Paper No. 13

APPLICATIONS OF SATELLITE SNOW COVER IN COMPUTERIZED SHORT-TERM STREAMFLOW FORECASTING 1/

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ABSTRACT

A procedure is described whereby the correlation between: (a) satellite derived snow-cover depletion and (b) residual snowpack water equivalent, can be used to update computerized residual flow forecasts for the Conejos River in southern Colorado.

INTRODUCTION

In the Rocky Mountain West seasonal or total flow forecasts are generally made utilizing regressions between snow accumulation and runoff and annual surveys of peak snowpack water equivalent. Extensions of these early-spring forecasts to a short-term basis using statistical methods is extremely difficult since precipitation and meteorological conditions during the ensuing melt season vary widely from year to year.

One index of runoff, which has been found useful for improving residual flow forecasts is areal snow cover. In the United States, aerial surveillance of the snow cover was proposed more than 30 years ago. More recently the areal extent of snow has become an important parameter in the growing emphasis on applications of remote sensing in the water resource field (Rango 1975). Advanced space technology and several new satellite snow mapping procedures (Barnes and Bowley 1974, Foster and Rango 1975) promise to make satellite snow cover observations available on a dependable and routine basis. These satellite snow cover estimates used in combination with conventional snow survey data as inputs to computerized simulation models should make the problem of short-term residual volume forecasting less difficult in the very near future.

This paper shows how satellite imagery can provide key information for making residual volume streamflow forecasts in the Rio Grande basin using a computerized simulation model recently developed by the U. S. Forest Service. Mapped snow cover estimates and model output are summarized for the Conejos River, a 282-square-mile tributary of the Rio Grande in southern Colorado.

1/This study has been funded by the USDA, Soil Conservation Service, Snow Survey Unit, Denver, Colorado.

The demonstration project is one of four currently being sponsored by NASA to determine the effectiveness of satellite-derived snow-cover estimates in operational streamflow forecasting (Rango 1975).

JUSTIFICATION

THE RIO GRANDE DRAINAGE BASIN

Waters of the Rio Grande are administered under the Rio Grande Compact between three States and by an international agreement with Mexico. Accordingly, it is imperative that accurate short-term forecasting procedures be developed so that water is dispatched fairly and efficiently throughout the Basin. In Colorado, the Rio Grande provides irrigation water to the San Luis Valley. To provide maximum delivery of water to these users and still meet the Compact obligations, accurate forecasts are required on a continuing 10-day basis starting April 15 of each year (Qazi and Danielson 1973).

Conejos River

The area selected for this study is drained by the Conejos River, a key headwater tributary of the Rio Grande River. Figure 1 is a map of this basin, and Table 1 summarizes pertinent geographic characteristics of subunits selected for the simulation analysis discussed subsequently in this report. Annual water yields, corrected for Platoro Reservoir, which regulates flows from approximately 40 square miles of the drainage basin, are summarized in Table 2. These data were obtained from surface water records published by the U.S. Geological Survey, As seen in Table 2, runoff during the past 17 years has varied from a low of 7.9 inches in 1959 to a high in 1965 of 22.1 inches.

METHODS

THE SUBALPINE WATER BALANCE MODEL

In order to make the best use of satellite imagery and to provide the most flexibility for updating forecasts, it was decided to use the "Subalpine Water Balance Model" (Leaf and Brink 1973a, 1973b) to simulate flows at 10-day intervals on the Conejos River. This model simulates winter snow accumulation, the shortwave and longwave radiation balance, snowpack condition, snowmelt and subsequent runoff on as many as 25 subunits. Each subunit is described by relatively uniform slope, aspect, and forest cover. Results from each subunit are compiled into a "composite overview" of an entire drainage basin. Figure 2 is a generalized flow chart of the system.

