EVOLUTION OF A RESEARCH-ORIENTED SNOWMELT-RUNOFF SIMULATION MODEL INTO AN OPERATIONAL FORECASTING TOOL

by

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INTRODUCTION

There are numerous hydrologic models in existence, and many have algorithms for calculating snowmelt runoff. Further, many model owners claim that their models can be used for operational runoff forecasting. A large number of these models were submitted to the World Meteorological Organization (WMO) Intercomparison of Models of Snowmelt-Runoff, but when the intercomparison was actually performed, only 11 models were really tested (World Meteorological Organization, 1986). Of these 11 models, several were not operated on certain basins because their data requirements were too demanding. The test was conducted on common data sets, and although it was meant to be relevant to a forecasting situation, the actual intercomparison was conducted in the simulation mode (i.e., actually observed data were used after the fact). The only difference from true simulation was that the observed runoff data were held back from the modelers during the four-year verification period. Just the fact that the actual runoff data were withheld made for a difficult simulation, and certain models completely failed in a number of simulation years.

When such performance problems are encountered in simulation situations, it is not hard to see why the development of an operational snowmelt-runoff forecast model is difficult. So, although many snowmelt-runoff models are proposed, only a few make it to the stage of true operational application in the forecast mode. There are many pitfalls and barriers that must be overcome to successfully transform a research model into an operational product. The research scientist must interact frequently with operational hydrologists in order to develop algorithms that will work efficiently in the "real world." The researcher discovers many useful applications for snowmelt runoff models, other than forecasting, during the course of development. The operational forecaster seldom is interested in applications of the model outside the basin of interest or for other purposes. To come up with a final useful product, the researcher must narrow his or her scope while the operational hydrologist must expand his or her outlook. The process is truly evolutionary. Through a complex series of steps, a useful forecasting tool is sometimes obtained and many useful ancillary advances can result.

SIMULATIONS ON THE RIO GRANDE BASIN

To eventually forecast snowmelt runoff on a basin, a model has to be developed or selected from existing models. The snowmelt-runoff model (SRM) was developed so that the areal extent of snow cover would be used as a primary input variable (Martinec, et al., 1983). Initally, tests were performed on small basins where such input data, in addition to temperature and precipitation, could be obtained. As satellite snow cover extent data became available, SRM was modified and tested on large basins. These tests were conducted in the simulation mode, i.e., all necessary input data were known and the model operators were trying to duplicate, as closely as possible, the observed hydrograph. These tests were performed successfully on a large number of basins around the world (Martinec and Rango, 1986). Confidence in the SRM performance for simulation was growing. At the same time a microcomputer version of SRM was developed (Rango and Roberts, 1987); it was very easy to distribute SRM and for users to apply if they also wanted to operate in the simulation mode.

