MEASURING SNOW COVER FROM ERTS IMAGERY ON THE BLACK RIVER BASIN

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INTRODUCTION

The increase in demand for water and the construction of multipurpose reservoirs to regulate snowmelt runoff in the western United States requires accurate streamflow forecasts. Such forecasts are needed to schedule allowable releases from reservoirs with assured refil (Leaf and Haeffner 1971).

In the Rocky Mountains, most streamflow results from snowmelt. However, the processes which produce runoff from snowmelt are varied and complex (Leaf 1971). As a result, relatively simple relationships have been derived which empirically relate important factors in the hydrologic cycle to snowmelt runoff. Included in these relationships are correlations between areal snow cover depletion and streamflow.

Many investigators have attempted to use snow cover depletion-runoff relationships for streamflow forecasting (U.S. Army 1956, Brown and Dunford 1956, Thoms 1961, Ffolliott and Hanson 1968, Leaf 1971, Meier 1973). Results of these investigations indicate that areal snow cover depletion measurements have the potential to improve various snowmelt runoff forecasting techniques. Despite its potential, use of areal snow cover depletion measurements in runoff forecasting has been limited because of the difficulty in obtaining measures of areal snow cover (Meier 1973).

Recently, the possibility of using imagery from the Earth Resources Technology Satellites (ERTS) for measuring areal snow cover has been explored. These satellites operate continuously, repeating scans of an area every nine days. ERTS offers small scale imagery while maintaining high resolution (Rango et al. 1974).

DESCRIPTION OF STUDY

A study was initiated to determine if ERTS imagery could be used to monitor changes in areal snow cover in east-central Arizona. The objectives were to:

(1) determine whether ERTS imagery could be interpreted for areal snow cover by use of manual or semi-manual methods of interpretation that could be available to those who would use snow cover data:
(2) determine whether quality ERTS imagery could be obtained frequently enough to monitor changes in areal snow cover; and
(3) compare estimates of snow cover from ERTS with estimates obtained from low-altitude aerial mapping of snow cover.

The Black River Watershed above the Black River Pumping Station, an area of 1450 square kilometers, was chosen as the study site. This watershed is an important water producing area in Arizona, with seasonal flow averaging 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. Soils have igneous materials, almost exclusively, as parent material. The watershed is almost totally basaltic in respect to geologic formation. Elevations range from 3533 meters at the top of Mt. Baldy to 1745 meters at the Black River Pumping Station.

The ERTS-1 satellite, launched on July 23, 1972, was the data source. The ERTS data was converted to, and analyzed in, an imagery format. Specifically, multi-spectral band 5 (0.6-0.7 Mm) was used because previous studies have shown this band to be the most effective for determining snow cover (Barnes and Bowley 1973, Evans 1974, Rango et al. 1974).

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The scale of imagery used in three of the methods of interpretation was 1:1000000. A watershed overlay delineating the Black River Watershed at 1:1000000 scale was developed to facilitate interpretation of only the desired areas.

The time period analyzed was November 2, 1972, to May 1, 1973. A near record snowpack existed in Arizona over this period (Barnes and Bowley 1974).

Snow covered areas were determined on the ERTS imagery by comparison of the brightness level on the watershed with the boundary of the snowpack. If areas within the watershed appeared brighter than areas at the boundary of the snowpack, they were judged snow covered. When not obliterating view of the snowpack on the watershed, 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 from the ERTS imagery. The first three methods viewed black-and-white transparencies at a 1:1000000 scale on a light table. The first method employed was a simple dot grid method. A dot grid with fifty dots per square centimeter, viewed under a microscope at 7X power, was used to obtain a measure of percent snow cover on the watershed.

A second method of interpretation utilized a grid of squares six millimeters per side. These squares were on a sheet of clear mylar. Snow cover within each square overlaying the watershed was estimated to the nearest multiple of twenty percent. These estimates were then multiplied by the area of the full or partial square, and the resulting numbers were summed and divided by the total area of the watershed to obtain an estimate of percent of areal snow cover.

A densitometer was used for the third method of interpretation. The densitometer views the imagery, splits the shades of gray into twelve discrete levels, and projects the image on a television-like screen. Attempts were made to have a given set of twelve discrete levels occupy the snow covered area on the photo by calibrating the densitometer to each particular photo. Percent area that was snow covered could then be read off directly.

Finally, black-and-white positive transparencies with a thirty-five millimeter format were made from seventy millimeter negative transparencies for use in a projection-planimeter method of interpretation. The watershed was projected to a 1:250000 scale base map because of the difficulty of planimetering at a 1:1000000 scale. Once the watershed projection was fitted to a 1:250000 scale base map, the snowpack boundary was drawn. The snow covered area was then planimetered and divided by the total area of the watershed to obtain an estimate of percent snow cover.

Areal snow cover estimates on the Black River Watershed were made by one observer using all four methods of interpretation to test for differences among techniques and differences in time of observations. Estimates of areal snow cover using the dot and squares grid methods were made by four observers to test for differences among observers and between methods. To test for differences, split plot analysis of variance tests were evaluated at a 95 percent significance level.

