# LANDSAT DERIVED SNOWCOVER AS AN INPUT VARIABLE FOR SNOWMELT RUNOFF FORECASTING IN SOUTH CENTRAL COLORADO

B.A. Shafer, Soil Conservation Service, Denver, Colorado
C.F. Leaf, Consulting Hydrologist, Sterling, Colorado

## ABSTRACT

Landsat imagery for the period 1973-78 was used to calculate snow covered area on six drainages in Colorado. Snow covered area was used as a predictor variable to forecast both short-term and seasonal snowmelt runoff volumes. Operational snowcover estimation techniques were compared. The Leaf-Brink Subalpine Water Balance simulation model was adapted to use snow covered area as an input parameter to predict residual volume runoff. Areal snowcover was also used in a statistical model to forecast runoff and is compared to current water equivalent index methods of forecasting. Results indicate that Landsat derived snowcover is highly correlated with seasonal streamflow volumes. Snowcover extent is an important variable for forecast purposes once the main snowmelt season begins but is of limited value before that time.

## INTRODUCTION

Knowledge of areal extent of snowpack coverage has long been a desire of snow hydrologists for both seasonal volume prediction and flood forecasting. Until recently this desire has been largely unfulfilled due to the expense and time needed to acquire and process aerial photo coverage. Since the early 1970's satellites have made available relatively high resolution imagery on a repetitive basis from which snow covered area could be determined.

Leaf (1971) and Rango, et al. (1975) demonstrated applications of snowcover estimates in forecasting seasonal snowmelt runoff. Use of satellite derived snowcover, however, was not widespread in any major ongoing forecast program. The National Aeronautics and Space Administration (NASA) in 1974 undertook the task of demonstrating the feasibility of using remotely sensed snowcover from satellites in operational streamflow forecasting programs.

As part of their Applications Systems Verification and Transfer (ASVT) program NASA funded four demonstration projects in the Western United States to study the ways in which Landsat derived snow maps could be constructed and incorporated into existing schemes for forecasting snowmelt runoff. Further, evaluations were to be conducted in each study site to ascertain the potential improvement in forecast accuracy that could be ascribed to use of snowcover data. The four demonstration study centers chosen were in Arizona, California, Colorado, and the Northwestern United States. This study effort within the ASVT program was called the Operational Application of Satellite Snowcover Observations (OASSO).

In Colorado three agencies were responsible for carrying out the intent of the ASVT program. The USDA Soil Conservation Service (SCS) was given lead responsibility, with assistance provided by the U.S. Bureau of Reclamation and the State of Colorado Division of Water Resources (State Engineer).

The study approach in Colorado consisted of four steps: (1) identify specific drainage basins and acquire the Landsat imagery to cover them; (2) examine various techniques of mapping the snowcover and determine which method is most useful in an operational mode; (3) develop a methodology for including snow covered area in a forecast of snowmelt runoff; and, (4) evaluate the adequacy of the forecasting techniques that employed snowcover.

## STUDY AREA

The Rio Grande Basin in Colorado was chosen as the primary drainage for study and the Upper Arkansas River as a secondary study basin. Within the Rio Grande Basin five watersheds were singled out for detailed analysis. In all, six watersheds encompassing some 9,335 $km^2$ (3,604 $mi^2$) were analyzed in the study, which corresponded to streamflow gaging stations currently forecasted by the Soil Conservation Service. They include the Arkansas River near Wellsville, Rio Grande above Del Norte, South Fork Rio Grande at South Fork, Alamosa River above Terrace Reservoir, Conejos River near Mogote, Culebra Creek at San Luis (Figure 1). The last five watersheds are in the Rio Grande Basin and flow into the San Luis Valley where they comprise the mainstem of the Rio Grande.

Both the Rio Grande and the Arkansas basins represent river systems whose primary source of water is snowmelt. The San Luis Valley is a virtual desert that could produce little in terms of agriculture were it not for the snowfed streams that enter it. Mean annual precipitation on the valley floor which averages 2,460 m (7,500 ft) elevation is only 17.8 cm (7 in) while the headwaters at elevations to 4,267 m (14,000 ft) averages 114 cm (45 in) annually. Over 80 percent of the annual flow of the Rio Grande is attributable to the snowpack contribution.

The Arkansas basin is similar to the Rio Grande. Valley floor elevations are between 2,438 m (8,000 ft) and 2,743 m (9,000 ft) and rise to heights of 4,389 m (14,400 ft). Mean annual precipitation ranges from 25 cm (10 in) on the valley floor to 102 cm (40 in) in the highest reaches of the basin. The mountain snowpack produces about 75 percent of the annual flow.

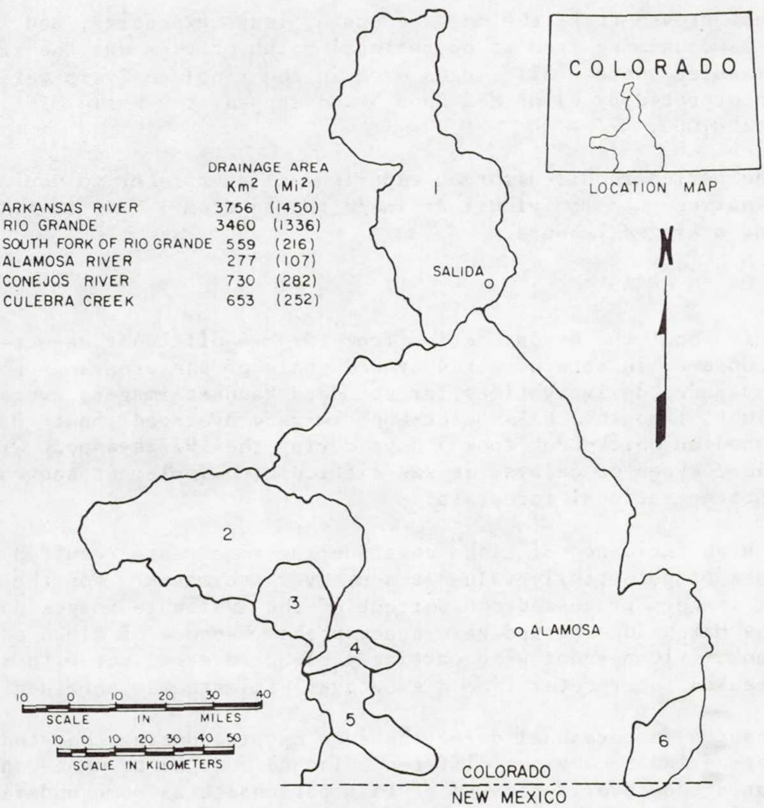


Fig. 1. Location of Colorado ASVT study drainages.