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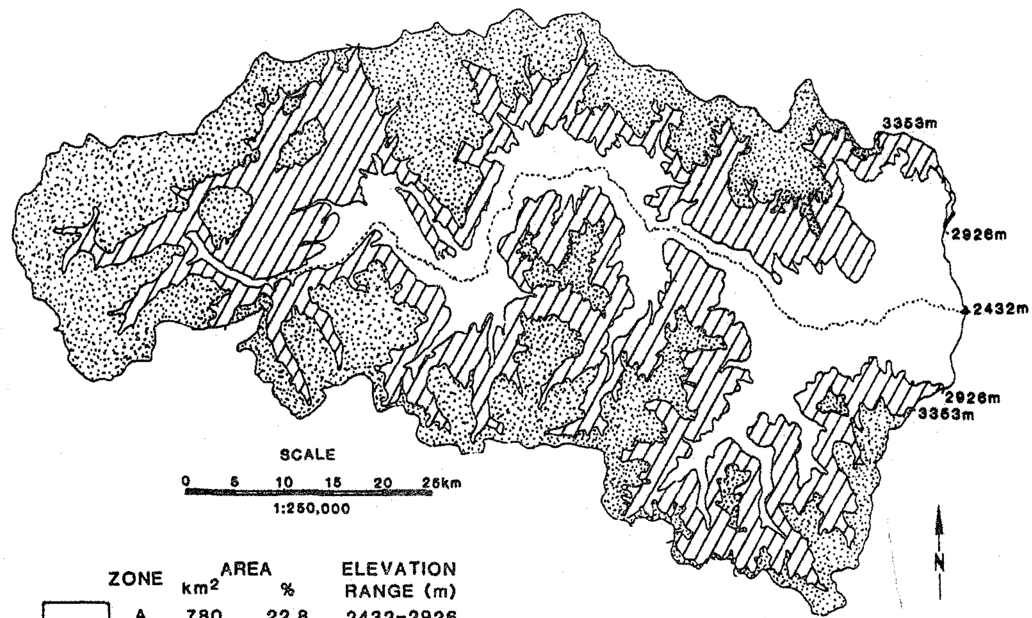
User agencies, such as the Soil Conservation Service (SCS), provided input to the research agency, the Agricultural Research Service (ARS), that for SRM to be useful to them, they needed to be able to operate it in forecast situations. In order to develop a way to do this, the Rio Grande basin near Del Norte, Colorado (3419 km^2) was selected for testing. The Rio Grande was divided into three elevation zones as shown in Figure 1, particularly for snow cover mapping purposes. Ten years of records (1973-1979 and 1982-1984) were available when all input data existed included satellite observed snow cover extent. SRM used these years for simulation and the average R^2 value measuring correspondence of daily flows was 0.86, and the average D_v value measuring correspondence of seasonal volumes was 1.7%. SRM model performance on the Rio Grande was very successful when compared to the R^2 average for all previously tested basins of 0.84 and the D_v average on all basins of 4.4%. Figure 2 shows the model performance during the 1984 snowmelt season.



ZONE	AREA km²	%	ELEVATION RANGE (m)
A	780	22.8	2432-2926
B	1284	37.6	2926-3353
C	1355	39.6	3353-4215
TOTAL	3419	100.0	

Figure 1. Elevation zones and areas of the Rio Grande basin near Del Norte, Colorado.

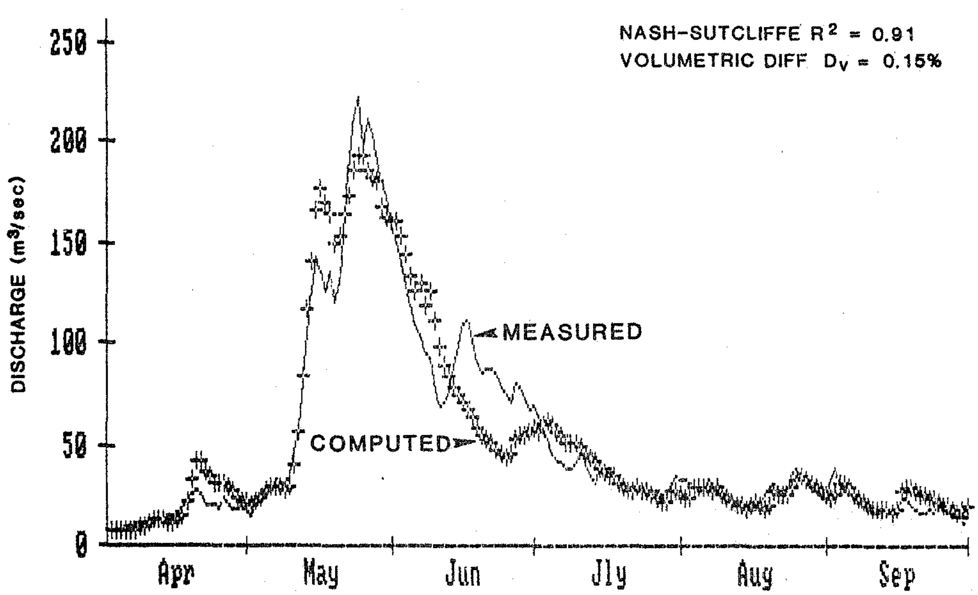


Figure 2. Snowmelt-runoff simulation for 1984 on the Rio Grande basin (3419 km^2) near Del Norte, Colorado using SRM.

