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USE OF AREAL SNOW COVER MEASUREMENTS FROM ERTS-1 IMAGERY IN SNOWMELT-RUNOFF RELATIONSHIPS IN ARIZONA

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ABSTRACT

An analysis of methods of interpreting ERTS-1 imagery to measure areal snow cover and the relationship of areal snow cover and runoff were among the objectives in this study of use of ERTS-1 imagery for forecasting snowmelt-runoff relationships.

INTRODUCTION

The increase in demand for water in the Southwest, coupled with the construction of multipurpose reservoirs to control and regulate snowmelt runoff, requires accurate streamflow forecasting. Forecasts are needed to determine allowable releases from reservoirs for power, irrigation, municipal use, recreation, pollution abatement, and flood control.

Areal snow cover measurements may be an especially valuable input to streamflow forecasting in Arizona. For example, snowmelt runoff accounts for two-thirds of the mean annual streamflow from the Salt-Verde Watershed (Warskow 1971). The Arizona snowpack is shallow and intermittent in contrast to most Rocky Mountain states. However, because of the nature of the snowpack, measures of snowpack depletion may have a high correlation with the volume of snowmelt runoff.

The Earth Resources Technology Satellites (ERTS) have shown potential use in determining areal snow cover (Barnes et al. 1974, Meier 1973). ERTS (now referred to as LANDSAT) has the advantage of offering small scale photography while maintaining high resolution. Each scan by ERTS views a swath 180 kilometers wide, and features greater than 70 meters in diameter can be detected on the imagery (Rango et al. 1974). Furthermore, ERTS operates continuously and, with two satellites currently in orbit, scans are repeated every nine days. With the availability of ERTS imagery, flights for photographing or reconnaissance of a snowpack need not be commissioned, assuming ERTS proves satisfactory in monitoring changes in areal snow cover.

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DESCRIPTION OF THE STUDY

An exploratory study was conducted to determine whether ERTS-1 imagery could be used to monitor changes in areal snow cover for use in developing snow cover-runoff relationships in east-central Arizona. ERTS-1 imagery was selected for study because this was the imagery available for the time period analyzed. The objectives of the study were to:

1. ascertain the availability of quality ERTS-1 imagery to monitor changes in areal snow cover;

2. determine whether ERTS-1 imagery could be interpreted for areal snow cover by employing manual or semi-manual methods of interpretation;

3. compare estimates of areal snow cover obtained from ERTS-1 imagery with estimates derived from low-altitude aerial snow surveys; and

4. determine whether a relationship exists between measures of areal snow cover and subsequent runoff during the snowpack depletion period.

Study Area

The Black River Watershed above the Black River Pumping Station, an area of 1,450 square kilometers, was chosen as the study area. This watershed ranges in altitude from 1,745 meters at the Black River Pumping Station to 3,533 meters at the top of Mt. Baldy and, therefore, receives relatively heavy snowfalls during the winter. The Black River is the 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 per year.

Vegetation on the Black River Watershed is primarily montane-conifer forest, with smaller areas in the spruce-fir, mountain meadow, and pinyon-juniper types. The watershed is almost totally basaltic in respect to geologic formation. Soils have igneous materials, almost exclusively, as parent material.

Interpretation of ERTS-1 Imagery for Areal Snow Cover

The ERTS-1 satellite was launched on July 23, 1972, into a near-polar, sun-synchronous orbit at an altitude of 910 kilometers. The orbital configuration provides day-to-day sidelap of the viewing swaths of 14 percent at the equator to more than 80 percent at high latitudes. ERTS-1 data are gathered and relayed in a digital format which may then be processed into imagery.

ERTS-1 imagery, in both 245 millimeter and 70 millimeter formats, was the data source for this study. The imagery was obtained from the Western Aerial Photography Laboratory, Division of the Agricultural Stabilization and Conservation Service, Salt Lake City, Utah. Specific imagery used was in the red band (0.6-0.7 Mm) because previous studies have indicated that snow cover can be most easily detected in this band (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 300 percent above normal on the Salt River Watershed in early April (Barnes et al. 1974). It was felt that a heavy snow year would provide the most ERTS snow cover data.

An overlay was developed for interpretation of the imagery. The scale of the 245 millimeter positive transparencies is 1:1,000,000 and, to interpret this imagery for snow cover, the Black River Watershed boundary had to be known. Therefore, the boundary was delineated on a 1:250,000 scale U.S. Geological Survey topographic map and reduced to a 1:1,000,000 scale through a photographic process. Shading film was laid over the outline of the watershed and cut with a fine razor knife along the boundary. The shading film was then removed and, by photographing the watershed, a 1:1,000,000 scale overlay was developed, with the watershed area being transparent and areas beyond opaque. The river channel on the overlay was opaque to facilitate location of the overlay on the ERTS-1 imagery.

