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Alan M. Lumb
U.S. Geological Survey

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Alan M. Lumb[1]

Abstract

Comprehensive hydrologic analyses can be very effective for the assessment of hydrologic effects of land use and climate changes, but the costs and expertise is often prohibitive. Progress has been made in four areas to reduce the costs and expertise required: (1) Watershed Data Management (WDM) system for the storage and retrieval of data used and generated by the model, (2) an expert system for the calibration of the model, (3) use of Geographical Information Systems to generate distributed parameters for the model, and (4) easy to use software for applications of the model.

Introduction

Continuous simulation of watershed processes with distributed parameter models is the most comprehensive method for assessing the hydrologic and water-quality effects of land-use change, climate change and dams and other control structures. Wide use of such models has been constrained by the costly tasks of data preparation and data management, and the expertise required for model calibration and application. Enhancements to watershed modeling systems have been developed to increase the effectiveness and efficiency of such systems for use by water-resources managers in impact assessment and water-management decisions. In general, the constraints are no longer the cost of computer hardware, but are the development of the software and available expertise. In this paper four software enhancements are discussed: 1) Watershed Data Management (WDM) system for the storage and retrieval of data used and generated by the model, 2) an expert system for the calibration of the model, 3) use of Geographical Information Systems to generate distributed parameters for the model, and 4) easy to use software for applications of the model.

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[1] Chief, Hydrologic Analysis Support Section, U.S. Geological Survey, 415 National Center, Reston, Virginia 22092

Watershed Data Management System

A substantial portion of the software for hydrologic analysis and modeling manages data input and output. In addition, software is commonly written for pre- and post-processing the data, which involves activities such as editing and producing graphs. Sometimes output from one model is needed as input to another model, but each model uses a different data-management scheme. Modeling software is commonly used with different hardware and operating systems. The Watershed Data Management (WDM) system was developed as a common data management system that could be used on any computer system that supports the Fortran computer language. (Lumb and others, 1988)

The major premise of the WDM system is that data are used in groups, such as daily streamflow, coordinates for a channel cross section, a table of hydraulic properties, or hourly rainfall. All or parts of one or more groups might be needed as input to the model, and all groups must be identified for easy and logical retrieval by the user. For a WDM file the groups are data sets, and the data set identifiers are called attributes. A WDM file can store as many as 32,000 data sets, and as many as 150 attributes for each data set. More than 300 pre-defined attributes can be used, and new attributes can easily be added.

The WDM file is a set of unformatted, direct-access records with several types of pointer systems and chaining for rapid access to the data and for efficient management of disk space after data editing and deletion. Although the file structure is moderately complex, end users can easily manage the file by using the interactive software package ANNIE (Lumb and others, 1990) and the programmer can use the file with a few simple subroutines. Basically, a subroutine contains arguments for the identifiers for the file, data set, and portion of data to be retrieved or stored, and an array variable containing the data retrieved or stored. Neither the end user nor the programmer needs to know the detailed structure and pointer system for the WDM file. The subroutines for the WDM file are very basic and could be replaced with subroutines that read and write to a different file structure without modifying any of the modules of the hydrologic programs.

Calibration with an Expert System

Parameters in watershed models are used to adapt the models to specific river basins. Some parameters can be determined from measured properties of the river basins, others must be determined by mathematical optimization or manual calibration. Optimization techniques attempted over the past two decades have not proven satisfactory. Such techniques divorce the model user from the modeling process, obscuring the links between the processes as simulated by the model and the actual processes in the watershed. Although error functions can be minimized by optimization, the physical meaning of such optimized model parameters is

left, for the most part, unexplained. Manual calibration requires experienced watershed modelers, but there are many more users of watershed models than there are experienced modelers. With that in mind, an effort was begun to use the expertise of the experienced watershed modeler within the context of an expert system.