ANCILLARY APPLICATION

During this development on the Rio Grande basin, ARS became aware that SRM could be used to assist in evaluations of the hydrologic effects of climate change. Simulations developed on the Rio Grande, as well as other basins, were used as baseline data. Temperature and precipitation were then modified to emulate the possible effects of increasing atmospheric CO_2. It was found that temperature change was the dominant factor to consider (Martinec and Rango, 1989). The effects of an increase in temperature of 3°C on the Rio Grande basin as compared with the simulated hydrograph is shown in Figure 3 for 1983. The redistribution of flow into the months of April and June as well as an increase in total runoff volume was consistent in the basins tested.

The use of models such as SRM will be of great value for evaluating the potential effects of climate change. This application has little direct application to the problems of forecasting, however. It is just an important result that came out in the pursuit of the original problem.

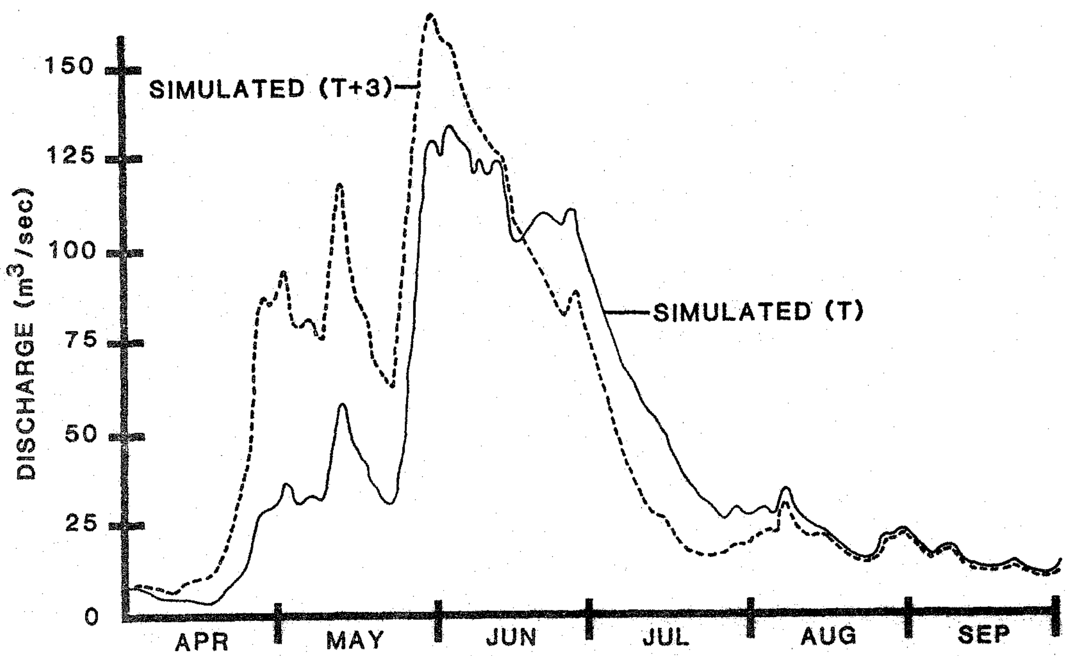


Figure 3. Simulated change in runoff on the Rio Grande basin for 1983 as a result of a 3°C increase in temperature (T+3).

QUASI FORECASTS USING SRM

The next step in development was to progress past the point where all data, both input and output, were known. In a true forecast situation, no data past the forecast date are known. When applying SRM for simulation, the minimum required sources of data are one climate station with temperature and precipitation records and two to three snow cover observations to construct a snow cover depletion curve. If we were to forecast for the Rio Grande basin on April 1, we would not know the snow cover extent after April 1 and perhaps not even know it before April 1, depending on cloud cover conditions. This will be true for temperature and precipitation after April 1 as well.