Snow covered areas were determined on the imagery by comparison of the brightness level on the watershed with the edge of the snowpack. If areas within the watershed appeared brighter than areas just beyond the edge of the snowpack, they were judged snow covered. When not obliterating view of the snowpack, clouds were differentiated from snow by pattern recognition, shadows, recognition of terrestrial features, and pattern stability.

Four methods were used in the interpretation of areal snow cover on the ERTS-1 imagery. The first method employed was a simple dot grid. A dot grid, with dots approximately 0.1 millimeter in diameter and with a density of 50 dots per square centimeter, was developed through a photographic reduction process. Black and white positive transparencies with a 245 millimeter format were viewed on a light table, with the watershed overlay used to delineate the watershed on the imagery. A dissecting microscope at 7X power was used for dot counting because the microscope, at this power, made viewing of the dots easier and still allowed the observer to see patterns on the watershed. A total number of dots over the entire watershed was determined by randomly dropping the dot grid on the watershed overlay and counting the number of dots. This process was repeated ten times to derive a mean total of dots. Percent of snow cover was found by randomly dropping the dot grid on the imagery covered by the watershed overlay, counting the number of dots landing on snow covered area, and dividing by the total number of dots on the watershed. This process was repeated three times to obtain a mean percent of snow cover.

A second method of interpretation utilized a grid of squares, six millimeters per side, drawn on a sheet of clear mylar. Black and white positive transparencies with a 245 millimeter format were viewed on a light table. The squares grid was placed over the watershed located on the imagery by the overlay. The grid was located in the same position with respect to the overlay each time it was used. Percent of snow covered area was determined by estimating the amount of snow cover in a full or partial square to the nearest twenty percent, multiplying that estimate of snow cover by the area of that full or partial square, and dividing by the total area of the watershed.

A third method employed a planimeter for interpretation of snow cover. Planimetering snow cover directly from 1:1,000,000 scale imagery was difficult. Therefore, it was necessary to transfer the imagery to a larger scale. To accomplish this transfer, 70 millimeter negative transparencies of the watershed area were used to make 35 millimeter positive slides. The slides were projected to a 1:250,000 scale base map of the watershed, and the projector was moved until the stream channels of the imagery and the base map coincided. Boundaries of snow covered areas were traced onto the watershed base map and planimetered to determine the snow covered area. Percent of snow cover was found by dividing the snow covered area by the total area of the watershed at a 1:250,000 scale.

Finally, a fourth method of interpretation utilized a densitometer. Black and white positive transparencies with a 245 millimeter format were viewed on a light table with the watershed overlay blocking out all areas outside the watershed. A camera above the light table viewed the imagery and projected it to a television screen, where it was zeroed-in and brought to full scale. In viewing an image, the densitometer splits the shades of gray on the imagery into twelve discrete levels and, by flipping a switch on the densitometer, the image on the screen goes from black and white to false color. Using this switch, the densitometer can be calibrated to a particular image with the objective, in this case, of making a given set of false colors occupy the snow covered area. When a given set of false colors occupied what the interpreter considered to be snow covered, switches above those false colors were flipped to the percent scale, and the densitometer gave area of snow cover as a percent of the total area of the watershed projected on the screen.

Analyses of Interpretations of ERTS-1 Imagery

To analyze whether ERTS-1 imagery could be interpreted for areal snow cover, analyses were made on the basis of estimates of areal snow cover by one observer and on estimates of areal snow cover by four observers.

Areal snow cover estimates were made by one observer, using all four methods of interpretation. Measurements of areal snow cover were made within a one week period. After a set of measurements was completed, a week was allowed to pass before again analyzing the imagery. This process was repeated three times. A split plot analysis of variance was used to test for differences.

Areal snow cover estimates were also made by four observers using the dot and squares grid methods of interpretation. All observers were instructed to interpret snow covered areas by the methods previously described. The dot and squares grid methods were selected for interpretation because these were the methods that were judged to be most readily available to those who may use areal snow cover data. A split plot analysis of variance was again used to test for differences.