Accurate forecasts of streamflow in both the Rio Grande and in the Arkansas basins are essential for several reasons. Agricultural interests relying upon the snowmelt waters for irrigation require planning information on their prospective water supply to effectively manage their operations. Second, waters of both streams are regulated and distributed according to interstate compact agreements between Colorado and downstream states. Administration of the compact ageements in an equitable and timely manner depends upon reliable estimates of streamflow both before and during the runoff season.

DETERMINATION OF SNOW COVERED AREA

During the period of the study six methods of mapping snowcover were investigated on one or all watersheds. They included zoom transfer scope, density slicing, color additive viewer, computer assisted classification, grid sampling, and NOAA/NESS basin snowcover maps prepared by Mr. Stanley Schneider. Each of these methods had some advantages and disadvantages. However, the technique that proved to be the most accurate, least expensive, and least time consuming from an operational point of view was the zoom transfer scope. All images used in the final analysis were interpreted by using MSS Band 5 and mapped at a scale of 1:250,000.

The period required for an experienced interpreter to map and planimeter an individual drainage ranged from 1 hour to 4 hours and averaged 2 hours.

## PROBLEM AREAS

Throughout the 6-year period from 1973-78 difficulties were encountered in attaining the avowed goals of the program. For instance, delivery times for standard Landsat imagery averaged almost 1 month. NASA Quick-Look imagery averaged about 10 days. Canadian Quick-Look took 5 days during the 1977 season. With these types of delays, it was difficult to implement snowcover into operational forecasts.

A high incidence of cloud cover during some years resulted in the loss of potentially valuable snowcover estimates. For the 6 years of imagery processed, 40 percent of the available images during the March-June period were unacceptable because of cloud cover. Another 10 percent were partially cloud covered, but with increased interpreter time a snowcover estimate was obtained.

Changes in personnel doing the snow mapping during the study period led to obvious difference in judgment as to what constituted snowcover. Because of this personal bias some undefined degree of error creeps into the areal estimates of snow. Four of the six watersheds were completely remapped by one individual to reduce this source of error. Accuracy in mapping snowcover is certainly desirable albeit difficult to measure. More important than accuracy, however, is consistency. Without consistent interpretation from one observer to another, any technique is bound to yield questionable results. To obtain the level of consistency felt necessary for a meaningful analysis, only two interpreters performed final mapping in the Colorado study.

## SNOWCOVER IN FORECASTING

All usable images in the March-June meltout period were used to produce the snowcover depletion curves in Figures 2 through 7. These curves depict the gradual loss of watershed snowcover during the primary melt season. Although the curves were developed from only 6 years of data, they represent a fairly wide spectrum of hydrologic conditions. A frequency analysis of streamflow and snow course data reveal that the drought conditions that prevailed during the 1977 season have a recurrence interval of 100 years. The 1973 and 1975 seasons were relatively high and had a recurrence interval of 10 years.

Examination of the snowcover depletion curves shows a melt sequence that is similar from one year to the next, resulting in roughly parallel curves. The displacement of the curves with time in different years is directly related to the amount of water stored in the snowpack. In low snowpack years, melting begins and ends earlier, resulting in reduced runoff. In high snowpack years, the onset of melt is initially retarded owing to the depth of the snowpack and the increased energy requirement necessary to bring the pack to isothermal conditions. Meltout and the corresponding runoff are prolonged accordingly. Snow areal extent during the main melt period is a good measure of the water stored in the snowpack and the volume of runoff likely to be produced. This relationship appears to be valid except when large scale late season storms significantly alter the watershed mean areal water equivalent. Such an event occurred on May 8, 1978. Figure 6 shows the effects of the storm in the form of displacing the snowcover depletion curve in time from where it would normally have been. Events of a lesser magnitude have little effect, as evidenced by the same storm on the Arkansas River (Figure 2), which did not change appreciably the watershed mean areal water equivalent.

The relationship of snowcover estimates between adjacent and nearby watersheds was explored in the hope of reducing the amount of interpreter time needed to map each drainage separately. Snowcover correlations for 23 common image dates were computed among all watersheds in the study area and are shown in Table 1. Table 1 reveals that an excellent to moderate relationship exists between snowcover estimates on the various drainages. The analysis shows a distinct probability that satisfactory estimates of snowcover on adjacent watersheds can be obtained if necessary but will be subject to a varying degree of precision. The necessity might be occasioned by cloud cover obscuring a watershed, missing images, or the press of time in making forecasts of streamflow.

| Basin | Arkansas | Rio Grande | South Fork | Alamosa | Conejos | Culebra |
|---|---|---|---|---|---|---|
| Arkansas | 1.0 | .90 | .89 | .85 | .94 | .92 |
| Rio Grande | | 1.0 | .97 | .90 | .96 | .88 |
| South Fork | | | 1.0 | .94 | .98 | .92 |
| Alamosa | | | | 1.0 | .95 | .89 |
| Conejos | | | | | 1.0 | .95 |
| Culebra | | | | | | 1.0 |