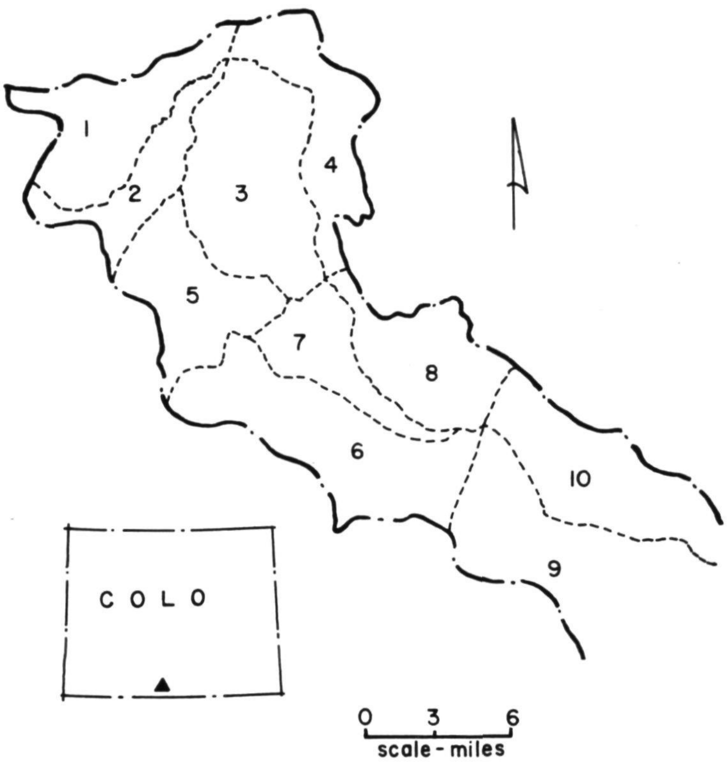

Figure 1 - Conejos River Base Map Showing Subunits (1mi.=1.61 km).

Table 1- Geographic Description of Conejos River Drainage Basin

Subunit	Area 1/ ($mi.^2$)	(km^2)	Average Elev. (ft.)	(m)	Average Aspect	Avg. Slope (percent)
1	25.4	65.8	11,000	3,355	SE	34
2	13.5	35.0	11,500	3,507	NNW	34
3	37.5	97.1	10,500	3,202	E	28
4	30.2	78.2	10,500	3,202	SW	33
5	24.0	62.2	11,000	3,355	ESE	25
6	40.0	103.6	11,000	3,355	NNE	23
7	16.1	41.7	10,500	3,202	ENE	27
8	9.3	24.1	10,300	3,141	SW	35
9	52.7	136.5	9,400	2,867	NE	15
10	32.7	84.7	9,500	2,897	SW	15

