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OPERATIONAL USE OF LANDSAT IMAGERY FOR THE ESTIMATION OF SNOW AREAL EXTENT

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ABSTRACT

Quantification of the surface area of snow covering watersheds can be a useful parameter in estimating snow water content for inclusion in water runoff prediction equations. This paper documents an operational manual interpretation technique which allows fast and accurate estimates to be made of the areal extent of snow parameter using LANDSAT-1 imagery. The analysis procedures and the statistical results are presented in this paper.

INTRODUCTION

One of the most easily detected of all resources from Earth orbiting satellites is snow. Investigators have proposed that relationships could be developed between snow-cover depletion and water runoff (Leaf, 1969)and in more specific terms, between snow-cover depletion and snow water content. Investigators have shown that areal extent of snow in specific vegetation, elevation and aspect relationships can be cost-effectively related to the actual snow water equivalent for a given area using snow survey data collection systems similar to those in use in many areas (Thomas, 1974; Thomas and Sharp, 1974). Since relationships such as the ones described above have been developed using areal extent of snow to provide the major portion of the information to be used in water runoff equations, techniques had to be developed which would provide fast, economical, and accurate estimation of this parameter. The following research deals with the development of techniques for estimation of snow areal extent.

Using conventional aerial photography as the data base for obtaining snow areal extent information would obviously prove extremely costly if this necessitated covering entire watersheds on a sequential basis. Satellite imagery, more specifically LANDSAT-1 satellite imagery, could provide the data base, relatively inexpensively and on a repetitive basis. In order to quantify areal extent of snow, techniques were developed which analyzed the imagery for areal extent of snow based on reflectance and such parameters as elevation, vegetation and aspect. The technique describes a relatively simple procedure which none-the-less provides very solid quantitative results.

PROCEDURE

The estimation procedure described in the following pages is based upon analyses of imagery defined by artificial units (grids). This technique differs substantially from the snow mapping approach reported in the literature (Barnes and Bowley, 1969; Rango and Foster, 1975; Rango, Salomonson, and Foster, 1975-Wiesnet, 1974), where the snowpack boundary is delineated directly. The procedures developed allow the image analyst to make decisions in discrete units of the imagery as to the areal extent of snow based upon such factors as density and type of vegetative cover, elevation, aspect, actual reflectance of the snowpack, and by inference (i.e., by the presence of directly observable snowpack). These techniques also provide for the direct application of appropriate statistical methods for the estimation of the true areal extent of snow, as well as providing a means of determining the precision of that estimate.

LANDSAT-1 imagery in the form of simulated color infrared enhancements of bands 4, 5, and 7 was used for the interpretation procedures. These enhancements were made from individual 9-1/2 inch LANDSAT-1 black-and-white positive transparencies and combined using a technique developed at the Remote Sensing Research Program (Katibah, 1973). Consequently, enhanced imagery of just that portion of the LANDSAT-1 frame desired could be produced with excellent quality. Use of this technique also provided original enhancements directly on negative color film so that high quality reflection prints could be produced for interpretation purposes.

Snow Areal Extent Inventory

During the spring of 1973, the LANDSAT-1 satellite provided essentially cloud-free coverage of the Feather River Watershed on April 4, May 10, and May 28. On these (or at the most, two days thereafter) random transects were flown across the watershed using a 35 mm camera to acquire large scale aerial photography that could be used as an aid in determining the actual snow condition on the ground (i.e. "ground truth").

To estimate the areal extent of snow, the LANDSAT-1 images were gridded with image sample units (ISU's), each equaling 400 hectares (Figures 1, 2, 3, and 4). These image sample units were then transferred to the large scale photography where applicable. The image sample units on the large scale photography were coded as follows:

Code	Snow Cover Class	Midpoints
1	No Snow present within the ISU	0
2	0-20% of ISU covered by snow	.10
3	20-50% of ISU covered by snow	.35
4	50-98% of ISU covered by snow	.74
5	98-100% of ISU covered by snow	.99

The gridded LANDSAT-1 images were then interpreted, sample unit-by-sample unit, and coded using the following method to account for vegetation cover and density and to some degree, aspect, elevation and slope as they impact snow cover.