TABLE 1. INTERBASIN CORRELATION OF SNOWCOVER USING 23 COMMON IMAGE DATES

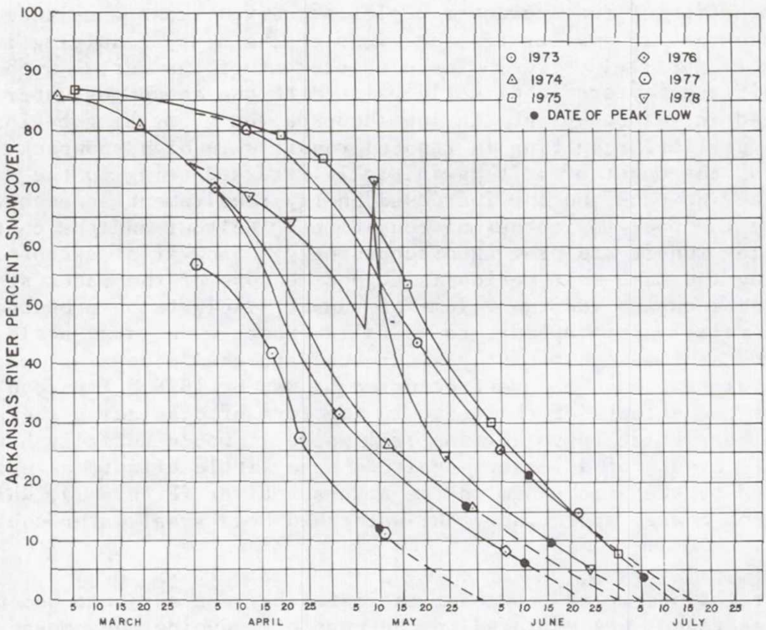


Fig. 2 Snowcover depletion curves for Arkansas River

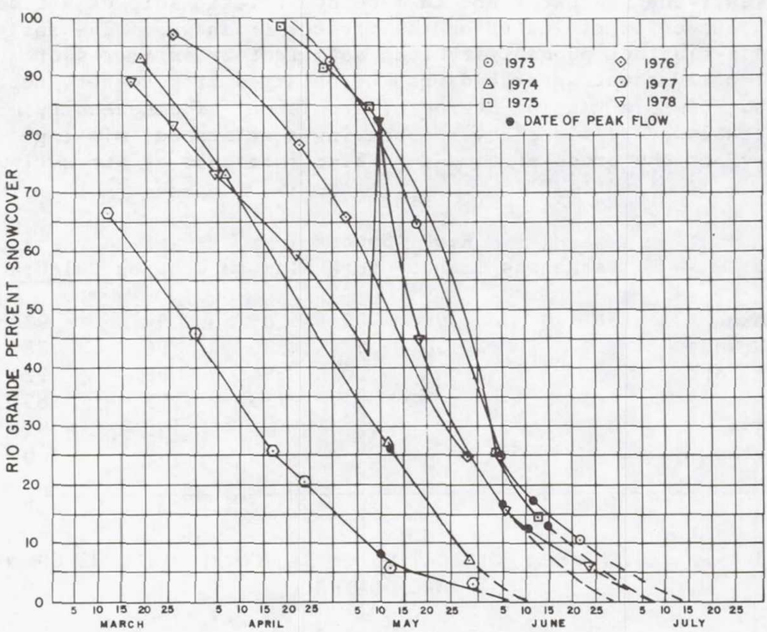


Fig. 3. Snowcover depletion curves for Rio Grande

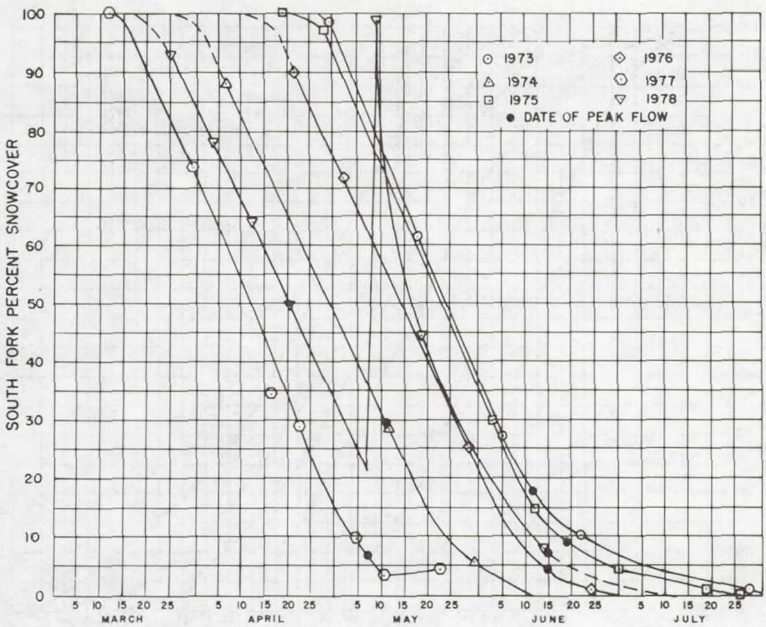


Fig. 4. Snowcover depletion curves for South Fork Rio Grande

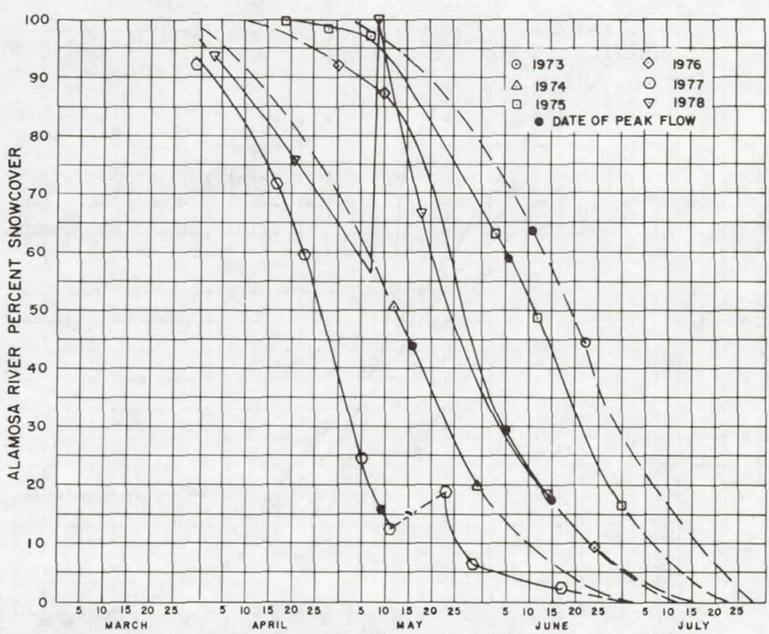


Fig. 5. Snowcover depletion curves for Alamosa River

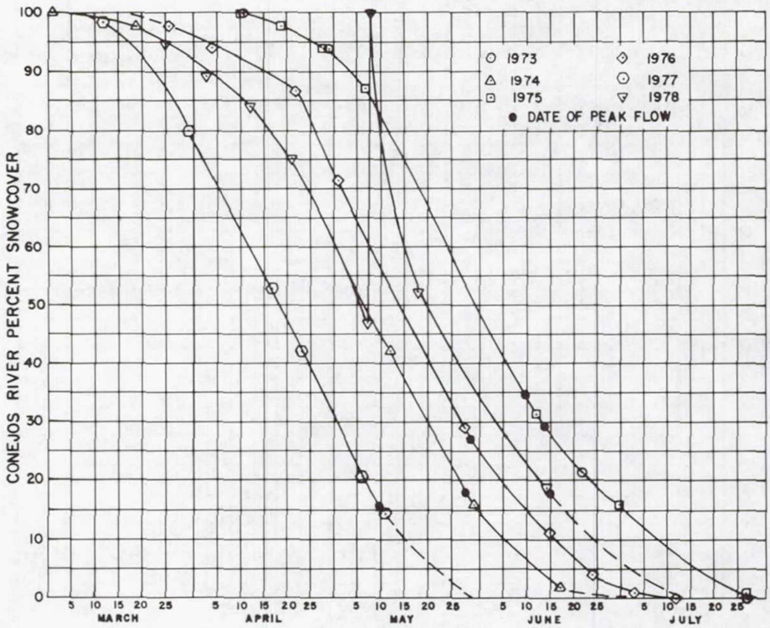


Fig. 6. Snowcover depletion curves for Conejos River

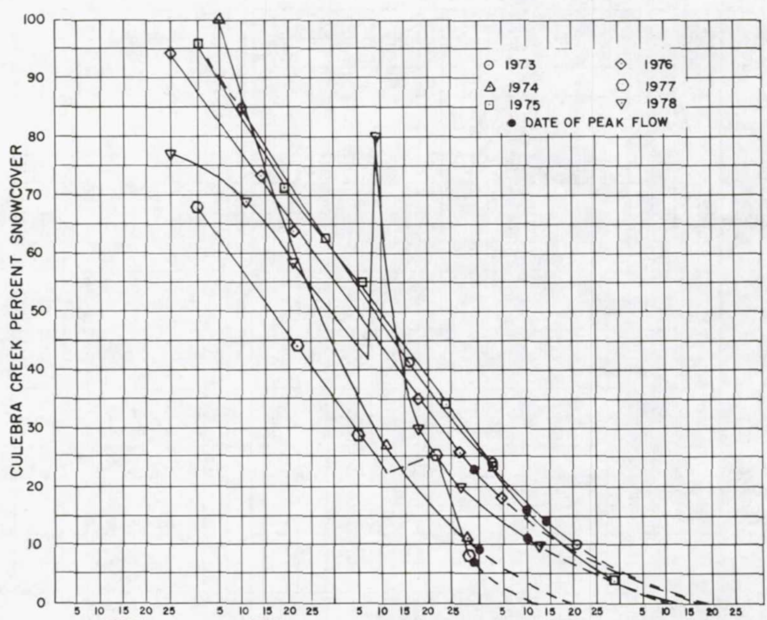


Fig. 7. Snowcover depletion curves for Culebra Creek

A statistical approach was taken to evaluate the relationship of basin snowcover to seasonal streamflow production. A simple linear regression analysis was performed between watershed snowcover on April 1, May 1, and June 1 and April-September streamflow. Snowcover values were derived from snowcover depletion curves. Table 2 summarizes the results. A high degree of correlation is apparent on all basins except Culebra Creek. A possible explanation for this exception may lie in the fact that only 40 percent of the watershed is in the main water producing zone above 3,048 m (10,000 ft), compared with between 65 and 80 percent for all other