To proceed in a logical way, our next step was to attempt to make a forecast from April 1 on with no snow cover information available. To be able to do this, we looked at each of the simulation years for the Rio Grande in reference to zonal snow cover depletion curves, actual snowmelt observed, and the April 1 observed snow water equivalent in the basin. The use of modified depletion curves, which plot snow extent versus snowmelt rather than versus time (Martinec, 1985), permitted us to develop a family of modified snow cover depletion curves as shown in Figure 4. These zonal snow cover depletion curves are labeled with the average snow water equivalent value for the zone obtained from conventional snow course observations for April 1. In the future the snow water equivalent might alternatively be obtained from SnoTel data or microwave remote sensing observations.

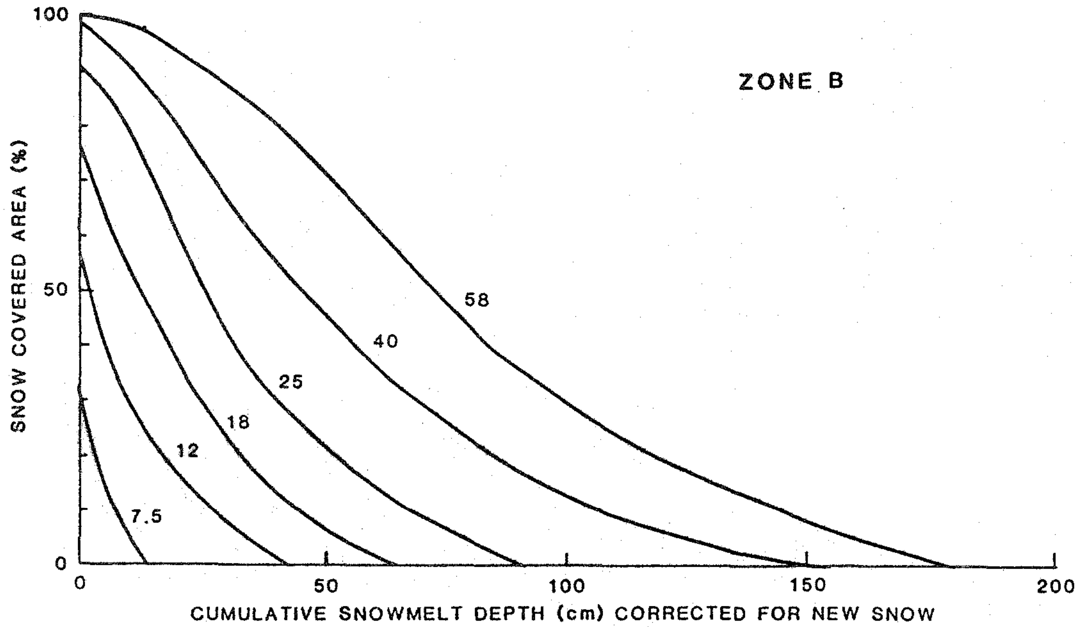


Figure 4. Modified snow cover depletion curves for elevation zone B (2926-3353 m a.s.l.) of the Rio Grande basin labeled with average snow water equivalent values (cm).

The simulations for the 10 prior years were critical in developing the family of curves. The years 1980, 1981, and 1985 originally did not have enough satellite snow cover observations to run SRM simulations. Because we now had a family of curves as well as snow water equivalent observations for April 1 for 1980, 1981, and 1985, we could treat these three years as a kind of forecast situation. To simplify the situation, we assumed that we knew the temperature and precipitation data exactly (i.e., our forecast was perfect), hence we termed the results quasi forecasts.

Using the actual snow water equivalent readings, the snow cover depletion curves for zone B of the Rio Grande basin were obtained as shown in Figure 5. The snow cover depletion curves thus obtained were used to extract the daily snow cover data needed by SRM. SRM was run for each quasi-forecast year and the results were similar to the prior simulations. An example of the successful results is shown in Figure 6 for 1985.