1/ Total: Forest and Open

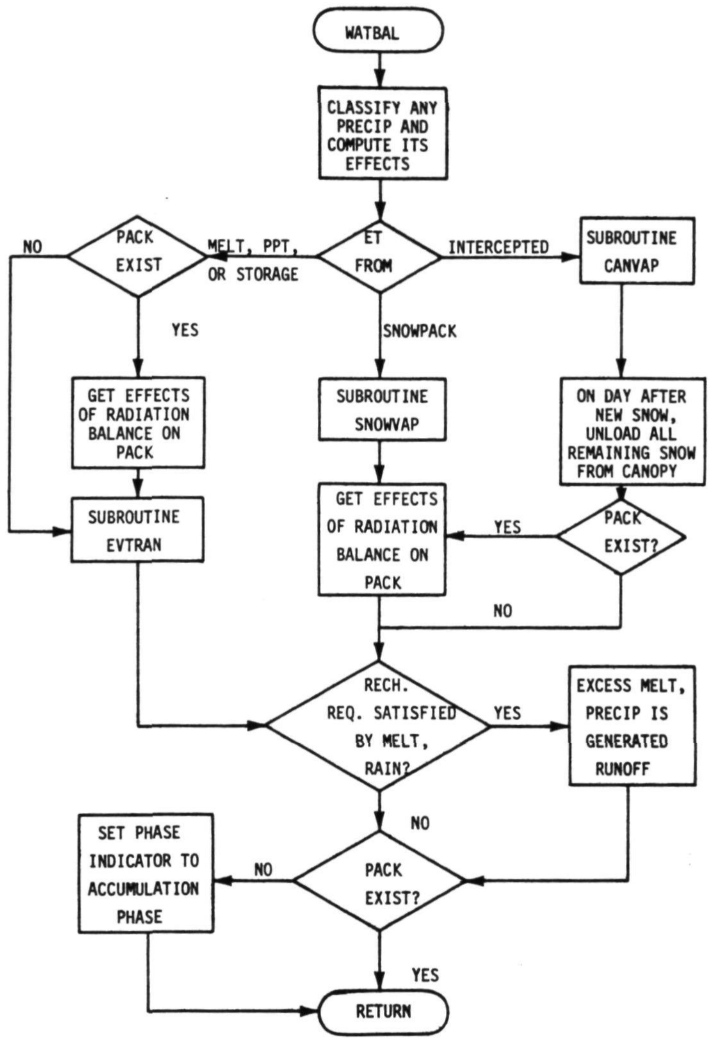

Figure 2 -Flow chart of "Subalpine Water Balance Model"(Leaf and Brink. 1973b).

Calibration of Model to Conejos River

Daily temperature extremes in each of the response units were estimated by extrapolating observed temperatures at the base station Wolf Creek Pass 1E. Because reliable long-term radiation data are not available in the Conejos drainage, short-wave radiation input to the model was generated from potential solar beam radiation adjusted for temperature and the slope/aspect characteristics of each subunit. In order to compute an index of the radiation received, potential radiation was reduced by means of a thermal factor. This factor was determined by degree-day relationships which vary according to season of the year.

Peak snowpack accumulation on the Conejos was estimated by extrapolating snow-course data published by the Soil Conservation Service. To ensure the proper snow accumulation in each response unit, base station precipitation (at Wolf Creek Pass 1E) was adjusted until the specified peak-water equivalent on each subunit was reached.

The Conejos River Basin was divided into 10 subunits as seen in Figure 1. Further division of forest and open areas resulted in 20 response units used for the simulation analysis.

RESULTS

RESIDUAL VOLUME FORECASTS (1958-1972)

Figures 3 and 4 show the comparison of simulated vs. actual residual runoff as of the first day of April, May, June, and July for 8 years. The close agreement between observed and simulated flows indicates that the model is a useful tool for continuous forecasting of short-term flows in the Conejos River for the full range of runoff observed during the past 15 years.

TEN-DAY RESIDUAL VOLUME FORECASTS (1973 and 1974)

Figure 5 summarizes observed and simulated residual flows on a 10-day basis for 1973 and 1974. Also shown in Figure 4 are satellite-derived snow cover estimates. Again, agreement is good even when residual volume forecasts are made at 10-day intervals. The superimposed snow cover estimates reveal a high correlation with simulated runoff and suggest that satellite snow cover data can provide key information for updating model input in a real forecasting situation. Just how this can be accomplished is discussed next.

INCORPORATION OF SATELLITE SNOW COVER OBSERVATIONS FOR FORECASTING

Table 3 compares mapped snow cover estimates on the Conejos River with residual water equivalent and streamflow for 1973 and 1974. In keeping with previous research, Table 3 and Figure 4 suggest that depletion vs. runoff relationships vary depending

Table 2 - Annual Runoff Corrected For Platoro Reservoir, Conejos River Basin.

Year	Runoff	Platoro Res. Change in Storage	Adjusted Runoff (in.)	(mm)
	-----------	inches -----------		
1958	16.6	-1.02	15.6	396.2
59*1/	9.9	-1.98	7.9	200.7
60	-	-	-	-
61*	13.3	-0.27	13.0	330.2
62	16.8	+0.60	17.4	442.0
63*	8.7	-0.70	8.0	203.2
64*	10.3	+0.31	10.6	269.2
65	20.2	+1.89	22.1	561.3
66	15.8	-1.24	14.6	370.8
67	15.0	-1.08	13.9	353.1
68*	15.4	+0.55	15.9	403.9
69	17.6	-0.46	17.1	434.3
70	15.8	+0.25	16.0	406.4
71	11.7	-0.43	11.3	287.0
72*	8.0	+0.01	8.0	203.2
73*	19.7	+2.14	21.8	553.7
74*	10.7	-1.20	9.5	241.3

1/ * Used in simulation analysis

Table 3 - Mapped Snow Cover vs. Residual Water Equivalent and Streamflow. (Conejos River, Rio Grande Drainage Basin)

Year	Snow Cover 1/ (percent)	Sim. Residual Water Equiv. (in.)	(mm)	Observed Residual Streamflow From Snowmelt (acre-ft)	(m^3)
1973					
June 22	31	3	76.2	1.379×10^5	1.700×10^8
1974					
May 12	42	4	101.6	7.015×10^4	8.649×10^7
May 30	18	1	25.4	5.333×10^4	6.576×10^7