watersheds in the study. It is also the only watershed studied in the Sangre de Cristo Mountain Range. Streams in this range of mountains exhibit characteristically high coefficients of variation owing to the reduced snowmelt contribution to seasonal runoff. Their flow can be substantially influenced by the occurrence of summer convective storms.

| Basin | Number of Observations | April 1 | May 1 | June 1 |
|---|---|---|---|---|
| Arkansas near Wellsville | 6 | .96** | .87* | .89* |
| Rio Grande near Del Norte | 6 | .86* | .98** | .95** |
| South Fork at South Fork | 6 | .79 | .97** | .92** |
| Alamosa River above Terrace Reservoir | 6 | .85* | .95** | .98** |
| Conejos River near Mogote | 6 | .89* | .97** | .96** |
| Culebra Creek at San Luis | 6 | .24 | .67 | .65 |

*Significant at the 5% level.
**Significant at the 1% level.

TABLE 2. CORRELATION BETWEEN BASIN SNOWCOVER AND APRIL-SEPTEMBER VOLUME RUNOFF

In an effort to increase the sample size, snowcover on May 1 for Conejos, Alamosa and South Fork watersheds were pooled and a correlation was run against their respective April-September flows normalized to their 1963-77 averages (Figure 8). A moderately high correlation coefficient of 0.92 and a coefficient of determination of 0.85 with a standard error of 18.5 percent resulted.