Scale matched simulated color infrared enhancement of LANDSAT-1 imagery were produced for April 4, 1973; May 10, 1973; May 28, 1973 and also for August 31, 1972 in reflection print form. The April and May dates represent the snowpack and were gridded, while the August 1972 date, representing a cloud-free summer image, was not gridded. The purpose of the August date was to provide a clear aerial view of actual ground relationships of vegetation/terrain features. The August date was superimposed with each of the snowpack dates using a mirror stereoscope. By blinking first one eye and then the other, the image analyst could observe what conditions actually occurred on the ground in the image sample unit he was interpreting for snowpack. Obviously this technique capitalizes on the human image analyst's ability to synthesize large amounts of pertinent data and quickly arrive at a decision.

The image analyst, using this technique, spent three hours training himself to interpret the LANDSAT-1 imagery. The April 4th date comprising 2218 image sample units was subsequently interpreted in nine hours, the May 10th date (2050 image sample units) in six hours, and the May 28th date (2013 image sample units) in three hours. The decrease in interpretation time can undoubtedly be related to the increasing experience of the analyst and the decreasing snowpack.

The LANDSAT-1 interpretation results were compared to the coded large scale photography where applicable. Tables I, II, and III summarize the interpretation test results. The sample unit-by-sample unit interpretation of the LANDSAT-1 image was then used to find the estimate for the areal extent of snow in the watershed. Totals for each of the individual snow cover classes were found and multiplied by 400 hectares, the area of each image sample unit on the ground. This gave the hectares for each class; these values were then multiplied by the appropriate snow cover class midpoints to give the total hectares of snow in each class. Finally, these totals were added to give the estimated areal extent of snow. See Table IV.

The areal extent of snow thus calculated was based solely upon the LANDSAT-1 interpretation results. To correct this estimate, the image sample units where snow areal extent "ground truth" was obtained (from large scale aerial photographs) were compared with the same image sample units on the LANDSAT-1 imagery. The relationship between the snow areal extent values on these corresponding LANDSAT-1 and "ground truth" sample units is the basis for the application of the ratio estimator statistical technique (Cochran, 1959). This technique not only provides a correction for the original interpretation estimate, but also allows for an estimate of the precision of this technique through the application of confidence intervals. The confidenece intervals around the areal extent of snow estimates were calculated for four different levels of confidence 99%, 95%, 90% and 80% for comparative purposes. The confidence intervals are expressed in hectares (Table V).

It is desirable to check and see if the values in the snow cover class from the LANDSAT-1 image data come from the same statistical probability distribution as the values in the snow cover classes from the large scale photography data. If they come from the same distribution, it may be expected that our estimation procedure will provide good results. If there were also a way to lump snow cover classes to improve the indications that the two sets of values came from the same distribution, this would give some idea on how to improve the estimation procedure in the future. To perform such probability distribution likeness tests, a Chi-square statistic,

$$\chi^2 \sim \sum_{i=1}^{k} \frac{(Oi-Ei^2)}{Ei} ,$$

was used. The values in the snow cover classes from the large scale photo data were designated as the expected values (Ei), since they were assumed to be "ground truth". The values in the snow cover classes from the LANDSAT-1 image data were designated as the observed values (Oi). For each date a Chi-square test was run, using the data as recorded versus the data with snow cover classes 4 and 5 combined, to see if an improvement in class widths could be realized.

Results of the Snow Areal Extent Inventory

The results of this inventory are summarized in the following tables of interpretation results, statistical computations (including areal extent of snow estimates, variance of areal of snow estimate, population ratio estimator, etc.), confidence intervals and allowable errors found in the following pages.

