SEASONAL STREAMFLOW FORECASTING IN THE UPPER RIO GRANDE BASIN BY INCORPORATING THE USE OF SNOTEL DATA IN THE SSARR HYDROLOGIC MODEL

BY

Tom R. Perkins [1/]

INTRODUCTION

Seasonal runoff from the Upper Rio Grande Basin has been above average eight of the last nine years. Since 1979, the only year that was below average was 1981. During this period, predictions of streamflow at strategic points within the basin have missed the mark, sometimes to a substantial degree. The obligation of Colorado to deliver water in the Rio Grande at the Colorado-New Mexico state line, measured at or near Lobatos, is determined largely by the amount of runoff in the Rio Grande at Del Norte, Colorado (7). Planned water deliveries are scheduled, based on the April-September volume forecast.

In September 1987, representatives from several federal agencies and the Water Commissions from Colorado, New Mexico, and Texas met to discuss past forecasting performance and to determine what could be done to improve future predictions. As an outgrowth of this meeting, a six member team met in Portland, Oregon in November to produce new and more reliable Rio Grande Basin forecast procedures. The group made very notable improvements in the multiple regression procedures used to project streamflow volumes. At the same September meeting, the Soil Conservation Service (SCS) was additionally charged with the task of developing a conceptual hydrologic computer model for the Rio Grande near Del Norte, Colorado, to determine if improvements to seasonal runoff estimates could be made.

The SSARR computer model developed by the U.S. Corps of Engineers (COE) (11) was used to calibrate the Rio Grande near Del Norte. In addition to using the model to try to improve streamflow forecasts, there were two other reasons for completing this study. First, the model is being evaluated as a possible replacement for the traditional regression techniques now employed by the SCS. Regression models use data that are easily obtainable at the time the forecasts are made and that have a long historical record. Data is normally limited to monthly precipitation, snow water equivalent (SWE) and antecedent streamflow. These data may account for a large portion of the variability in the forecasts, however, hydrologic variables that may be very important in determining basin runoff, such as soil moisture content, are difficult to obtain operationally. Also, models can be developed for basins that are not well served by statistical procedures. Second, the SCS is reducing its traditional manually measured snow course networks and placing increased reliance on SNOTEL data. Until recently, SNOTEL data were used only subjectively to determine if streamflow forecasts were reasonable. The hydrologic model and several years of data collected from the high runoff producing zones of the mountainous West, now provide the means to objectively incorporate SNOTEL information.

UPPER RIO GRANDE BASIN

The Upper Rio Grande above Del Norte, Colorado (Figure 1), lies between 106° 30' and 107° 30' west longitude and 37° 25' and 38° 00' north

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1. Hydrologist, Soil Conservation Service, Portland, Oregon