Although a strong positive correlation is evidenced by the data in Table 2 and in Figure 8, it is instructive to compare them with the performance of forecast techniques using only snow course data and with techniques using both snowcover and snow course data. Snowcover and snow courses serve to index watershed moisture stored in the form of snow; both account for much the same proportion in streamflow variance and are therefore highly intercorrelated. One possible method of assessing their relative contribution in explaining the variance in runoff would be to perform a linear multiple regression analysis with a number of snow courses and snowcover as predictor variables. Unfortunately, the length of record in this study was so short as to preclude this type of analysis.

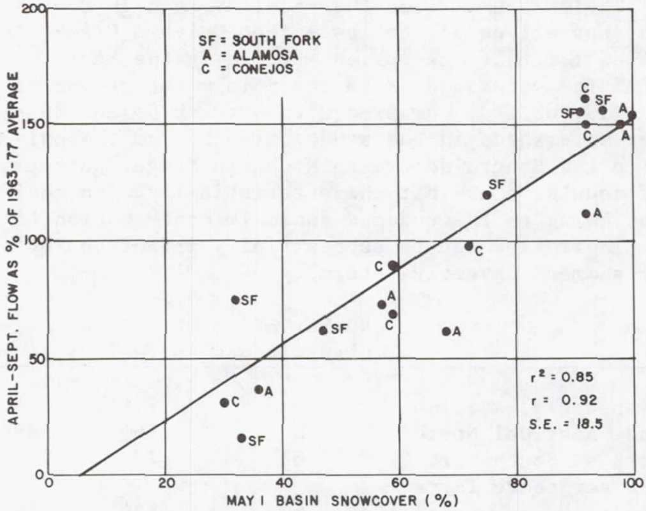


Fig. 8. Pooled linear regression analysis between snowcover on May 1 and normalized April-September streamflow.

An alternative approach was therefore devised that would indicate the improvement in forecast accuracy that might be obtained by incorporating snowcover into operational forecast techniques. A simple linear regression was calculated between a weighted snow course index consisting of snow course variables currently used to forecast each drainage on May 1 and April-September flow normalized to the 1963-77 average. A second regression was computed relating the product of the snow index and the fractional amount of snowcover on May 1 to the normalized runoff. Both of these analyses were compared to the regression analysis relating May 1 snowcover and streamflow tabulated in Table 2. Table 3 presents the results of this investigation.

In four of the six drainages addition of snow covered area to the forecast procedure improved the accuracy over snow course data alone; in one it decreased accuracy, and in one it remained unchanged. This tends to support the argument that use of snowcover can lead to better forecasts. However, care must be exercised in drawing conclusions from such a small sample.

The magnitude of snowmelt peaks is also known to be related to watershed snowpack. The date of occurrence of the maximum daily snowmelt peak is plotted on the snowcover depletion curves of Figures 2 through 7. Percent snowcover on the date of the peak

| Drainage | No. of OBS. | Weighted Snow Course Index May 1 | Landsat Snow Cover May 1 | Combined Snow Index and Snowcover May 1 |
|---|---|---|---|---|
| | | Variable | | |
| Arkansas | 6 | 0.985** | 0.834 | 0.895* |
| Rio Grande | 6 | 0.974** | 0.979** | 0.998** |
| South Fork | 6 | 0.907* | 0.972** | 0.981** |
| Alamosa | 6 | 0.941** | 0.946** | 0.998** |
| Conejos | 6 | 0.979** | 0.976** | 0.999** |
| Culebra | 6 | 0.881* | 0.670 | 0.874* |

*Significant at 5% level.
**Significant at 1% level.

TABLE 3. SIMPLE CORRELATION COEFFICIENTS BETWEEN INDICATED VARIABLES AND APRIL-SEPTEMBER FLOW NORMALIZED TO 1963-77 AVERAGE.

flow was correlated with the discharge. Table 4 summarizes the results of this analysis. A high correlation is observed between peak discharge and watershed snowcover. Correlations range from 0.81 on Culebra Creek to 0.96 on the Alamosa River. This relationship is of sufficient accuracy to be considered useful in making forecasts of peak flows. Making a forecast of the date when the peak will occur is much less precise. A review of the snowcover depletion curves shows that with few exceptions the peaks generally occurred in a range of about 15 percent in the last third of the melt period.

| Basin | Number of Observations | Correlation Coefficient |
|---|---|---|
| Arkansas near Wellsville | 6 | .88* |
| Rio Grande near Del Norte | 6 | .99** |
| South Fork at South Fork | 6 | .94** |
| Alamosa Creek above terrace | 6 | .96** |
| Conejos River near Nogote | 6 | .93** |
| Culebra Creek at San Luis | 6 | .81* |

*Significant at the 5% level.
**Significant at the 1% level.

TABLE 4. CORRELATION BETWEEN BASIN SNOWCOVER ON MAY 1 AND MAXIMUM DAILY SNOWMELT PEAK

Computerized Short-Term Streamflow Forecasting

Statistical and graphical methods are reliable tools for making seasonal forecasts. However, extensions of these early-spring forecasts to a short-term basis using such methods is difficult, because precipitation and meteorological conditions during the ensuing melt season can vary widely from year to year. Because short-term forecasts that respond to varying hydrometeorological conditions are becoming increasingly important in water resource management, several procedures have been developed for making such forecasts. For example, one method used by the National Weather Service is the "Extended Streamflow Prediction (ESM)" model (Twedt, *et al.*, 1977).

In Colorado, the Subalpine Water Balance model developed by Leaf and Brink (1973a, 1973b) is being used for making and updating residual streamflow forecasts. Updating of this model during the snow accumulation season is accomplished by means of the SCS Snow Telemetry (SNOTEL) system. During the snowmelt season, when snow-cover on the watershed is less than 100 percent, forecasts are revised on the basis of the percent snowcover and associated residual water equivalent.