1/ Personal communication with Jack Washichek, Soil Conservation Service, Denver, Colorado

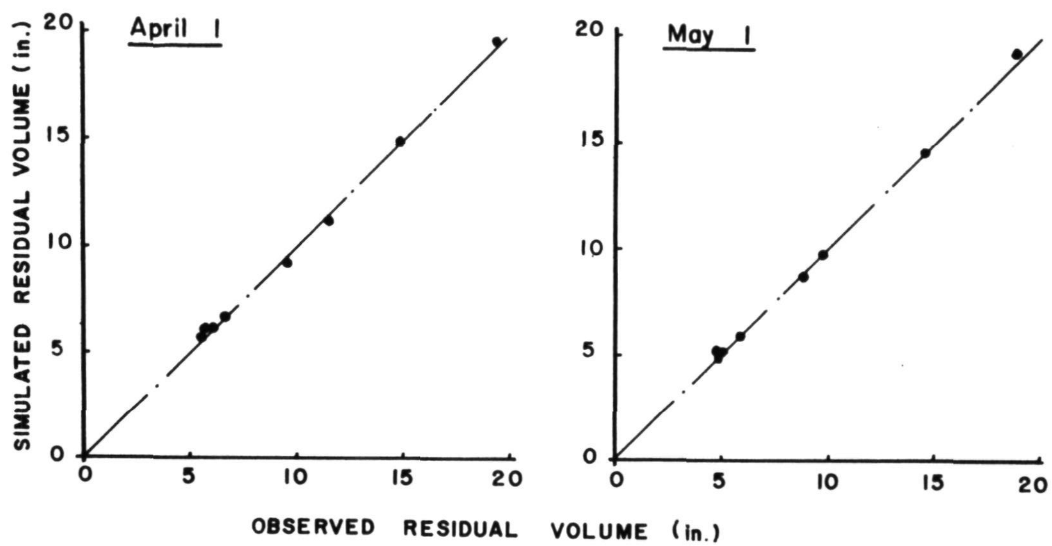

Figure 3 - Simulated vs. Observed Residual Flow Volumes, Conejos River. (1 in. = 25.4 mm)

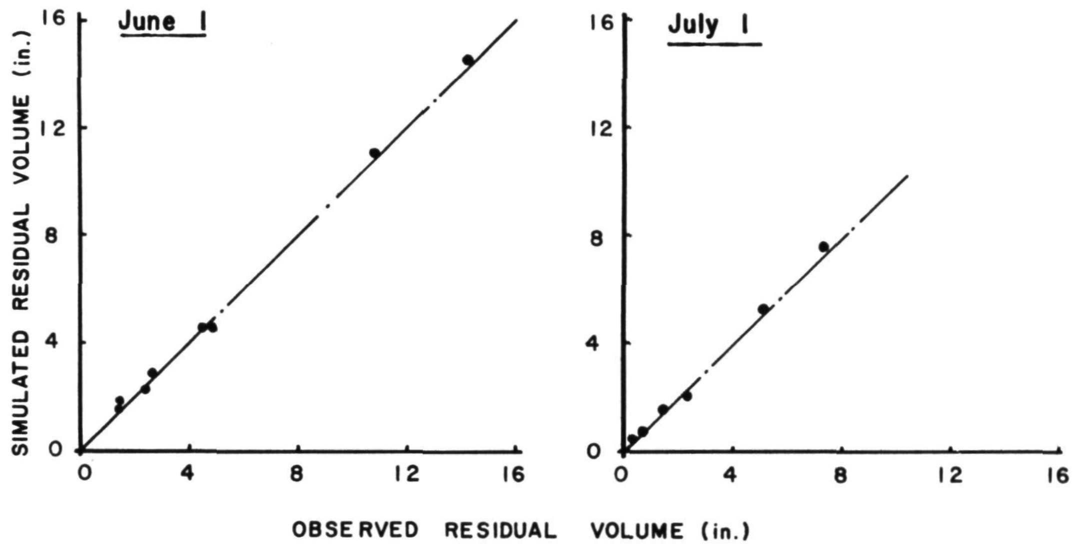

Figure 4 - Simulated vs. Observed Residual Flow Volumes, Conejos River. (1 in. = 25.4 mm)