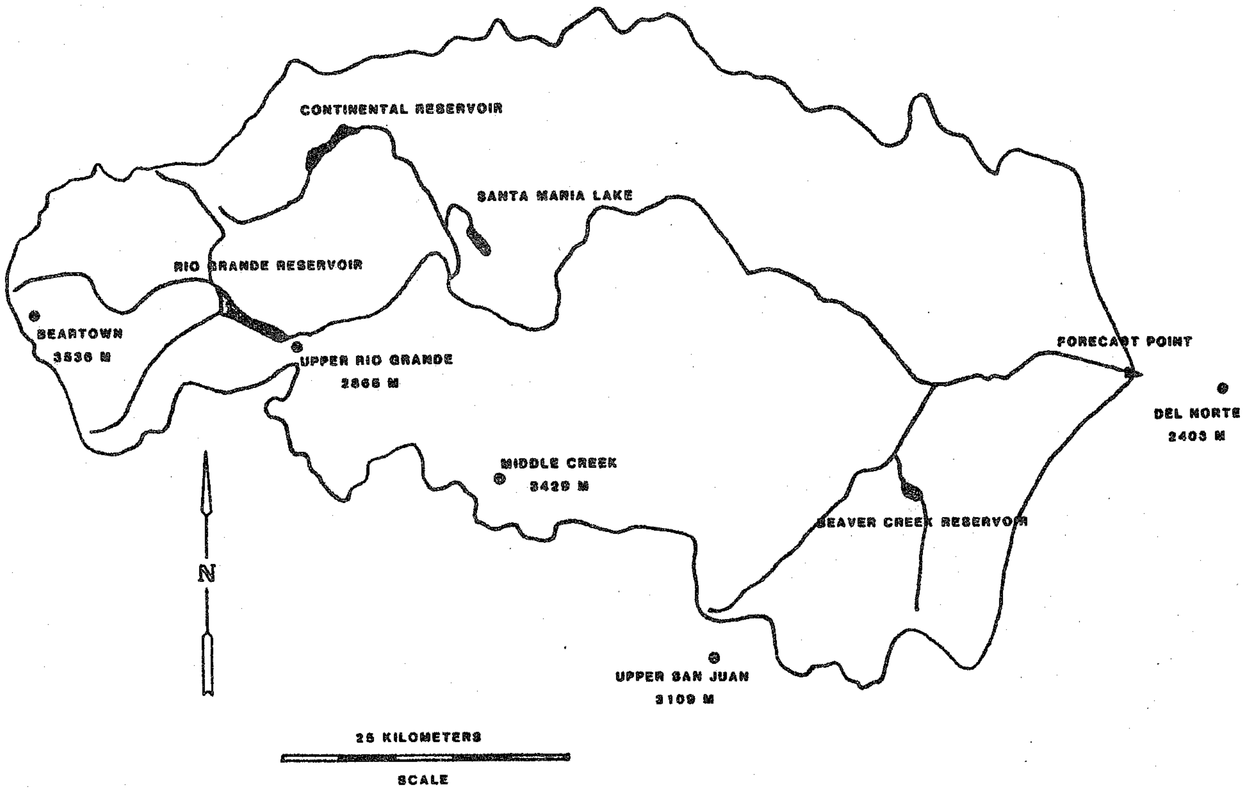

Figure 1. Rio Grande Watershed near Del Norte, Colorado.

latitude. The basin is 3,419 km in area and rises from 2,432 meters at the outlet to 4,215 meters at the highest point along the Continental Divide in the San Juan Mountains.

Average annual precipitation for the basin is about 70 cm, and ranges from 25 cm at the basin mouth, to nearly 130 cm in the upper reaches. The average annual seasonal runoff (April-September) is 18.4 cm (62,908 ha-m) based on the 1961-1985 period. The snowmelt runoff usually starts in mid-April and lasts until mid-July.

Initially, four precipitation stations (Del Norte, Middle Creek SNOTEL, Rio Grande Reservoir, and Upper San Juan SNOTEL) and one temperature station (Del Norte) were used in the model simulations for the 1981-1986 period. Although National Weather Service (NWS) data may be superior to SNOTEL data for assessing timing of precipitation events (Doesken and Schaefer, 1987), only SNOTEL data was used for the study. SNOTEL data is readily available for operational forecasting and it was feared that there would be a delay in obtaining data from sites that were not automated. The SNOTEL sites used during the final calibration process were Beartown, Upper Rio Grande, Middle Creek, and Upper San Juan (Figure 1). With the exception of Upper Rio Grande, these four sites have reliably reported daily precipitation, daily maximum temperature, daily minimum temperature, and daily average temperature from water year 1984 to the present time. The Upper Rio Grande site was established in 1986 and provided only 1987 water year data for the study. In order to provide the 1984-1986 time series for the Upper Rio Grande SNOTEL site, the data from the NWS Rio Grande Reservoir gage site was substituted without correction. Rio Grande Reservoir is just upstream from the SNOTEL site and is only 29 meters higher in elevation. The Upper Rio Grande data was needed for the study, because it represents a lower elevation site - 2,865 meters, whereas the other three range from 3,109 meters to 3,536 meters.

The decision to use only SNOTEL sites for model calibration was prompted by the availability of the data in an operational mode, the data sites are located in the high runoff producing areas of the watershed, and SNOTEL data had already been used by the SCS to successfully calibrate another basin in Utah. SCS SNOTEL data is readily available, on a daily basis, for operational use. At the SCS West National Technical Center (WNTC), software has been written to reformat the data and then transfer it into the model work files. Software to access and reformat telemetered data from other agencies is not yet available. NWS climatic stations, the traditional source for climate data for analysis and research in the U.S., locate most of their stations at low elevations and in populated mountain valleys. Studies have shown that extrapolating this lower elevation data to higher areas is often not valid (Doesken and Schaefer, 1987). In 1986, an earlier version of the SSARR model was used to calibrate the upper Weber River Basin in Utah, using SNOTEL data. Results were encouraging and the model has been used as a tool to verify the forecast results of the SCS regression models for that basin.

In order to input realistic evaporation data into the model for the various parameters and tables, evaporation data from standard evaporation pans were analyzed from three sites in and around the study basin. These sites were Alamosa WSO AP (2,297 m), Rio Grande Reservoir (2,894 m), and Platoro Reservoir (3,021 m).

SSARR WATERSHED MODEL

The current version of SSARR is called SSARR-8 (11). This version includes most of the facilities of the earlier versions of the program. Major enhancements include additions designed for interactive operation of the program to assist the hydrologist in forecast operations; long-term data storage and retrieval suitable for holding in excess of 50 years of data; and the integrated snowband watershed option, to provide the capability to simulate on a continuous basis, rainfall runoff, snow accumulation and ablation, and snowmelt runoff in mountainous areas. The version available on the SCS Data General (DG) computer was written in FORTRAN-77 for the VAX-11/780 computer. The program has been modified to run on the DG. The general structure of the SSARR program is shown in Figure 2, however, a detailed explanation of the model will not be discussed in this paper. Adequate information is available in the COE SSARR user manual (11) and an AWRA Water Resources Bulletin authored by Cundy and Brooks (2).