One of the more widely-used watershed models, the Hydrological Simulation Program - Fortran (HSPF) (Johanson and others, 1984), was selected as the basis for testing the feasibility of developing an expert system. In an earlier effort, an expert system was developed to estimate initial parameters for HSPF (Gaschnig and others, 1981). Also, the number of parameters to calibrate in the HSPF rainfall-runoff module is more appropriate than similar type models for the amount and type of data typically available.

Two surface-water modeling experts, the author and Norman Crawford, and the knowledge engineer, Richard McCammon, documented procedures used to calibrate the rainfall-runoff module of HSPF with a set of diagrams and charts. The calibration procedures are divided into four major phases: (1) water balance, (2) low flow, (3) storm flow and, (4) seasonal adjustments. A fifth phase, to identify any bias within the model, is also identified. Under each of the four major phases, simulated streamflow is compared with the observed streamflow from tables of output, statistics and time-series plots. In a decade of experience over a wide range of climates and topographies, experienced modelers have learned which parameters can be meaningfully adjusted in order to reduce the simulation errors.

The expert system designated HSPEXP (Lumb and others, 1991) is made up of a set of rules that are based on statistical measures, such as errors in simulated seasonal and annual volumes and storm peaks and volumes, and subjective judgments that reflect the role of the parameters in the rainfall-runoff module of HSPF. The statistical measures are calculated after each HSPF run. The subjective judgments can be provided at the user's option, and when supplied are used in combination with the rules to affect the advice offered by the program. In its simplest form, a rule can be expressed by the following:

IF condition 1, condition 2, condition 3
THEN action,

where the conditions are tested from left to right. Each of the previously specified conditions represents a Boolean expression. The respective action will be taken if any of the previously specified conditions are true. The action in these situations is advice given to the user about whether to increase or decrease the value of a particular parameter. To take one rule as an example:

IF (the simulated total runoff is E1 % higher than measured

AND the ET difference is less than the flow difference)
(the simulated total runoff is E1 % higher than measured
AND there could be recharge to deeper aquifers)
THEN the advice is to increase DEEPFR,

where the error level E1 is set by the user, the simulated and measured runoff and the evapotranspiration (ET) and flow difference are calculated from the output for the run, and the judgment about whether there could be recharge to deeper aquifers is provided by the user if known. In this case, if the simulated total runoff is not E1 % higher than measured, there is no need to pursue this rule further, and no need to use the information about recharge to deeper aquifers. Furthermore, if the first condition is true, the advice is to increase the deep percolation parameter, DEEPFR. There is no need to ask the user about possible deeper recharge. Only if the simulated total runoff is E1 % higher than measured, and the ET difference is greater or equal to the flow difference is there a need to use the information about recharge to deeper aquifers. Such a strategy uses but does not require the subjective judgments that can be supplied by the user.

In addition to the advice offered by the system, an explanation is provided. Such information has the greatest value to inexperienced hydrologists and to hydrologists unfamiliar with the HSPF program. Such an explanation affords an excellent training mechanism. As the knowledge of the user increases over time, explanations become less important.

Within HSPEXP there are currently 37 rules that involve 84 conditions of the type described above. The rules apply to the 13 major, process-related HSPF parameters. For many of the these parameters, there is more than one rule that contains advice about whether or not the value of the parameter should be increased or decreased. To avoid the potential conflict in the advice offered by the system, the rules are divided into the four phases previously defined, each phase determining the order in which the rules will be applied. Within each phase, there is only one rule that will advise whether a particular parameter should be increased or decreased. All rules within a phase are tested before moving on to the rules in the next phase. If after testing the rules within a phase any action is indicated, that advice is given and no further testing of the rules is performed. Such a strategy eliminates the possibility of conflicting advice being offered by the system.

