# USE OF SATELLITE DATA TO DEVELOP SNOWMELT-RUNOFF FORECASTS IN ARIZONA

by

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## INTRODUCTION

Increase in demand for water in Arizona, coupled with multipurpose reservoirs to control and regulate snowmelt runoff, requires accurate streamflow forecasting. Forecasts are needed to determine allowable releases from reservoirs for power, irrigation, and municipal use.

Areal snow cover measurements may be an especially valuable input to streamflow forecasting in Arizona. The snowpack in Arizona is shallow and intermittent in contrast to those in most Rocky Mountain states. However, this difference may allow measures of changes in areal snow cover to have a high correlation with the volume of subsequent snowmelt runoff.

The Earth Resources Technology Satellites (ERTS) have potential use in determining areal snow cover (Barnes et al., 1974; Meier, 1973). ERTS (now referred to as LANDSAT) offers small scale imagery while maintaining high resolution. Furthermore, ERTS operates continuously and, with two satellites currently in orbit, scans of a given surface feature are repeated every nine days.

An exploratory study has been conducted to determine the feasibility of using ERTS imagery to monitor changes in areal snow cover for application in developing snow cover-runoff relationships in east-central Arizona (Aul and Ffolliott, 1975). Specifically, ERTS-1 imagery was selected because this was the only imagery available for the time period analyzed. The objectives of the study were to: (1) determine if ERTS imagery could be interpreted for areal snow cover by employing manual and semi-manual methods of interpretation; and (2) determine if a relationship existed between measures of areal snow cover and subsequent runoff during a snowpack depletion period.

## DESCRIPTION OF THE STUDY

The Black River Watershed, an area of 1,450 square kilometers, was chosen as the study area. This watershed, ranging in altitude from 1,745 meters at the Black River Pumping Station to 3,535 meters at the top of Mt. Baldy, receives heavy snowfalls during the winter. Black River is a major contributor to the Salt River, which is an integral part of the reservoir system that provides water to Phoenix and central Arizona. Seasonal flow from the Black River Watershed averages over 125 million cubic meters annually.

Vegetation on the Black River Watershed is primarily montane-conifer forest, with small areas of spruce-fir, mountain meadow, and pinyon-juniper. The watershed is almost totally basaltic in geologic formation.

ERTS imagery, in both 245 millimeter and 70 millimeter formats, was the data source for the study. Specific imagery used was in the red band (0.6-0.7 $\mu$) because previous studies have indicated that snow cover can most easily be detected in this spectral range (Barnes and Bowley, 1973; Evans, 1974; Rango et al., 1974).

The time period analyzed was November 1, 1972 to June 12, 1973. A near record snowpack accumulated in Arizona during this period, with estimates of snowpack water equivalent (WE) 300 percent above normal on the Salt River Watershed (Barnes et al., 1974).

A 1:1,000,000 scale overlay was developed for interpretation of the imagery. Snow covered areas were determined by comparing the brightness level on the watershed with that on the edge of the snowpack. Thus, areas within the watershed which appeared brighter than areas just beyond the edge of the snowpack, were judged snow covered. When not obliterating the view of the snowpack, clouds were differentiated from snow by pattern recognition, shadows, and identification of terrestrial features.

Four methods were used in the interpretation of areal snow cover: (1) a simple dot grid, (2) a grid of squares, (3) a planimeter, and (4) a densitometer. Estimates of areal snow cover were made by one observer, using all four methods of interpretation. Areal snow cover estimates were also made by four observers using the dot and squares grid methods. Split plot analyses of variance were used to test for differences.

Measures of areal snow cover and runoff subsequent to a date of snow cover measurement were needed before a relationship between these two variables could be ascertained. A single value of areal snow cover was obtained by calculating a mean of the values from all methods of interpretation judged feasible for assessment. Runoff prior to each areal snow cover measurement date was determined by

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accumulating daily runoff records through June 12, 1973. This date was chosen as the termination date for three reasons: the hydrolograph was approaching base flow (suggesting that no significant snowmelt runoff was occurring); examination of the imagery on June 5, 1973, indicated little snow cover remained on the watershed; and a heavy rainstorm occurred over the watershed on June 13 and 14 (so runoff after that storm was assumed largely from rainfall rather than snowmelt).

Arbitrarily, the snowpack depletion period was chosen when the general trend of data appeared to indicate a decrease in snow covered area over the watershed.

## RESULTS AND DISCUSSION

Arizona has more days suitable for aerial photography than any other state (Avery, 1968). Furthermore, the sidelap of viewing swaths of ERTS-1 and the position of the Black River Watershed in the viewing swaths allowed cover of the watershed on two consecutive days for each sweep by the satellite. Despite these advantages, however, only imagery from seven of 13 possible two-day periods could be interpreted for areal snow cover, as clouds obscured all or significant portions of the watershed on the remaining dates.

All scans from November 1, 1972, to May 19, 1973, that could be interpreted were evaluated for areal snow cover. While it was not used in assessing areal snow cover, the June 5, 1973 scan was used to develop a snow cover-runoff relationship.

Significant differences ($\alpha$ = 0.05) were detected among the four methods of interpretation by one observer. However, based on a multiple range test, it was concluded that no single method can be considered unfeasible because none of the results from a particular method of interpretation were unreasonable in relation to results obtained by the other methods. Significant differences were also noted among observers and between methods when four observers used the dot and squares grid methods to determine areal snow cover. These latter differences indicated that individuals have different interpretations of snow covered areas despite following the same guidelines.

The general trend of the source data showed a decline in snow covered areas beginning on February 18, 1973. Therefore, this date was chosen as the beginning of the snowpack depletion period. A significant linear regression ($\alpha$ = 0.05) existed between areal snow cover and subsequent runoff during this snowpack depletion period, based on four observations of areal snow cover from ERTS imagery. The regression was:

$$Y = 5.2(10^5) + 2.7(10^5)(X)$$

where $Y$ = subsequent runoff, in cubic meters

$X$ = areal snow cover, in square kilometers

$r^2 = 0.995$

The results of the regression relationship defined in this exploratory study appear encouraging for using ERTS imagery for snowmelt runoff forecasting, and for residual volume forecasting in particular. However, the analysis should be viewed with some restraint. The limited source data may not have accurately monitored changes in areal snow cover. For example, measures of areal snow cover from ERTS imagery indicated a peak in extent in February or March, but snow course measurements of WE indicated that peak seasonal accumulation on the Salt-Verde Watershed occurred in early April (Barnes et al., 1974). Another possible limitation was that the data represented a year having a near record snowfall. Therefore, the relationship between areal snow cover and subsequent runoff may have been influenced by the unique nature of the winter. A technical difficulty encountered in using ERTS imagery was the time necessary to obtain the imagery. If attempts are made to employ ERTS imagery in real-time monitoring of areal snow cover, this delay must be overcome.

Verification of the preliminary relationship between areal snow cover and subsequent runoff is a prerequisite to operational snowmelt-runoff forecasting employing ERTS imagery. Therefore, dependent upon available support, the validity of the regression defined in this exploratory study will be assessed as a first approximation in time and space. Specifically, it is proposed that measures of areal snow cover from satellite imagery and succeeding runoff during snowpack depletion periods be monitored on watersheds that contribute snowmelt runoff to the reservoir system in central Arizona. These quantifications should also be made over time with respect to the satellite imagery currently available to evaluate differences, if any, among seasons. In this way, the operational feasibility of using satellite data in snowmelt-runoff forecasting can be ascertained.

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