CALIBRATION OF THE UPPER RIO GRANDE BASIN

The study was performed with three years (1984-86) of daily streamflow, precipitation, average temperature, and snow pillow data for the calibration period and one year (1987) of validation data. The calibrated model was then used, in addition to newly developed regression procedures, to forecast April-September streamflow volumes for the 1988 runoff season.

The forecast runoff season (April-September) was of primary interest during the calibration process. The SCS is authorized to make volume forecasts for streams and rivers and are not normally concerned with day-to-day projections. For purposes of this study, the model was adjusted to produce the best fit possible to the seasonal runoff volumes for the calibration period. To make sure that the model was calibrated correctly, and that realistic state parameters were being used, attention was paid to the timing of the hydrograph in regards to initial snowmelt, peaks, and baseflow recession. The fact that the daily streamflow had to be adjusted for the effects of three upstream reservoirs was also taken into account. Daily changes in reservoir storage were only available for all three reservoirs during the April-September period, and even then the data were

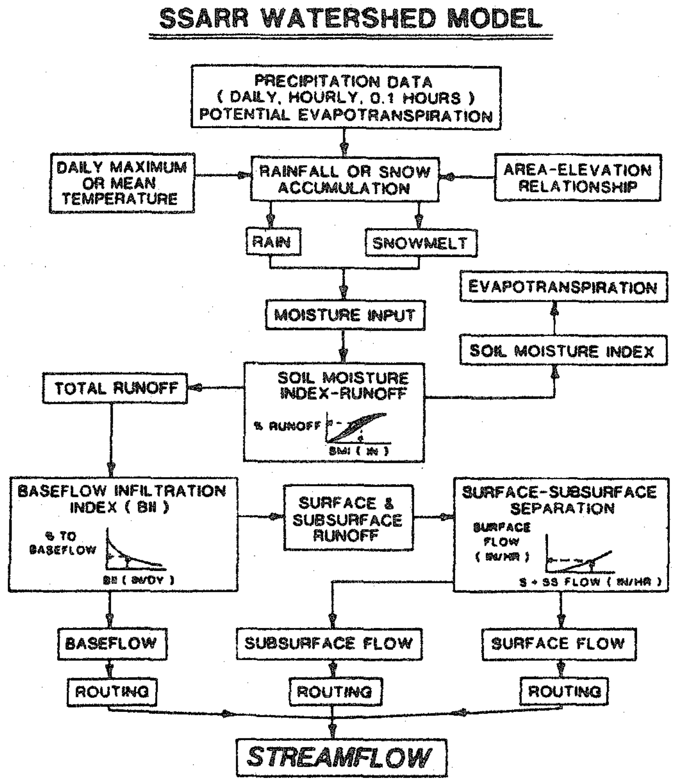

Figure 2. General Structure of SSARR Watershed Model (adapted from Cundy and Brooks, 1981 (2)).

not continuous. Because of this reservoir adjustment, it was realized that there would probably be irregularities in the hydrographs that the model could not match with the available data.

The method of calibration suggested by Cundy and Brooks (2) was utilized along with experience gained from the calibration of the Weber Basin. Initially, functions and parameters which could be estimated from physical watershed characteristics were fixed. The remaining parameters were initially estimated from those used in the Weber Basin model. The Weber Basin is not geographically close to the Rio Grande, however, except for the work done by Jones (4) on the Clarks Fork of the Yellowstone, this is one of very few basins outside of the Columbia Basin that has been modeled using the SSARR integrated snowband model.

Average temperature data from all four SNOTEL sites were weighted equally and averaged together by the program. A constant lapse rate of 1.7 °C per 305 meters (3 °F/1000') was used. A variable lapse rate, calculated using Del Norte WSO AP and Beartown SNOTEL, was used during the early part of the study. The use of the variable lapse rate was abandoned, because it did not improve the calibration and the data would probably not be available for operational forecasting.

Precipition data from each of the four SNOTEL sites was weighted based on the average annual precipitation for the basin. This procedure attempts to produce areal average precipitation over the basin for any given storm event. Weighting coefficients to define the increase in precipitation as the watershed elevation increases, were determined by using a NWS prepared isohyetal map (12).

The evapotranspiration index (ETI) was determined by evaluating standard pan data from three sites in and around the Upper Rio Grande Basin. These sites were mentioned earlier in the report. By chance, there was an excellent elevational gradient between the sites that aided in determining ETI coefficients for the various snowbands defined within the basin.

