MODERNIZATION OF NATIONAL WEATHER SERVICE RIVER FORECASTING TECHNIQUES

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INTRODUCTION

The National Weather Service (formerly U.S. Weather Bureau) has the responsibility for making and issuing river and flood forecasts throughout the United States. This work is presently being performed at twelve River Forecast Centers. These offices are separate from those which are concerned with reporting and forecasting weather. They are staffed by professional hydrologists and the river forecasting program is their only responsibility.

In 1961, a River Forecast Center was established at Fort Worth, Texas. Although there were nine previously established centers operating at the time, Fort Worth was the first such office to be equipped with an electronic computer. The use of a computer for river forecasting was considered at the time to be experimental. Now, eleven years later, every Center is equipped with some type of on-site computing equipment, ranging from an in-house IBM 1130 to a terminal connected to a remote CDC 6600. The commitment to computers was partly the result of experience at Fort Worth and partly due to general acceptance of these machines as the proper computing device for this day and age. The primary motivation, however, was the anticipation of new, more sophisticated and improved hydrologic forecasting techniques, the complexity of which would require the use of high speed computing equipment. The transition to the new techniques is now in its final phase. The process has taken about five years and this paper describes some of the problems associated with it.

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INVESTIGATION OF NEW TECHNIQUES

In 1966, a project was initiated for the purpose of evaluating some of the newly developed techniques for predicting basin response. In this evaluation, the standard of comparison was to be the existing type of river forecast procedure, API type rainfall-runoff relationship and unit hydrograph [Linsley et al., 1949]. The newer techniques took the form of complete models for the continuous simulation of streamflow. In order to make possible a direct comparison of results, it was necessary to convert the existing API type procedure to a model capable of producing a continuous hydrograph. This resulted in the API continuous model [Sittner et al., 1969]. Test data were assembled for a group of seven carefully selected basins. These basins are distributed throughout the country and exhibit a wide variety of hydrologic and climatic conditions. It is felt that any conclusions resulting from tests on all of them are applicable throughout most of the conterminous United States.

During this project, it was learned that the difference in accuracy between two models is likely to be evident in only one or two aspects of the simulation or only in certain hydrologic situations. Because of this, no single error function is indicative of all pertinent aspects of model response. Consequently, a series of statistical and graphical analyses were devised which together give a comprehensive evaluation of a model's accuracy.

Two models emerged from this project. One model is substantially the same as the Stanford Watershed Model IV [Crawford and Linsley, 1966]. The differences are primarily those necessary to adapt it to operational conditions. The other is the Sacramento River Forecast Center Hydrologic

Model [Burnash and Ferral, 1971] and was developed by the staff of the NWS River Forecast Center at Sacramento, California. While the overall structure of this model bears some similarity to that of the Stanford Model, it contains some basic hydrologic concepts and some mathematical formulations which are significantly different.

These are conceptual models. That is, the parameters and variables involved in the mathematical formulations represent actual physical quantities rather than, as in the case of API, indices to the quantities. This quality is expected to enhance the applicability of forecast models to problems outside the field of pure river forecasting. Examples are land use and groundwater pollution studies.

Under certain conditions, these models show a demonstrable accuracy advantage over API and other methods of analysis. Most notable of these is the modelling of river response during and after a long dry spell. The complex moisture accounting techniques give these models a long "memory". Consequently, they are able to duplicate situations where large amounts of rain give little or no river response. Relative to each other, the accuracy of these two models is nearly identical.

PARAMETER OPTIMIZATION

Parameter optimization or the fitting of a model to a particular basin is an extremely important problem. A model is obviously useless if its parameters cannot be evaluated. In our studies, we have experimented with both manual and automatic optimization techniques. The term, manual, refers here to a procedure in which subjective adjustments to various parameters are made on the basis of specific characteristics of the output of previous computer runs. Automatic techniques are those in which the computer itself adjusts parameters in a semi-random manner, based on changes in the value of a single numerical error function. The method used is an application of the "Pattern Search" technique [Hooke and Jeeves, 1961], [Monro, 1971].

There is no doubt that a good set of parameters can be obtained using only manual methods. The procedure, however, is time consuming in terms of man hours and requires a degree of interplay with the computer often not available from the larger systems. Most important, however, is that the hydrologist performing the optimization must possess a considerable degree of skill acquired through experience with the model being used. At this stage in the conversion to a new technology, not all River Forecast Center personnel have had the opportunity to attain these skills. Automatic methods on the other hand are fast, and simple to use. Besides being expensive from a computer usage standpoint, they have some inherent disadvantages. Some of these are complete dependency on one error function, climbing the wrong "mountain" as a result of poorly selected starting points, and failure to recognize the effect of perturbing a group of parameters simultaneously. At its worst, such a procedure can degenerate into pure curve fitting and produce a set of parameters which fit the calibration data reasonably well, but which are hydrologically unrealistic.