Comparison of ERTS-1 and Snow Survey Data

Low-altitude aerial snow surveys were frequently flown by the Salt River Project throughout the 1972-73 snow season because of the near record snowpack and the transient characteristics of the snowpack on the Salt-Verde Watershed. To provide a basis for comparison with ERTS imagery, areal snow cover obtained from the snow surveys was mapped on a 1:1,000,000 scale base map of the Salt-Verde Watershed. Percent of areal snow cover on the Black River Watershed was obtained from the snow survey maps by orienting the watershed overlay on the snow survey map, planimetering the snow covered area, and dividing by the total area of the watershed.

Developing Relationship Between Snow Cover and Runoff

Measures of areal snow cover and runoff subsequent to a date of snow cover measurement needed to be determined before it could be ascertained whether a relationship existed between areal snow cover and subsequent runoff during the snowpack depletion period. A single value of areal snow cover for each date of imagery interpreted was obtained by taking a mean of values from all methods of interpretation judged to be feasible for measuring areal snow cover. Runoff subsequent to each date that snow cover was measured was determined by accumulating daily runoff records through June 12, 1973. This date was arbitrarily chosen as the termination date because: the hydrograph was approaching base flow, suggesting that no significant amounts of snowmelt runoff were occurring; examination of imagery on June 5, 1973, indicated little snow cover remained on the watershed; and heavy rainstorm occurred over the watershed on June 13 and 14, so runoff after that storm would be largely from rainfall rather than snowmelt.

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

RESULTS AND DISCUSSIONS

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

All scans from November 1, 1972, to May 19, 1973, that could be interpreted were evaluated in determining the feasibility of using ERTS-1 imagery for areal snow cover interpretation. The June 5, 1973, scan was not used in evaluating the use of ERTS-1 imagery for snow cover interpretation because of the lack of a sizeable snowpack on that date. However, this scan was used in attempting to develop snow cover-runoff relationships.

Interpretation of ERTS-1 Imagery

Significant differences (a = 0.05) were detected among the four methods of interpretation by one observer for six dates throughout the 1972-73 snow season. A multiple range test was used to determine which methods differed (Table 1). Based on this test, it was concluded that no single method can be considered unfeasible because none of the results from a given method of interpretation were unreasonable in relation to results obtained by the other methods.

Table 1. -- DIFFERENCES AMONG FOUR METHODS OF SNOW COVER INTERPRETATION BY ONE OBSERVER FOR SIX DATES THROUGHOUT 1972-73 SNOW SEASON.

Densitometer	Dot Grid	Squares Grid	Projection-Planimeter
-- percent areal snow cover --			
69	71	72	74

Note: line under means indicates not significantly different (a = 0.05).

Each method of interpretation has advantages and disadvantages. The squares grid method required approximately 25 minutes per date of imagery and only a light table for interpretation. The dot grid method yielded results in the same amount of time as the squares grid method but required a microscope, in addition to a light table, for interpretation. The planimeter method yields a map of areal snow cover but required approximately 45 minutes per date of imagery for interpretation; also, a "Zoom Transfer Scope" is needed if more accuracy is needed than can be obtained from the available imagery. Finally, the densitometer method yields an estimate of snow cover in the least amount of time, approximately 15 minutes per date of imagery, but requires a high initial investment and may yield less precise values than the other methods.

No difference in estimates of snow cover in time was discerned among the methods of interpretation on the basis of one observer. This lack of difference would indicate that, once an observer has guidelines in mind as to which areas to consider snow covered, these measures can be reliably repeated at a later time.

Significant differences (a = 0.05) were noted among observers and between methods when four observers used the dot and squares grid methods to determine percent of areal snow cover. The differences among observers indicated that individuals have different interpretations of snow covered areas despite following the same guidelines for interpretation.

The results of the tests among the four observers indicated that interpretation of snow cover from ERTS-1 imagery was not necessarily a matter of distinguishing black from white. Specific problems encountered were: the imagery often varied in density and contrast within and among the dates of interpretation; differing types and densities of vegetation frequently caused snow covered areas to appear in differing shades of gray; patchiness of snow cover created problems in deciding whether an area was snow covered; poor illumination due to shadowing effects resulted in misinterpretations of snow covered areas; and, in addition to totally preventing interpretation, clouds also created problems on dates when cloud cover was not severe enough to prevent interpretation.

Comparison of ERTS-1 and Snow Survey Data

On the basis of a paired *t*-test, no difference (a = 0.05) was found between estimates of percent snow cover obtained from a mean of values from all four methods of interpretation of ERTS-1 imagery and from low-altitude aerial snow surveys. These results are in accordance with those from a study designed to compare measures of snow cover from ERTS-1 imagery and from low-altitude aerial snow surveys over the entire Salt-Verde Watershed (Barnes *et al*. 1972). These results would indicate that an experienced observer familiar with a particular watershed could obtain comparable measures of snow cover extent from ERTS imagery and aerial reconnaissance.