The Rio Grande Basin was divided into eight elevation bands. Four of the bands, or zones as they are frequently called, were defined so that the elevation at each of the SNOTEL sites would fall into the middle of the band. It was hoped that the accumulation and ablation on these bands would closely follow the snow pillow traces at the sites and thus, provide evidence that the basin was being modeled correctly. The other bands were added to prevent the stair-stepping effect that takes place when each snow zone is depleted.

Snowmelt parameters and melt rates were within the guidelines documented in "Snow Hydrology" (10).

RESULTS AND DISCUSSION

Streamflow volumes from snowmelt were calibrated within 8 percent of observed April-September volumes for the Rio Grande watershed above Del Norte, Colorado (Table 1). While the model demonstrated the feasability of using SNOTEL data to generate a continuous runoff hydrograph, the validation year simulation was not encouraging (Figures 3-6). The validation was the last thing attempted prior to the commencement of this paper, and was done after the calibration period was totally complete. These results indicate the danger of using too few years in model calibration and validation periods. Also, the calibration period, as described previously, was composed of all above normal runoff years. Still, one would have hoped that the validation data would have yielded better results. There is some evidence from the observed versus simulated snow pillow tracings (Figures 3-6), that the precipitation weights for the lower zones may need to be adjusted. Although, with a model as complex as SSARR, any one of several parameters may need adjustment.

Table 1. SSARR Simulated and Observed Runoff Comparisons for Rio Grande near Del Norte, Colorado, 1984-1987.

YEAR	OBSERVED	SIMULATED	%ERROR
	-- CALIBRATION --		
1984	81,040 ha-m	87,824 ha-m	+ 8.4
1985	107,807 ha-m	110,151 ha-m	+ 2.2
1986	102,010 ha-m	93,992 ha-m	- 7.9
	-- VERIFICATION --		
1987	109,904 ha-m	90,168 ha-m	-18.0

Another encouraging result of this study was the relationship of the simulated SWE versus the observed SNOTEL SWE (Figures 3-6). From the model results, each of the SNOTEL sites was best indexed by snowbands at higher elevations. This suggests that the SWE at the snow pillow site is not the same as an average SWE for the zone. This result was not unexpected. SNOTEL sites and snow courses have traditionally been located in high snow accumulation areas to insure snow index values would be available late into the forecast season. While these sites may be good indices of streamflow runoff, they do not represent the total basin. This observation was also documented by Cooley (1), Kuehl (5), and Marron (6).

The simulation process exposed the fact that while the SNOTEL sites were located in the high runoff producing zones of the watershed, the average temperature data were not areally representative. Model parameters that index energy supplied to the snowpack, had to be modified from values that would be considered reasonable. This was not the case when data from the NWS temperature site at Del Norte was used with Beartown SNOTEL data to yield a more representative temperature regime for the basin. This further emphasized the results documented by Kuehl (5) and later by Cooley (1) and Marron (6), that SNOTEL sites were installed to measure the snow and climatic resources at a carefully chosen point, but may not necessarily represent the mean areal distribution on the watershed. In the case of average temperature, it would be prudent, in the future, to carefully locate sites at representative lower elevations. Of course, this would not be critical in a basin that has telemetered sites that have been installed by the NWS or other agencies.

Two of the stated reasons for this study were to try to improve streamflow forecasts and to evaluate the model as a possible replacement for the current regression procedures. To use SSARR or any other model as a forecast tool, the model must be able to run for an initialization period to tune it to current conditions and then run from the initialized date through the end of the forecast period, using all available historical data. This will develop a range of possible runoff conditions. Future runoff volumes can then be computed using ESP techniques as described by Twedt (7,8) and Marron (6). SSARR, through use of a large bulk data storage file, is capable of producing multiple hydrographs from historical data; and statistical software is available on the DG to perform the frequency analysis. However, since only four years of data were available and stochastic values were not developed, a shortcut was used to evaluate the effectiveness of the model for the 1988 forecast season. From current conditions, it appears that the spring of 1988 will be below normal, in terms of precipitation yield. Out of the four years of data used in this study, only 1987 produced below normal precipitation during the spring and summer period. Because of this, watershed initial conditions were developed for April 1, using observed SNOTEL data, and then the 1987 data were used to produce an April-September volume to compare with the regression values. Results of this analysis are shown in Table 2. The results were encouraging, but more years of complete data and recalibration of the model are needed before complete reliability on the model results is justified.

Table 2. 1988 April-September Runoff Forecasts for Rio Grande near Del Norte, Colorado.