The conclusion is that to fit large numbers of basins in a reasonable time and under operational conditions, the only feasible procedure is one involving both manual and automatic fitting and in which the strong points of each compensate the weak points of the other.

COMPUTER REQUIREMENTS

The decision to equip River Forecast Centers with first generation computers was, as stated earlier, based on the anticipation of new hydrologic methods. Paradoxically, as we now adopt these new methods, we must determine if the second generation machines that we now have are powerful enough to do the job. As in other fields, the development of technology seems to run ahead of hardware development. Shop size computers such as the IBM 1130 seem barely adequate for operational forecasting with the new hydrologic models. Parameter optimization, however, definitely requires considerably more power than is available with this type of computer. Turn around requirements vary considerably. For operational forecasting, practically instantaneous turn around is needed and, at times, conversational mode becomes almost a necessity. For procedure development work including parameter optimization for catchment models, the requirements are less demanding. For automatic optimization runs, overnight batch processing is usually adequate.

A recently completed study by an outside consultant [Medearis, 1972] has determined that the above requirements can be met, within anticipated fiscal constraints, through the use of a single large computer, centrally located, and connected to terminals in each River Forecast Center. This computer would be dedicated to the work of the centers, precluding priority problems with other users. With such a system, stand-alone capability at the terminals and a back-up computer facility are two features which are felt to be highly desirable. They are not essential, however, and the proposed system, due to economic considerations, has neither.

DATA REQUIREMENTS

Conceptual models use an explicit evapotranspiration function. This particular function is probably the most neglected area to date in catchment model research. Intuitively, one would think that the use of real time evapotranspiration data in a model would yield results superior to those obtained from a normal evapotranspiration curve. Recent preliminary studies, however, have indicated that this may not be the case and the conclusion is that the evapotranspiration functions in existing catchment models may be inadequate. It is likely that future research will improve these functions and result in the accrual of benefits from the use of real time evapotranspiration data. This will present a requirement for meteorological data on an operational basis which was not present with the API type models.

With respect to the types of data which are used by the API models, precipitation and river stage, the new models are no more demanding than the old. It is likely, however, that the conceptual models can make better use of more data to a shorter time scale than can the index type models. Recognition of this may result in the strengthening of data collection networks.

For development purposes, data requirements are much greater than with the API type models since development is done on a continuous basis rather than by analyzing specific storm events. The conversion of raw data to the form required for model optimization is a formidable task in itself. Recently, computer programs have been developed to more effectively and efficiently process the hourly and daily basic data available from the National Climatic Center, Asheville, N.C.

MAJOR BASIN DEVELOPMENT

Fitting a catchment model to a headwater basin, while a complex procedure, is straightforward since the basin output is directly observable. The calibration of an entire river basin involves fitting the model to intervening catchments where the observed outflow includes not only the yield of the area under study, but the flow from upstream catchments as well. The sub-basin outflow appears as the difference between two large flow volumes and any observational errors in the measurement of these flows are magnified when the residual is computed. The sub-basin yield may be even further influenced by industrial regulation. A direct fitting process applied to such a catchment is therefore not as accurate as for headwater areas.

This problem results in a need for techniques for translating individual model parameters from headwater catchments to downstream areas. These techniques are being devised in conjunction with the application of conceptual models to major river systems.

TRAINING

The hydrologic techniques under discussion are new to most field personnel. A training program has therefore been instituted to acquaint them with the theory and rationale of the new models and the methods which have been devised for implementing them operationally. Most of the research work has been done in the Hydrologic Research and Development Laboratory at National Weather Service Headquarters. Technical write-ups have been distributed to the forecast centers and seminars have been conducted both at headquarters and in the field offices.

MANPOWER PROBLEMS

The first priority duty of the staff of a River Forecast Center is the preparation of forecasts and as much time as is required must be devoted to this work. Another essential activity is the continuing revision of forecast procedures to reflect changes (natural and man made) in the hydraulic characteristics of a river system. Only the remaining time, often minimal, is available for the development of procedures in connection with new methodology or expansion of the area of forecast responsibility. In recognition of this, the Hydrologic R & D Laboratory has attempted to devise methods which are amenable to a high degree of automation in the application phase and also to develop the automated techniques. Notwithstanding, the conversion to new models presents the field offices with a severe workload, and may require a considerable period of time to accomplish.

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