Tables I, II, and III deal with April 4, May 10, and May 28 interpretation data respectively. Table IV deals with the results of the ratio estimator statistic on all three dates. Table V deals with the confidence intervals associated with the areal extent of snow estimates on all three dates.

Conclusion of Snow Areal Extent Inventory

Improvement in the snow areal extent inventory, as it is currently done is possible by increasing the sample size and by optimizing the image sample unit size.

The Student's-t statistic reaches its smallest value when the degrees of freedom (sample size minus one) are approximately 120. In subsequent inventories using this approach, each date for which large scale aerial photography is flown should have approximately this number of image sample units definable.

One of the items that should be investigated is the optimum size of the image sample unit. Several approaches are possible as well as a combination of all of them. For instance, image sample unit size may be plotted against interpretation time, variance, or variance times cost to determine the optimum image sample unit shape and size under those constraints.

The one improvement that by itself can substantially decrease the width of the confidence intervals is that of decreasing the sample variance. As already shown, the April 4 data had the smallest variance, the May 10 data had the next smallest and the May 28 data had the largest. The reason for this progressive increase in sample variance most likely can be attributed to the decrease in the snow pack over the three dates. The image analyst's ability to classify seems to be related to the proportion of snow cover; however, the majority of the variance may not be due to the analyst, but rather to a natural state of greater snow areal extent variability among sample units over an area defined as a watershed.

The Chi-square test indicated that on all dates the experimental set-up was adequate. Substantial improvements in matching the corresponding value distributions of the large scale photography data and the LANDSAT-1 image data were realized by lumping snow cover classes 4 and 5. This indicates that the analyst had difficulty in separating snow areal extent class 4 areas from class 5 areas. If the snow cover classes were to be redistributed (0-20%, 20-40%, 40-60%, 60-80%, 80-100% for example) the analyst might realize an improvement in his ability to classify snow cover conditions. Provided the analyst's ability to classify snow cover conditions did improve, then it would be expected that the sample variance for each set of interpretation results would go down, and consequently, the width of the confidence interval would decrease given constant sample sizes and confidence levels.

Conclusions and Recommendations

Although the nature of the data acquired by the LANDSAT-1 satellite lends itself directly to automatic computer analysis for areal extent of snow estimation, research in manual techniques can be justified by comparing the two methods of operation to one another on a cost-effective basis. Research is currently being carried out on both phases of snow areal extent estimation procedures and analyses will be conducted testing both automatic, manual and a combination of automatic and manual on a cost-effective basis.

Besides being justifiable on this basis, continued research utilizing manual techniques can provide analyses in certain circumstances where computer classification has not been sufficiently refined. Scattered cloud cover over snowpack may present some difficulty to present computer analysis; however, the human has little difficulty distinguishing the two as they appear on LANDSAT-1 imagery.

The inventory methods for areal extent of snow estimation described in this paper show great promise for providing fast, economical, and accurate inventories of snowpack extent. As it is refined, such as by optimizing image sample unit sizes and snow cover class width, estimates as to the true areal extent of snow should become more precise and should be made with greater confidence, all other factors being equal.

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TABLE I

APRIL 4, 1973 LANDSAT-1
AREAL EXTENT OF SNOW INTERPRETATION RESULTS
(ALSO LISTING OF x_i's AND y_i's)

LANDSAT-1 Image Data Snow Cover Classes	Large Scale Photo Data Snow Cover Classes: 1	2	3	4	5
1	0 0 [6]	40 [1]			
2		40 40 [10]		296 40 [1]	
3		40 140 [2]	40 140 [6]	296 140 [2]	
4			140 296 [1]	296 296 [12]	
5				296 396 [6]	396 396 [33]

TABLE II
May 10, 1973 LANDSAT-1
AREAL EXTENT OF SNOW INTERPRETATION RESULTS
(ALSO LISTING OF x_i's AND y_i's)