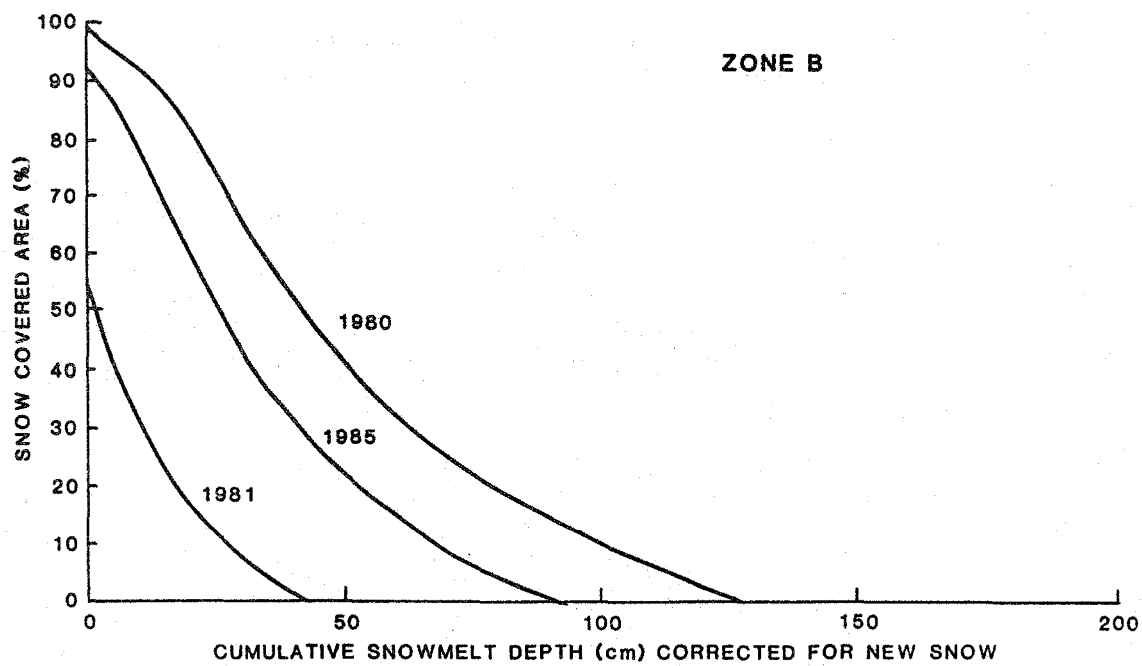


Figure 5. Modified snow cover depletion curves for elevation zone B of the Rio Grande basin for 1980, 1981, and 1985 determined using measured snow water equivalent values.

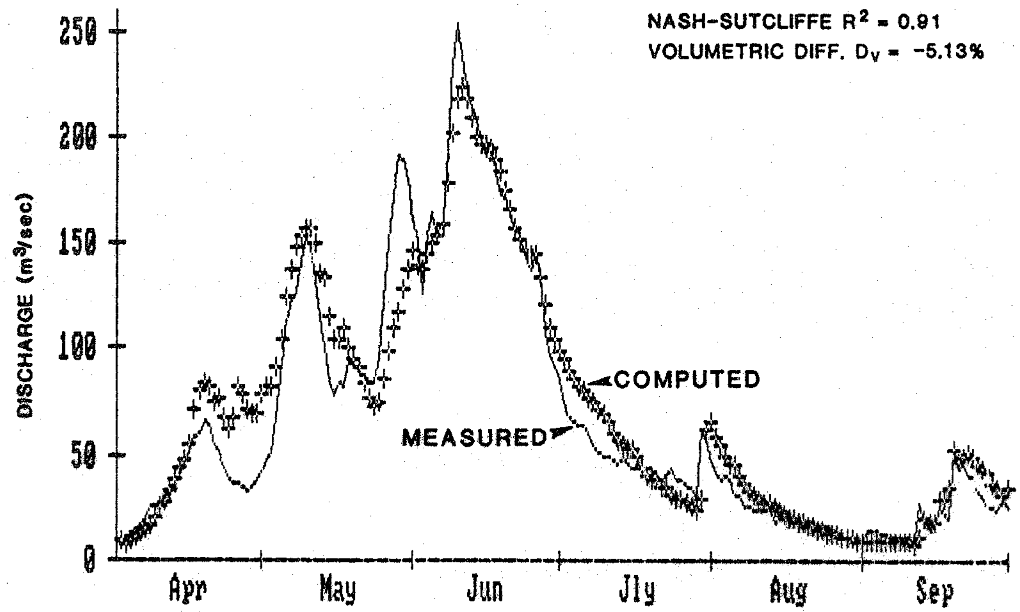


Figure 6. Snowmelt-runoff hydrograph for 1985 on the Rio Grande basin using forecast snow cover input data and SRM.