Aerial snow surveys were frequently flown by the Salt River Project in the winter of 1972-73 because of the near record snowpack and the transient characteristics of the snowpack. Values of percent snow cover on the Black River Watershed were obtained from snow survey maps, developed from these low-altitude surveys, by planimetering the snow covered area and dividing by the total area of the watershed. A paired t test evaluated at 95 percent significance level was used to test for differences between estimates from snow surveys and estimates from ERTS.

RESULTS AND DISCUSSION

Arizona has more days per year suitable for aerial photography than any other state (Avery 1968). Despite this advantage, only six of eleven possible imagery dates could be interpreted for snow cover, with clouds obscuring all or significant portions of the Black River Watershed on the other dates.

Significant differences were detected among the four methods of interpretation on the basis of one observer. A Student-Newman-Keul multiple range test at a 95 percent significance level was used to determine which methods differed (Table 1).

TABLE 1. -- Differences among four methods of snow cover interpretation on the basis of one observer.

Densitometer Method	Dot Grid Method	Squares Grid Method	Projection-Planimeter Method
- - - - - - - percent of areal snow cover over the six dates analyzed - - - - - - -			
69	71	72	74

NOTE: line under means indicate not significantly different.

Each of the methods of interpretation used has advantages and disadvantages. The dot and squares grid methods required approximately twenty-five minutes per date of imagery and requires only a light table for interpretation. The densitometer yields an estimate of snow cover in the least amount of time, approximately fifteen minutes per date of imagery, but requires a high initial investment and may yield less precise values than the other methods. The projection-planimeter method yields a map of the snow cover extent but required approximately forty-five minutes per date of imagery for interpretation. A Zoom Transfer Scope is needed with the projection-planimeter method if more accuracy is needed than can be obtained from the available imagery (Wiesnet and McGinnis, Jr. 1974).

No difference in estimates of percent 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 what areas to consider snow covered, these measures can be reliably repeated at a later time.

Differences were noted among observers and between methods when four observers used the dot and squares grid methods to determine percent of areas snow cover. The differences among observers indicate that individual observers have different interpretations of snow covered areas despite having followed the same guidelines for snow covered area interpretation. The difference between the dot and squares grid methods may indicate indecision as to which areas were snow covered. Previous tests on the basis of one observer, familiar with the imagery, indicated no difference between dot and squares grid methods.

The results of the tests among the four observers indicate that interpretation of snow cover from ERTS imagery is not necessarily a simple matter of distinguishing black from white. Specific problems were encountered in the interpretation of snow cover. The ERTS imagery varied in density and contrast within and among the dates of interpretation. Differing types and densities of vegetation often cause snow covered areas to appear in differing shades of gray. Patchiness of snow cover may create problems in deciding whether an area is snow covered. Poor illumination due to shadowing effects may cause an observer to misinterpret snow covered areas. Clouds, in addition to totally preventing interpretation, can also create problems on dates when cloud cover is not severe enough to prevent interpretation. Problems in interpreting ERTS imagery for snow cover were not unique to this study, as other investigators have encountered similar problems (Barnes and Bowley 1974, Meier 1973).

No differences were found between estimates of percent snow cover on the Black River Watershed obtained from low-altitude aerial snow surveys and estimates from ERTS imagery. These results would indicate that an experienced observer who was familiar with a particular watershed could obtain comparable measures of snow cover extent from aerial reconnaissance and ERTS imagery.

A specific difficulty encountered in use of ERTS imagery was the time necessary to obtain the imagery. Normally, a minimum two weeks wait was encountered 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.

CONCLUSION

None of the methods of interpretation of ERTS imagery for snow cover could be ruled unusable by the results of this study. The particular method a user would ultimately choose to use would depend upon the investment he cared to make, the level of precision he desired, the time he cared to spend in interpretation, and whether he wanted a map of snow cover extent.

ERTS imagery, by itself, cannot effectively be used to monitor changes in areal snow cover in Arizona. Arizona snowpacks are shallow, intermittent, and large changes in areal snow cover can occur rapidly (Warskow 1971). To serve any functional purpose in monitoring changes in snow cover depletion, reliable estimates may need to be determined for periods of twenty-four hours or shorter during the snowmelt season. At the present time, the two Earth Resources Technology Satellites repeat scans of an area every nine days. In this study, nearly one half of the possible dates of observation were obscured by cloud cover. The possibility of not obtaining an estimate of areal snow cover for weeks at a time may preclude dependence on ERTS for monitoring snow cover depletion in Arizona.

Differences among observers in estimating percent snow cover indicates difficulty in using ERTS to measure areal snow cover. However, if an observer is familiar with an area, he may be able to obtain estimates of snow cover from ERTS that are quite similar to estimates of snow cover obtained by low-altitude aerial reconnaissance. In this way, estimates of snow cover from ERTS imagery may be used in combination with estimates of snow cover obtained from aerial snow surveys to monitor changes in extent of snow cover.

Any use of ERTS imagery for measuring changes in areal snow cover is dependent on the turn-around time for obtaining ERTS imagery. If ERTS imagery cannot be obtained within twenty-four hours after its scan of an area, the snow cover information obtained from ERTS may be limited in practical application.

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