LANDSAT-1 Image Data Snow Cover Classes	Large Scale Photo Data Snow Cover Classes: 1	2	3	4	5
1	0 0 [4]	40 0 [4]			
2		40 40 [13]	140 40 [2]		
3		40 140 [1]	140 140 [9]	296 140 [1]	
4			140 296 [2]	296 296 [3]	
5				296 396 [5]	396 396 [8]

TABLE III

MAY 28, 1973 LANDSAT-1
AREAL EXTENT OF SNOW INTERPRETATION RESULTS
(ALSO LISTING OF x_i's AND y_i's)

	Large Scale Photo Data				
	Snow Cover Classes				
	1	2	3	4	5
1	0 0 [3]	40 0 [4]			
2	0 40 [1]	40 [16]	140 40 [1]		
3		40 140 [2]	140 140 [9]	296 140 [3]	
4			140 296 [2]	296 296 [4]	
5				296 396 [4]	

y_i x_i [f]

x_i = sample LANDSAT-1 estimate of the number of hectares of snow per cell by snow cover class = (snow cover class midpoint) (400 hectares).

y_i = sample large scale photo estimate of the number of hectares of snow per cell by snow cover class = (snow cover class midpoint) (400 hectares).

f = interpretation frequencies

TABLE IV

SUMMARY OF RESULTS
AREAL EXTENT OF SNOW ESTIMATION

		April 4, 1973	May 10, 1973	May 28, 1973
LANDSAT-1 estimate of the areal extent of snow	x	511,378	205,768	60,516
Estimate of the true areal extent of snow	$\hat{Y}_R$	501,355	195,644	57,847
Standard deviation of the areal extent of snow estimate	$\sqrt{V(Y_R)}$	12,776	14,526	17,126
Population ratio estimator	$\hat{R}$	.9804	.9509	.9559
Total number of acres inventories		879,642	813,014	798,340
Total number of image sample units inventories	N	2,218	2,050	2,013
Total number of image sample units sampled	n	80	52	49

TABLE V

CONFIDENCE INTERVAL AND ALLOWABLE ERROR STATEMENTS

AREAL EXTENT OF SNOW ESTIMATION

Level of confidence	April 4, 1973	May 10, 1973	May 28, 1973
	Confidence Interval	Confidence Interval	Confidence Interval
99%	$477{,}649 \leq Y_R \leq 545{,}107$	$166{,}897 \leq Y_R \leq 244{,}638$	$14{,}566 \leq Y_R \leq 106{,}466$
95%	$485{,}940 \leq Y_R \leq 536{,}816$	$176{,}601 \leq Y_R \leq 234{,}935$	$26{,}075 \leq Y_R \leq 94{,}958$
90%	$530{,}575 \leq Y_R \leq 532{,}651$	$181{,}423 \leq Y_R \leq 230{,}112$	$31{,}778 \leq Y_R \leq 89{,}242$
80%	$494{,}858 \leq Y_R \leq 527{,}898$	$186{,}899 \leq Y_R \leq 22{,}463$	$38{,}252 \leq Y_R \leq 82{,}781$