FORECAST DATE	MODEL	RUNOFF FORECAST
MARCH 1	REGRESSION	54,274 ha-m
APRIL 1	REGRESSION	43,789 ha-m
APRIL 1	SSARR	47,983 ha-m

SUMMARY AND CONCLUSIONS

The SSARR model was used to simulate flows for the Rio Grande near Del Norte, Colorado for the 1984-1987 period. Data input to the model consisted of SNOTEL daily precipitation and average temperature. The study demonstrated the feasibility of using SNOTEL data in the SSARR model to generate runoff hydrographs that can be used as input for ESP techniques. Thus, after careful calibration, the model becomes a useful tool for water supply forecasting. In addition, because the model was calibrated with readily available data, frequent forecast updates can be made readily available.

In general, simulated streamflow values displayed the same timing patterns and volumes as the observed hydrographs, although the model underpredicted the streamflow volume, using the 1987 validation data. It is felt that recalibration using more years with more representative data values (a mixture of high and low years), will improve the model. This study has also demonstrated the need to have low elevation temperature sites in order to more adequately represent the temperature regime within a given basin.

Because the spring of 1988 started out dry and regression procedures indicate a below normal runoff in the Rio Grande for the first time since 1981, the 1987 spring and summer SNOTEL data was used to evaluate the model based on regression results. The 1987 data represent the only below normal year in the calibration/validation period. Results of the comparison at least indicate that the model volume output is in the "ball park" of the regression values.

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I wish to express my appreciation to several people that made this paper possible. First of all to Ken Jones, who developed the SSARR workbench and much of the software needed to make data input to the model as painless as possible. Ken also developed software to strip data from the SSARR output, so that it could be used by our graphics software to produce comparison streamflow hydrographs and snow pillow traces. To Ed Davis for providing me with the VAX version software of the SSARR model and never tiring of my many questions when I was converting the "standard" FORTRAN-77 source code to compile on the DG computer. To Denice Schilling for the effort that she put forth in retrieving data and reformatting it for SSARR. To John Huddleston for writing neat little shell scripts to straighten out some of my data files. Last, but not least, to Bernie Shafer for his encouragement.