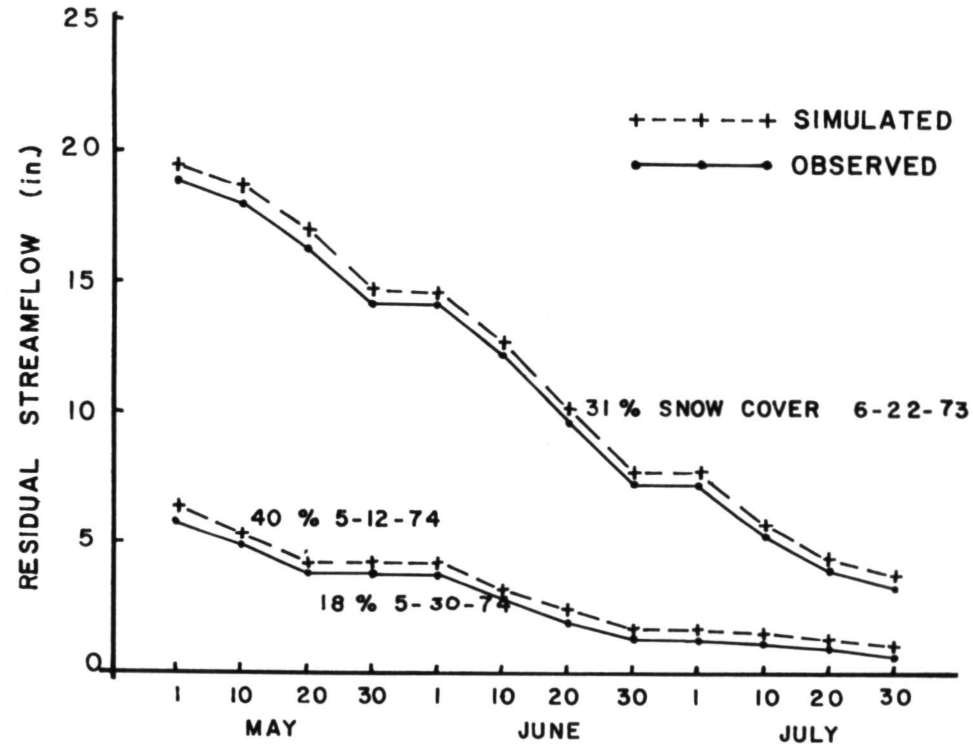

Figure 5 - Simulated vs. Observed 10-day Residual Flow Volumes For 1973 and 1974, Conejos River Basin. (1 in. = 25.4 mm)

on the magnitude of the snowpack and precipitation through the snowmelt season (Leaf and Haeffner 1971). For example, in Table 3, 31 percent snow cover on June 22 corresponds to a residual flow of 137,900 acre-feet in 1973--a big snow year, whereas on May 12 in 1974--a low snow year--40 percent snow cover represents a residual flow of only 70,150 acre-feet. However, if one looks at residual water equivalent, one finds that a direct relationship exists between this variable and the areal extent of snow cover.

The stable correlation between snow-cover depletion and residual water equivalent is independent of precipitation input and can be utilized in combination with direct snowpack measurements through the melt season to revise model estimates of streamflow. In most areas, satellite imagery would provide the primary basis for updating streamflow forecasts so long as the drainage basin is partially snow covered. Streamflow forecasts prior to the onset of snowmelt and during those times when the watershed is completely covered with snow would rely on direct snowpack measurements.

CONCLUSIONS

Satellite snow cover data used in combination with the recently developed Subalpine Water Balance Model can provide a sound physical basis for making continuous short-term streamflow forecasts in the Upper Rio Grande Basin. Reconstitution studies of a 15-year streamflow record indicate that the model is adequate for making residual volume forecasts at time intervals as short as 10 days. A comparison of model results with mapped snow cover estimates indicates that an apparently stable relationship between satellite derived snow cover and residual water equivalent can be the primary basis for modifying short-term forecasts and ultimately delivery schedules to ensure the maximum amount of water for Colorado users while at the same time meeting Compact commitments downstream.

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