A FORECAST ATTEMPT

Seeing the success in this controlled situation, the SCS urged us to carry the development one step further and combine forecast temperature and precipitation with the forecast snow cover data. Knowing that success with several years on one basin does not validate the approach, we were reluctant. However, in the early spring of 1987 the Rio Grande basin seemed to have the potential for heavy runoff and possible flooding. SCS requested that we specifically run SRM in the forecast mode starting on April 1 and give them the forecast as one of many inputs for their water supply projections. The fact that this would be only one of several inputs was reassuring, and we agreed to make the forecast on the condition that SCS supply the forecast temperature and precipitation data for 1987. They directed us to use average daily maximum and minimum temperatures and 110% of monthly precipitation randomly scattered through the specific month. The forecast snow cover depletion values came from the nomogram in Figure 4.

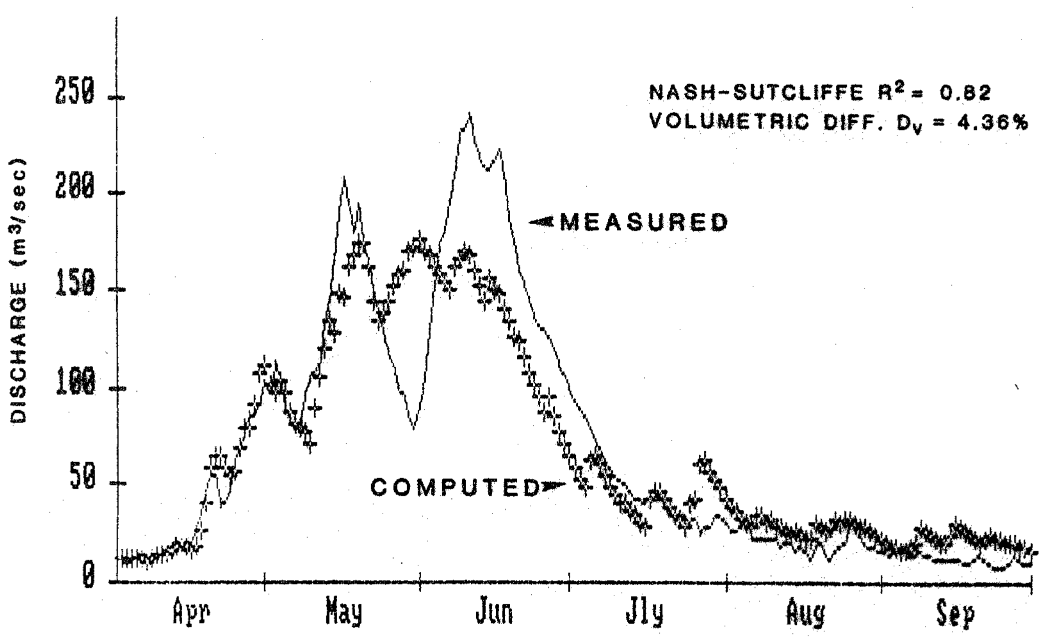


Figure 7. Snowmelt-runoff forecast for 1987 on the Rio Grande basin using SRM.

The resulting forecast and actual hydrographs for 1987 are shown in Figure 7. The results are not as good as the prior year simulations, but still very useful. Because we would be working in realtime with observed streamflow values available, we also decided to update the forecast hydrograph with actual streamflow every seven days, an option currently available in SRM. An improvement results as shown in Figure 8. Additional updating techniques making use of observed snow cover, temperature, and precipitation could also be used to improve the forecasting techniques.