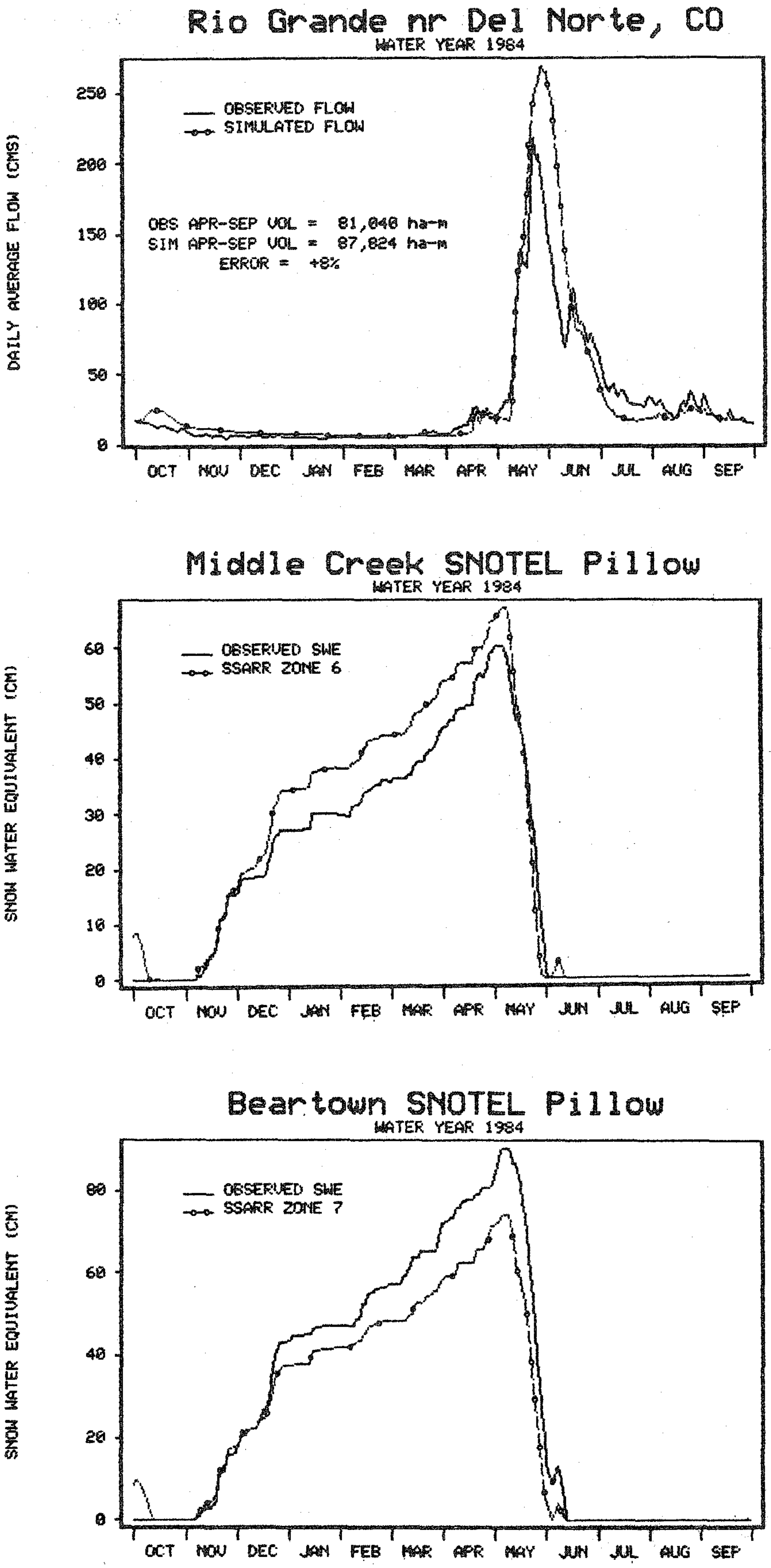


Figure 3. Comparison of the Observed and Computed Hydrograph and SNOTEL and Model Snow Water Equivalents for 1984.