SUBALPINE WATER BALANCE MODEL FORECASTING PROCEDURE

The Subalpine Water Balance model was developed by the USDA Forest Service to simulate daily streamflow. This model simulates winter snow accumulation, shortwave and longwave radiation balance, snow-pack condition, snowmelt and subsequent runoff on as many as 25 watershed subunits. Each subunit is described by relatively uniform slope, aspect, and forest cover. The simulated water balances on each subunit are compiled into a "composite overview" of an entire drainage basin.

Detailed flow chart descriptions and hydrologic theory have been published (Leaf and Brink 1973a, 1973b). Operational computerized streamflow forecasting procedures using the Subalpine Water Balance model are keyed to real-time telemetered snowpack (SNOTEL) data and satellite imagery. Landsat and SNOTEL data are used to update the model at any time by means of "control curves" for a given drainage basin which relate:

1. Satellite snowcover data to residual water equivalent on the basin and

2. SCS SNOTEL data to area water equivalent on the basin.

With these relationships, simulated residual volume streamflow forecasts can be revised as necessary to reflect the current meteorological conditions and the amount of snow.

## MODEL CALIBRATION

During the study period, the Subalpine Water Balance model was calibrated to several index watersheds in the Rio Grande and Arkansas River basins as follows:

1. Rio Grande Basin
   a. Conejos River near Mogote
   b. Culebra Creek near Chama
   c. Rio Grande River above Wagonwheel Gap
   d. South Fork at South Fork

2. Arkansas Basin
   a. Arkansas River above Salida

All are key headwater tributaries that characterize the hydrologic regimes of the two basins. Table 5 summarizes pertinent geographic characteristics of each.

| Watersheds | Drainage Area ($km^2$) | Mean Elev. (m m.s.l.) | Aspect | No. Subunits[1/] |
|---|---|---|---|---|
| Conejos River | 730 | 3,200 | SE | 20 |
| Culebra Creek | 189 | 3,185 | W | 12 |
| Upper Rio Grande | 2,090 | 3,475 | E | 10 |
| South Fork | 559 | 3,124 | NE | 4 |
| Arkansas | 3,155 | 3,125 | SSE | 11 |

1/ Includes all forested and open areas.

TABLE 5. GEOGRAPHIC CHARACTERISTICS OF COLORADO ASVT INDEX WATERSHEDS

Areas of the index watersheds vary from 189 $km^2$ (73 $mi^2$) (Culebra Creek) to 3,155 $km^2$ (1,218 $mi^2$) (Upper Arkansas), and the number of subunits used to characterize a given watershed varied from 4 (South Fork) to 20 (Conejos River). This range of size and level of detail has indicated that the model performs well on both large and small watersheds.

Figure 9 shows observed vs. simulated runoff on a water-year basis for the Conejos River for 1958-71. Having fixed model parameters for 1958-71, four subsequent years (1972-75) were then used for validation. These results are shown in Table 6.

Observed vs. simulated runoff from the South Fork are plotted in Figure 10. The calibration period on this basin was 1973-77.

## FORECASTING SYSTEM DESIGN

The way in which the Subalpine Water Balance model is used to update streamflow forecasts is schematically illustrated in Figure 11. The primary model response is area snowpack water equivalent, and this variable is plotted as a function of time in Figure 11. Typically, the snowpack builds to a "peak" in late spring. To the left of this peak is the winter snow accumulation season (100 percent snowcover) and to the right is the snowmelt runoff (snowcover depletion) season.

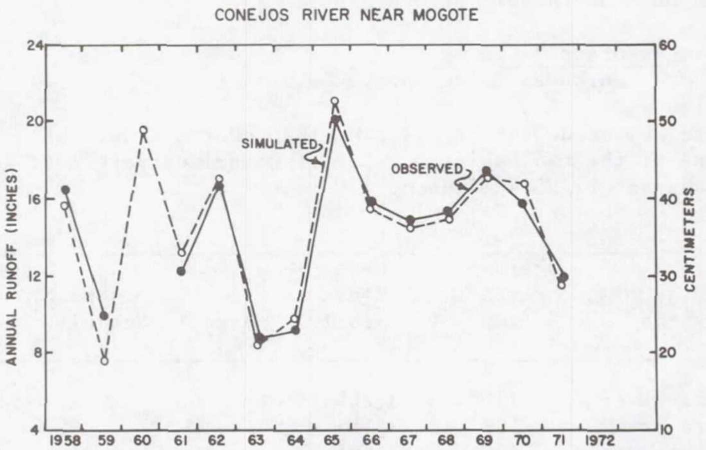


Fig. 9. Simulated vs. observed annual runoff, Conejos River 1958-71

| Year | October 1 - September 30 Runoff in cm(in) Simulated | Observed |
|---|---|---|
| 1972 | 21.8 (8.6) | 20.3 (8.0) |
| 1973 | 51.0 (20.1) | 55.4 (21.8) |
| 1974 | 27.7 (10.9) | 24.1 (9.5) |
| 1975 | 46.7 (18.4) | 46.2 (18.2) |

TABLE 6. OBSERVED VS. SIMULATED STREAMFLOW, CONEJOS RIVER, 1972-75.

