Model continuity depends on the continuity of the developers and the support from their institution.

Are generic models sustainable? Does one need to make such models commercial to maintain them, like MikeBasin or WBalMo? How can we best route flows when our time steps require it? How can we best track water ownership where applicable? These are just a few of the challenges facing those interested in the development of improved generic river basin simulation models. In the ideal world, it would be nice to think that such models could be developed, maintained and serviced without cost to the user. In this ideal world all such models should be open source and in the public domain free of charge. Regretfully this is rarely possible. Of the models reviewed in this paper, MODSIM from Colorado State University manages to do this, at least to a large extent. Some of us involved in the early development of interactive generic river basin modelling (under DOS!) tried, but finally had to admit we could not sustain such efforts, so our hat is off to CSU! (For more discussion of this topic see Paper W13a of the workshop at http://www.iemss.org/iemss2006.)

Model developers will always be developing new and better models, and this effort will be helped if we do a better job of documenting what has been done before and why. There are also real advantages in learning from the experiences of others in possibly different disciplines (see for example, Castelletti and Soncini-Sessa, 2006, 2007; Letcher et al., 2007; Nidumolu et al., 2007; Rees et al., 2006).

Conclusion: Real generic models that will serve all stakeholders in all river basins probably cannot be developed. Existing generic models are in a constant state of development. Developing and maintaining models is expensive. Does it make any sense for those building such models to cooperate? Or does competition result in improved products and state of the art? It seems these are interesting questions to ponder.

13.6.5 On content

The motivation for developing MODSIM, beginning in 1979, was to incorporate water law and rules into an allocation model suitable for western US conditions. At that time few generic models had this capability. Today MODSIM also includes water banking (as do some Australian river basin simulation models) that most models still ignore.

One weakness felt is that all models do not adequately address decision-maker issues such as poverty, socioeconomic and environmental impacts. While not directly addressing these overriding issues WEAP is especially rich in policy analysis tools related to costs and demand estimations.

Modelling actor or stakeholder behaviour is problematic, and certainly not subject to optimisation methods as economic theory might suggest. Integrated modelling should include socioeconomic drivers or processes since human behaviour can change more than physical processes.

Ecological objectives are becoming increasingly important. Most consider ecological impacts using separate analyses based on the outputs of the river basin simulation models, yet this output does not always conform to the needs of ecologists. Included within the MIKE suite of models is a generic ecosystem simulator EcoLab which, like the popular MatLab toolbox, provides some basic tools that allow engineers and planners, with the assistance of ecologists and environmental systems modellers, to consider ecological impacts more comprehensively. The future use of toolboxes such as EcoLab with the models discussed in this paper might provide increased opportunities for interdisciplinary hydroecology or ecohydrological modelling.

Conclusion: Defining the scope of our generic models is a challenge given the many special features of various basins throughout the world and their particular water management issues and constraints. It therefore makes sense to build into our generic water resource simulation models maximum flexibility. Continuing software and technological developments can help make this possible (Argent et al., 2006; Klopfer, 2003).

13.7. Overall Conclusion

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 and at the same time appropriate for facilitating stakeholder involvement in the planning and decision-making process. Yet there remain many challenges. There is still much to do in developing generic modelling or decision support platforms that when fed with input data become models of particular systems. In almost every application, there seems to be some features of the physical river basin system, or some performance measures of interest, that motivate some modifications that will increase the capabilities of the so-called generic model. And each successive application leads to model complexity, and fatter user manuals.

Yet there is a real need to perform preliminary screening analyses of proposed water infrastructure development plans or management policies. And it is not easy, nor cheap, to develop from scratch and in a short time, a simulation model of a particular river basin. Perhaps these relatively simple simulation studies using generic models will be sufficient, but more likely the results of such simulations will be able to identify just where more detailed, and more expensive, data collection and analyses are needed. One of the advantages of modelling is not only to identify the best designs and operating policies, but also just what data are needed and how accurate they need be in order to determine what is best.

Finally just what is best is very dependent on stakeholder perceptions. Getting a group of stakeholders to come to a shared vision of how their river basin system works is not a trivial exercise, and getting them to come to a common view of how it should work (meaning be developed, managed and/or operated) is even harder. But this is where generic simulation modelling software that permits interactive system definition and data input, editing and rapid testing via simulations of alternative assumptions is useful. If one can get the influential stakeholders to sit around the table with a computer in front of them, they can all become involved in defining their system and inputting data, i.e. model development, and then performing simulation and sensitivity studies. They can be involved even if they do not want to touch any part of the computer. They can express their opinions and concerns while learning the concerns and interests of other stakeholders. These inputs can be incorporated within the generic model in ways they can observe. This iterative interactive process has helped stakeholders in the past, and should be able to help stakeholders in the future, feel ownership of the resulting model and eventually, one hopes, come to a consensus on just what decisions are the best.

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