Barnes _et al_. (1974) noted that more detail can be mapped from ERTS-1 imagery than from low-altitude aerial reconnaissance. Results of this study also showed snow cover being mapped in more detail from ERTS-1 imagery than from snow surveys. However, this does not necessarily imply that greater accuracy can be obtained in mapping snow cover from ERTS imagery. The lack of detail on low-altitude snow survey maps may simply be a function of the time the observers chose to spend mapping rather than an inability to map in detail.

Relationship Between Snow Cover and Runoff

To determine whether a relationship exists between areal snow cover and subsequent runoff, it was first necessary to select the beginning of the snowpack depletion period. The general trend of the snow cover data appeared to indicate a decline in snow covered area beginning on February 18, 1973. Therefore, this date was arbitrarily chosen as the beginning of the snowpack depletion period.

A significant linear relationship (a = 0.05) was determined to exist between areal snow cover and subsequent runoff during the snowpack depletion period, based on four observations of areal snow cover from ERTS-1 imagery. The relationship is:

$$\hat{Y} = 5.2(10^5) + 2.7(10^5)\ X$$

where $\hat{Y}$ = subsequent runoff in cubic meters;

X = areal snow cover in square kilometers.

The coefficient of determination (r^2) was 0.995.

As mentioned earlier, measures of snow cover from ERTS-1 imagery and from low-altitude aerial snow surveys were similar. Therefore, data from the two sources were combined to assess what effect an increased amount of snow cover data would have on the regression analysis. The general trend of the combined snow cover data appeared to indicate a decline in areal snow cover beginning on February 15, 1973, the data arbitrarily chosen as the beginning of the snowpack depletion period.

A significant linear relationship was also found to exist between areal snow cover and subsequent runoff during the snowpack depletion period, based on nine combined observations of areal snow cover from ERTS-1 imagery and low-altitude aerial snow surveys.

The above-mentioned regressions, which do not differ significantly from each other, indicated that a highly significant relationship existed between the tested variables. Therefore, the increased amount of areal snow cover data available from the two sources did not change the results of the regression based on data from ERTS-1 imagery alone.

The results of the regression relationships appear encouraging for using measures of areal snow cover obtained from ERTS-1 imagery for snowmelt runoff forecasting, especially residual volume forecasting. However, the analysis should be viewed with some restraint. The limited amount of source data might not have accurately monitored changes in areal snow cover. Temperature variations in Arizona cause the snowpack to advance and recede many times throughout the winter. For example, measures of areal snow cover from ERTS-1 imagery indicate a peak in extent of areal snow cover in February or March, but snow course measurements of water equivalent throughout the Salt-Verde Watershed indicated that the peak seasonal snowpack occurred in early April (Barnes et al. 1974). It is possible that measures of areal snow cover from ERTS-1 imagery may have been too infrequent to detect the peak accumulation.

Another possible limitation of the data was that it represented a year with a near record snowfall. Therefore, the regressions between areal snow cover and subsequent runoff may have been influenced by the unusual nature of the winter, possibly limiting their overall usefulness.

A technical difficulty encountered in use of ERTS-1 imagery was the time necessary to obtain the imagery. A minimum wait of two weeks was common after an order was submitted. If attempts were made to use ERTS imagery in real-time monitoring changes in areal snow cover, this delay would have to be overcome.

SUMMARY

1. Nearly one-half of the scans of ERTS-1 imagery analyzed over the study period were obscured by cloud cover, which may preclude dependence on satellite imagery, by itself, for monitoring snow cover depletion in Arizona.

2. Differences among observers in estimating areal snow cover suggests difficulty in using ERTS imagery for this purpose unless an observer is familar with the area.

3. None of the methods of interpretation employed to measure areal snow cover could be ruled unusable, with the method to be used dependent on the investment to be made, the level of precision desired, and whether a map of snow cover extent is wanted.

4. Estimates of areal snow cover from ERTS-1 imagery were similar to comparable estimates obtained by low-altitude aerial reconnaissance.

5. A significant relationship between snow cover and subsequent runoff during the snowpack depletion period for the year of study suggests that measures of areal snow cover obtained from ERTS imagery may become a valuable tool in forecasting snowmelt runoff in Arizona.

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