### Control Functions

As seen in Figure 11, primary control of the hydrologic model during the winter months is from SNOTEL, whereas during snowmelt runoff, control of the model derives from Landsat. If field data obtained from these two systems indicate that the model is over or under predicting the snowpack, measures can be taken through use

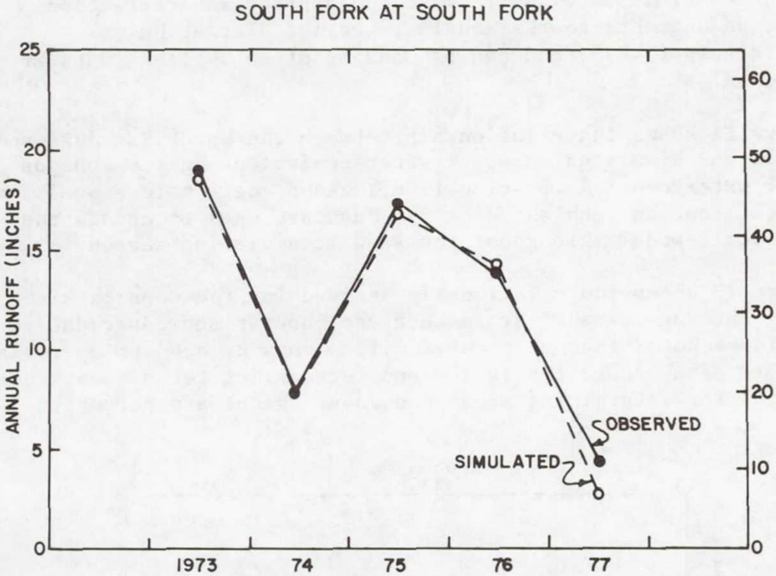


Fig. 10. Simulated vs. observed annual runoff, South Fork 1973-77

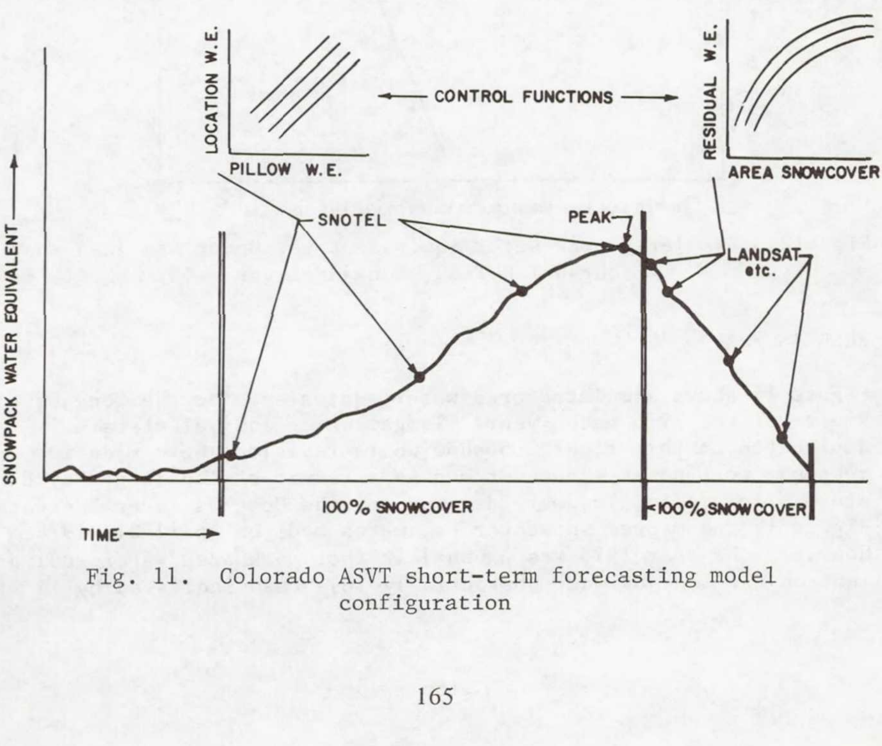


Fig. 11. Colorado ASVT short-term forecasting model configuration

of the control functions to make the appropriate correction. These adjustments to the model are called "Target Water Equivalents (TWE)", and can be made as often as field data are received.

Figure 12 shows the relationship between the Upper San Juan snow course and simulated snowpack water equivalent on the Conejos River watershed. As previously discussed, data telemetered from a SNOTEL location such as Upper San Juan are used to update the hydrologic model throughout the snow accumulation season.

Figure 13 shows the relationship derived for the Conejos River by using the Subalpine Water Balance and Landsat snowcover data. It should be noted that this curve will always be subject to revision as more data become available, and forecasting techniques and methods for determining areal snowcover extent are perfected.

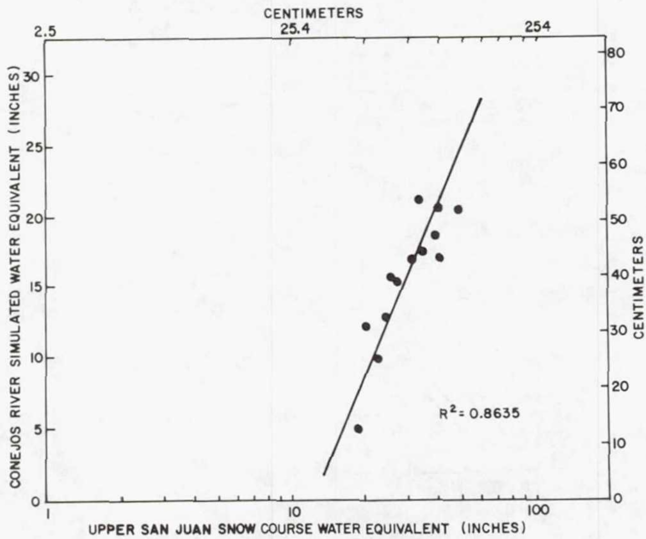


Fig. 12. Simulated peak water equivalent vs. Upper San Juan snow course (SNOTEL), Conejos River

RESULTS

Figure 14 shows simulated area water equivalent for the Conejos River for the 1978 water year. Target water equivalents are designated on this figure to show where revisions were made in response to Landsat snowcover and as a result of the large May 8 storm. Initially, TWE were derived for the Conejos River based on Figure 12 and mapped snowcover estimates made on April 21, 1978. However, the year 1978 was unusual in that peak area water equivalent on the Conejos was substantially less than indicated by

Figure 12. Thus, initial TWE were revised downward to approximately 25.4 cm (10 in) as opposed to 35.5 cm (14 in) based on the amount of snow accumulation at the Upper San Juan SNOTEL site.