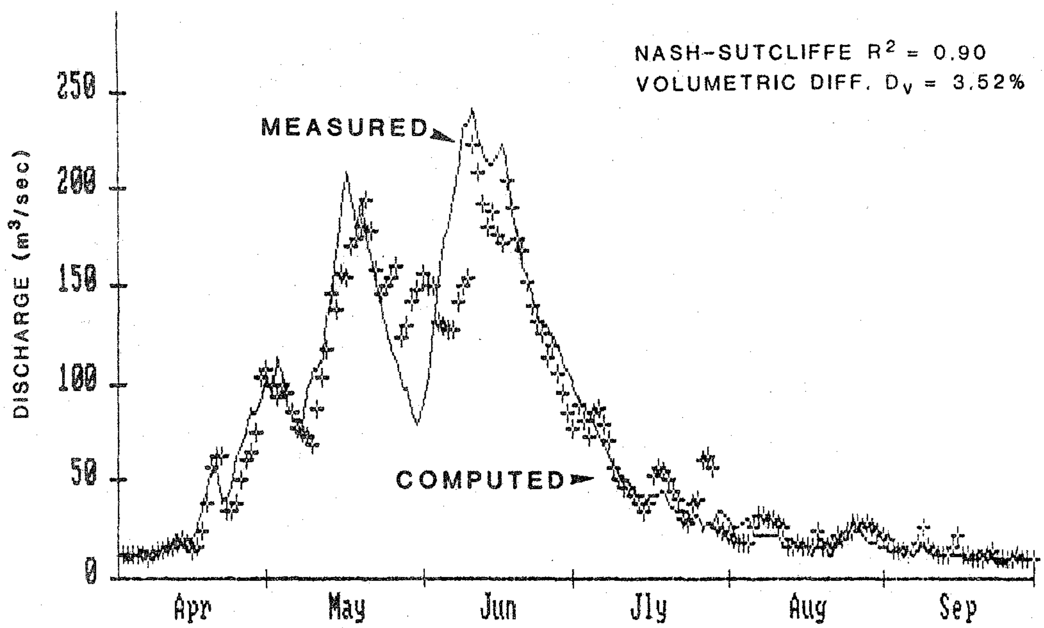


Figure 8. Snowmelt-runoff forecast for 1987 on the Rio Grande basin using SRM and actual streamflow updates every seven days.

FUTURE DEVELOPMENT

The results from this attempt at forecasting with SRM were extremely successful, however, both research and operational scientists should not jump to conclusions that SRM is ready for widespread operational application. Rather, they need to realize that further evolution is required which will involve close interaction between researcher and hydrologist to ensure that progress toward an effective forecasting tool is made. Additional years and basins need to be tested. Determination needs to be made on how snow water equivalent data can be used most effectively, and whether SnoTel and microwave remote sensing information can be used for selection of the proper modified snow cover depletion curve. Updating techniques need to be exploited to their potential to improve forecasting.

Once these various aspects have been explored and incorporated into the SRM forecast version, a final bit of improvement is needed to assure the technology is transferred. Even with a simple model like SRM, it is difficult for a new user to easily apply the model. To assist in this final step, we are in the process of developing an expert system for SRM (Engman, et al., 1989). To help in application, the SRM expert system will assist the user in parameter selection, choice of proper data, and computation of basin variables. After a SRM run has been achieved, the expert system will again aid the user by evaluating results, providing feedback to fine tune the model, and identifying possible data problems.

Even after all these improvements are in place, SRM will continue to evolve. Experience from the operational applications of SRM will be used for identifying new problems and potential improvements and handling new data sources.

CONCLUSIONS

The development of a snowmelt-runoff forecast model is a slow, steady, and continuous process. Input and feedback from user to researcher is a prime requirement. The effective application of the model depends on considerations of model complexity, user compatible software, operational requirements, availability of required input data, forecasts of meteorological data, model reliability, application in geographically diverse areas, and realtime updating. Experiences with the snowmelt-runoff model (SRM), which requires remote sensing input, are used as examples of this evolutionary process. In particular, some of the steps are illustrated for the Rio Grande basin near Del Norte, Colorado. After several preliminary tests, SRM was used to forecast the 1987 snowmelt season successfully. Rather than concluding that we have a forecast model, it is more logical to assume that we are well on our way to providing a product useful for operational forecasting.

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