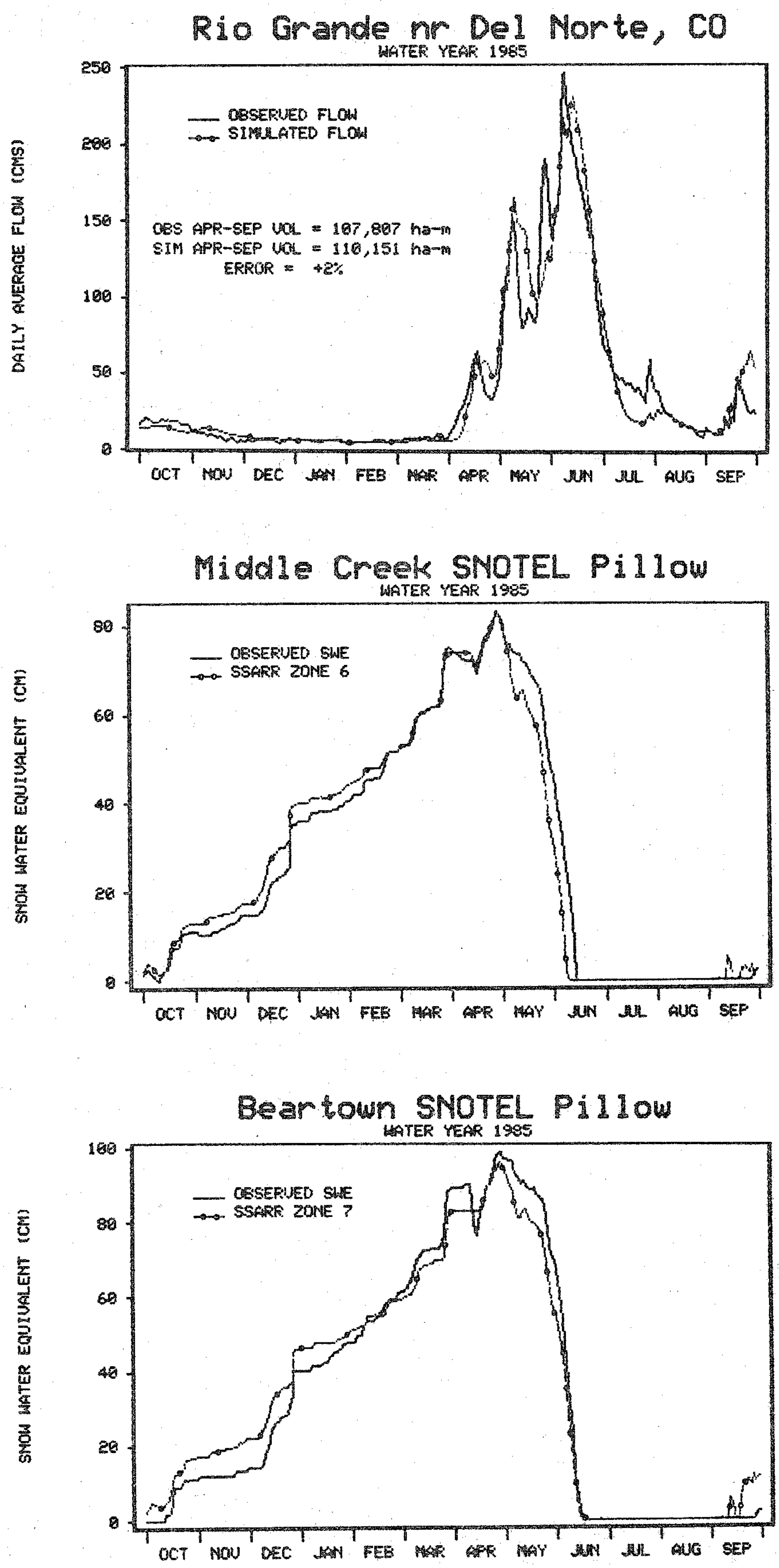
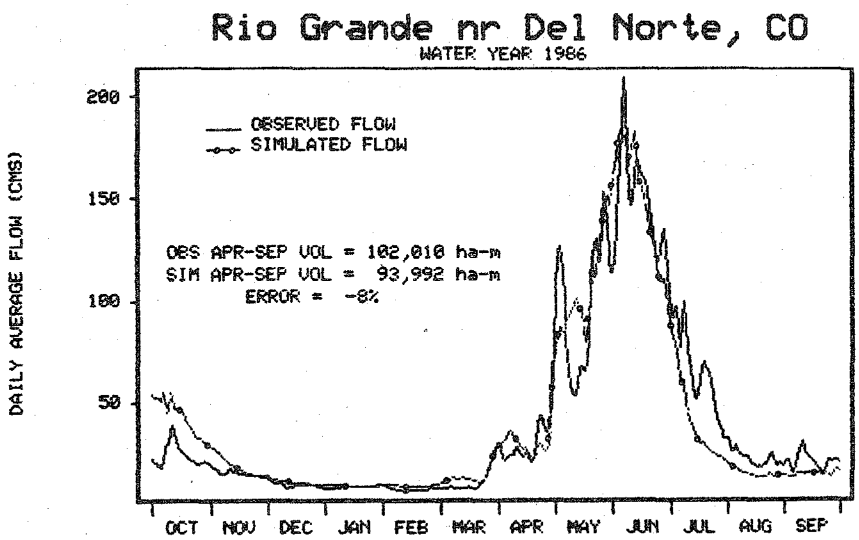
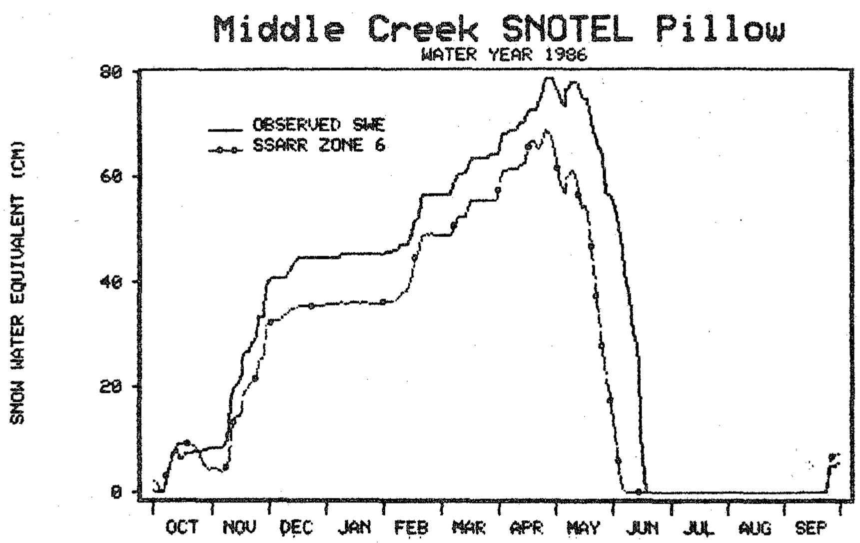


Figure 4. Comparison of the Observed and Computed Hydrograph and SNOTEL and Model Snow Water Equivalents for 1985.





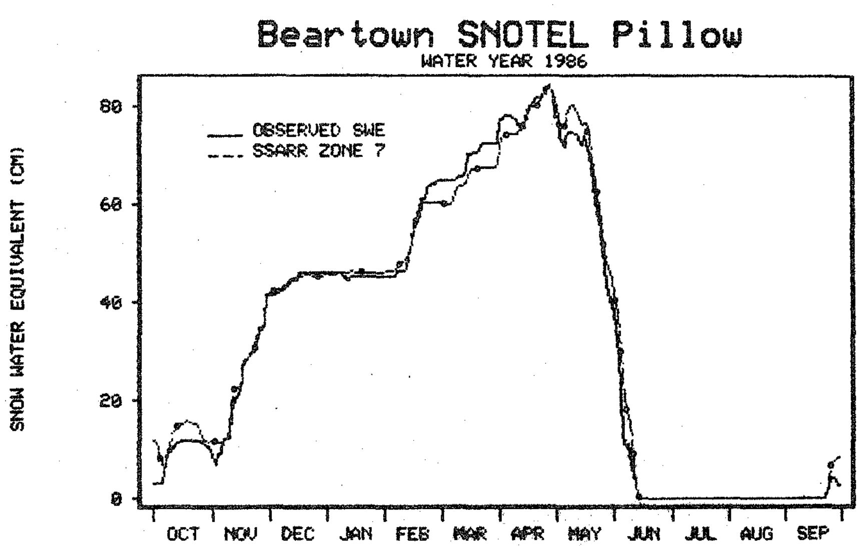


Figure 5. Comparison of the Observed and Computed Hydrograph and SNOTEL and Model Snow Water Equivalents for 1986.