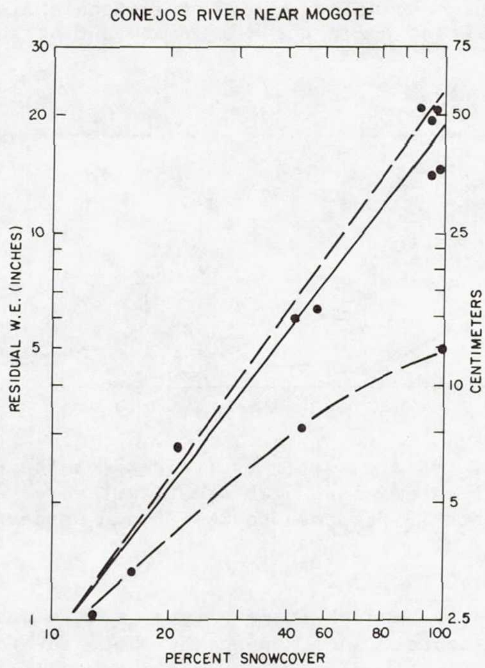


Fig. 13. Preliminary relationship showing residual water equivalent as a function of snowcover on the Conejos River. The lower curve was derived from the 1978 snowmelt season.

On April 21, snowcover extent was 75 percent which corresponded to less than 10.2 cm (4 in) of area water equivalent for 1978 (Figure 13). As seen in Figure 14, relatively minor but significant increases in snowpack were made through use of the TWE. Soon after the first adjustment, SNOTEL indicated that Upper San Juan snowcover gained 13.5 cm (5.3 in) of water equivalent between April 30 and May 10. Also, data from Landsat on May 8 showed that snowcover on the Conejos River was 100 percent. In response to this information, TWE were adjusted upward.

Total runoff for the 1978 water year was 30.5 cm (12 in) as compared to a simulated 31 cm (12.2 in) based for the most part on the original estimates of snowpack water equivalent. Subsequent corrections using the TWE capabilities in the model increased the initial residual streamflow estimates perhaps 2.5 cm (1 in). The increase in snowpack on the Conejos, as the result of the May upslope storm, was satisfactorily simulated by the model without appreciable corrections using TWE.

SUMMARY AND CONCLUSIONS

Use of snow areal extent measurements in snowmelt runoff prediction shows promise but with the short period which the study encompassed it is difficult to assess its long range impact. However, a number of conclusions can be drawn concerning the use of snowcover in forecasting in the Rio Grande and Arkansas basins.

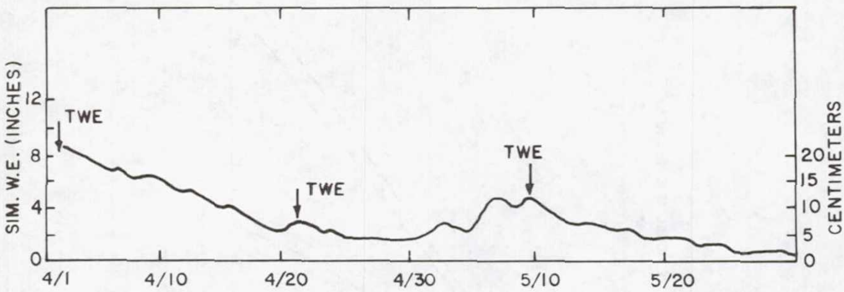


Fig. 14. Simulated area water equivalent for the Conejos River for the 1978 water year. TWE are target water equivalent adjustments in response to SNOTEL and Landsat data.

Currently available Landsat imagery is of sufficient quality and resolution for accurate snow mapping by photo interpretative means. Delay in image delivery, occurrence of cloud cover, and a nine-day interval between satellite coverage diminish to a significant extent the amount of reliance one can place in using snowcover as a forecast parameter.

Two methods of using snow covered area in forecasting have been explored and have proven successful. A statistical regression model relates snowcover to seasonal volume flow directly. A computerized simulation model provides short-term and seasonal forecasts using snowcover as an input variable. Results indicate about a ten percent reduction in average forecast error can be realized through use of satellite derived snowcover in forecast procedures.

A significant drawback to using snow covered area exclusively to make streamflow predictions is the lack of applicability prior to commencement of the main snowpack recession which normally occurs after May 1. Water management decisions frequently need to be made late in March and in April, necessitating streamflow forecasts before snowpack depletion gets well underway. For this reason, present forecast methods utilizing snow course and precipitation data will continue to be used. Use of snow covered area in hydrologic models and statistical prediction techniques in late spring will be valuable as an independent method of checking the standard forecasts now being produced.

As successive years of satellite imagery are accumulated covering a wider range of hydrologic and climatic conditions forecasts can be expected to improve through the use of snow mapping. Satellite snow mapping together with improvements in remote hydrometeorological data collection systems will enable more frequent and accurate forecasts because of increased knowledge of what is happening in the major water producing zone above valley floors.

## References


Leaf, C.F. (1971) Areal snowcover and disposition of snowmelt runoff in Central Colorado, USDA Forest Service, Research Paper RM-66, Fort Collins, Colorado, 19 pp.

Leaf, C.F. and G.E. Brink (1973a) Computer simulation of snowmelt within Colorado subalpine watershed, USDA Forest Service, Research Paper RM-99, Fort Collins, Colorado, 22 pp.

Leaf, C.F. and G.E. Brink (1973b) Hydrologic simulation model of Colorado subalpine forest, USDA Forest Service, Research Paper RM-107, Fort Collins, Colorado, 23 pp.

Rango, A., V.V. Salmonson, and J.L. Foster (1975) Seasonal streamflow estimation employing satellite snowcover observation, X-913-75-26, Goddard Space Flight Center, Greenbelt, Maryland, 34 pp.

Twedt, Thomas M., J. C. Schaake, Jr., and E. L. Peck (1977) National Weather Service extended streamflow prediction, Proc. Western Snow Conference, pp. 52-57.