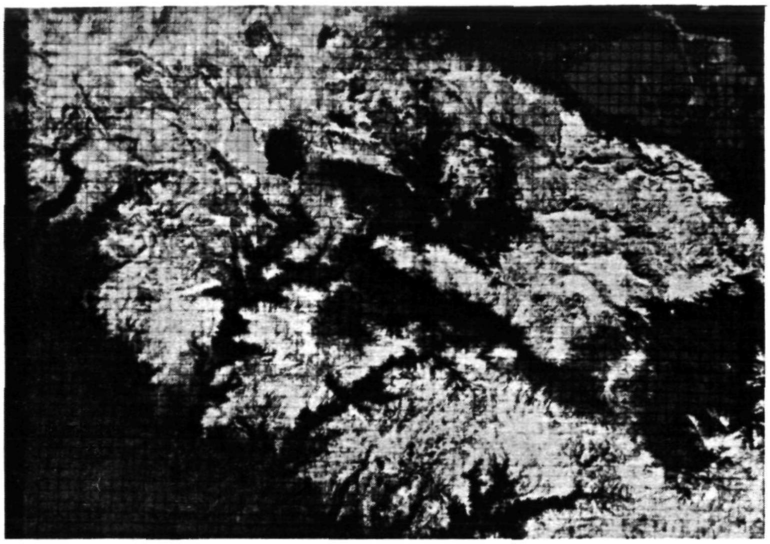

Figure I. April 4, 1973 LANDSAT-1 simulated color infrared enhancement. Image sample units (grids) = 400 hectares each.

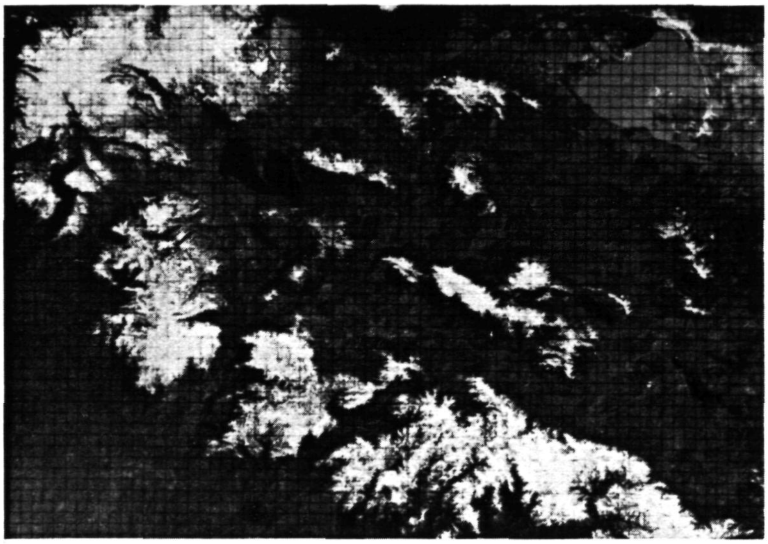

Figure II. May 10, 1973 LANDSAT-1 simulated color infrared enhancement. Image sample units (grids) = 400 hectares each.

Figure III. May 28, 1973 LANDSAT-1 simulated color infrared enhancements. Image sample units (grids)= 400 hectares each.

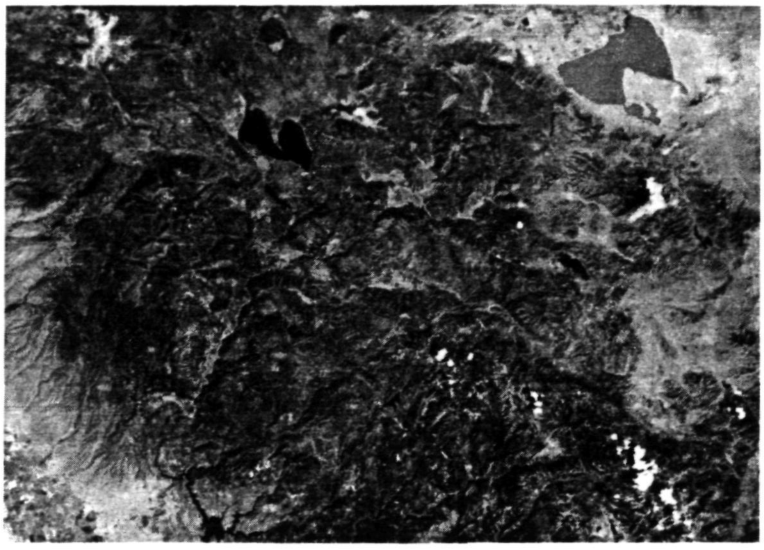

Figure IV. August 31, 1972 LANDSAT-1 simulated colored infrared enhancement. Cloud-free summer image.