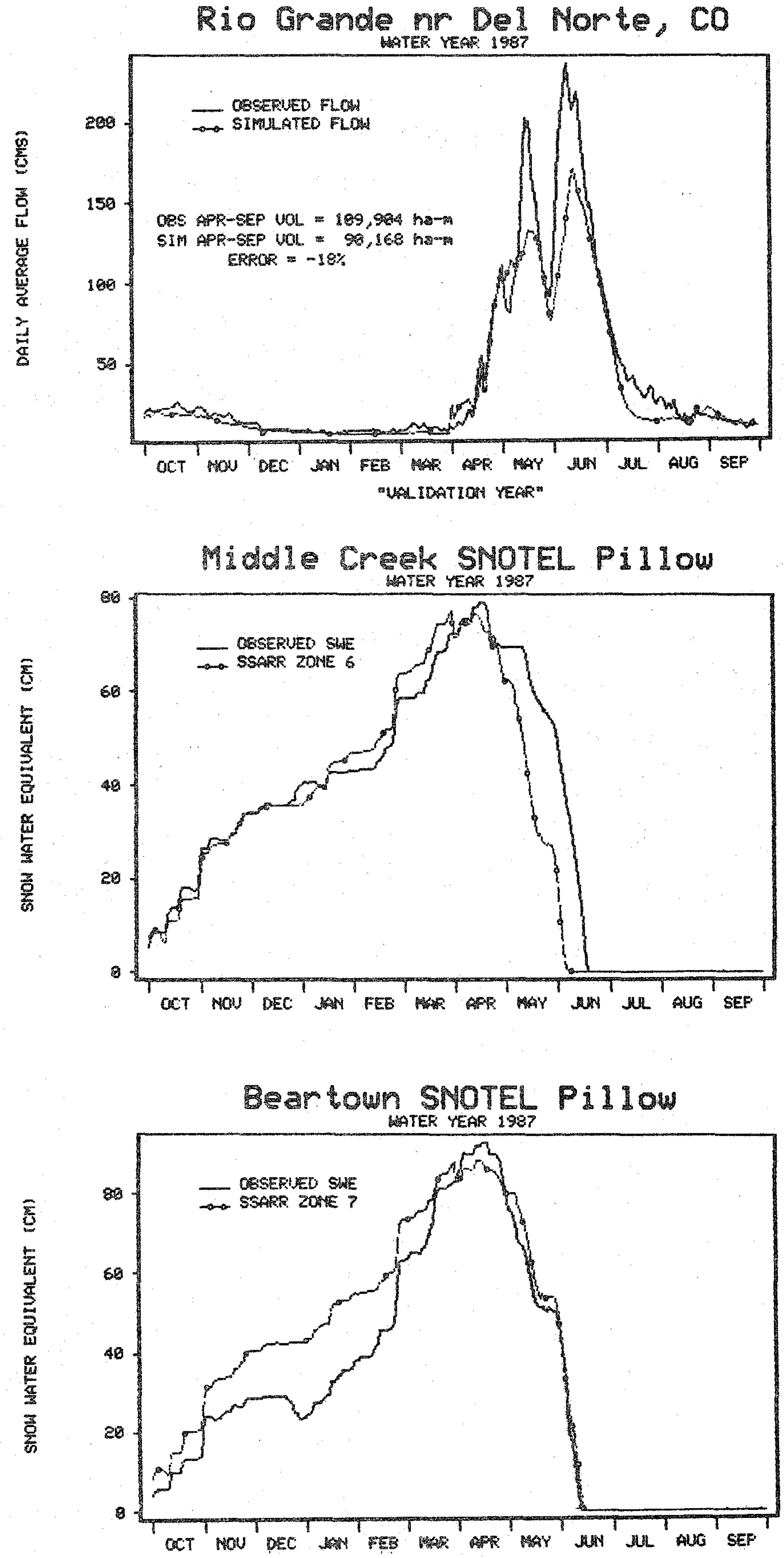


Figure 6. Comparison of the Observed and Computed Hydrograph and SNOTEL and Model Snow Water Equivalents for 1987.

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