Geographical Information Systems

Geographical Information Systems (GIS) can be used with watershed modeling in the pre-processing and post-processing stage. For pre-processing, GIS has been used to delineate river basin and tributary boundaries and compute areas, slopes, aspect, and flow lengths from digital elevation data. Those boundaries when combined with spatial coverages of land use and soils characteristics can be used to estimate watershed model parameters. Formatted files have been designed for GIS

systems to compute and table the information on tributary drainage areas, linkages to channels, and linkages between channels. These files will then be read by HSPEXP to create the input necessary for HSPF based on a set of rules relating these characteristics to model parameters. The most challenging aspect for the expert system is to take the modeling objectives and GIS coverages and determine the appropriate aggregation or number of tributary areas and channel reaches. This expertise would utilize information on the sensitivity of the level of aggregation on the accuracy of the simulation.

The other use of GIS or at least river basin schematics is the post-processing or decision support systems. When analyzing effects with a watershed model, the user can most effectively communicate the planning scenario with a map of the basin and even interpret the results in the context of a map. These tools are being explored with an objective that the software could be transferred to a variety of computer platforms.

Decision Support System

It is both difficult and expensive to use a comprehensive, continuous-simulation, watershed model for every assessment of effects of each building permit or each proposed land use change. The computer resources are no longer of major concern, but manpower constraints limit the time available to prepare the data for the computer analysis. Thus, the concept of decision support systems, easy to use systems to do complex analyses. Such systems can greatly reduce the required manpower and expertise. However, an initial investment in highly skilled professionals is required to develop such systems. Decision support systems in water resources is analogous to the use of robotics in manufacturing. The use of the the system must be done in sufficient quantities to justify the capital expenditures. It is quite likely the quantities of analyses in many water resources management agencies is sufficient to justify the costs. An early decision support system was developed and used over 15 years ago in DeKalb County, Georgia (Lumb, 1976). Comprehensive analysis of urban development could be done with minimal input. The major hurdle at that time was access to the computer systems by the professionals. Today that is not a problem.

Although decision support systems commonly use a graphical user interface sometimes coupled with Geographical Information System, they use simple hydrologic models. Other systems use a simpler keyboard interface that is easy to use with more comprehensive hydrologic modeling. With time the graphical user interfaces will be used with the more comprehensive models.

Summary

Comprehensive hydrologic analyses with watershed models can be used to easily assess the effects of land use and climate changes with the

capital investment in data management systems, Geographical Information Systems, expert systems, and decision support systems. Progress has been made in each of these categories and the potentials can be seen, but much has yet to be done to place them in common use for water resources management decisions.

References

Gaschnig, John, Rene Reboh, and John Reiter, 1981, Development of a Knowledge-Based Expert System for Water Resources Problems, Final Report, SRI Project 1619, SRI International, Menlo Park, California, 133pp.

Johanson, Robert C., John C. Imhoff, John L. Kittle Jr, Anthony S. Donigian, 1984, Hydrological Simulation Program - Fortran (HSPF): Users Manual for Release 8, EPA-600/3-84/066, Environmental Research Laboratory, Athens Georgia, 767pp.

Lumb, Alan M., and Douglas L. James, 1976, Runoff Files for Flood Hydrograph Simulation, Journal of the Hydraulics Division, ASCE, No HY10, v.102, pp 1515-1532.

Lumb, Alan M., Robert F. Carsel, and John L. Kittle, Jr, 1988, Data Management for Water-Quality Modeling Development and Use, Proceedings of the International Symposium Water Quality Modeling of Agricultural Non-Point Sources, Logan, Utah, pp785-797.

Lumb, Alan M. and Richard B. McCammon, 1991, HYDRO-II, An Expert System for Watershed Model Calibration, Proceedings of the International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology, January, New Orleans.

Lumb. Alan M., John L. Kittle, Jr. and Kathleen M. Flynn, 1990, Users manual for ANNIE, A Computer Program for Interactive Hydrologic Analysis and Data Management, US Geological Survey Water-Resources Investigations Report 89-4080, Reston, Virginia, 236pp.