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SNOW COVER MONITORING BY MACHINE PROCESSING OF MULTITEMPORAL LANDSAT MSS DATA

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ABSTRACT

LANDSAT frames were geometrically corrected and data sets from six different dates were overlaid to produce a 24 channel (six dates and four wavelength bands) data tape. Changes in the extent of the snowpack could be accurately and easily determined using a change detection technique on data which had previously been classified by the LARSYS software system.

A second phase of the analysis involved determination of the relationship between spatial resolution or data sampling frequency and accuracy of measuring the area of the snowpack.

INTRODUCTION

Climate and subsurface geology combine to make water a scarce and valuable commodity in the western United States. Most of the water supply comes from the spring and summer runoff of winter snow accumulations in the Rocky Mountains. A network of reservoirs has been constructed to conserve this resource to satisfy the water needs of urban communities and to provide water for irrigation. In addition, this water is used for generating hydroelectric power and for providing recreational facilities. The network is operated by various state and federal government agencies and private corporations.

In order to regulate these reservoirs properly, these agencies must have an estimate of both the discharge required downstream and the concommitant recharge needed from the reservoir's source, which

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in most cases is a mountain stream. The objective of this research is to investigate methods by which MSS data can be applied to the process of snow cover monitoring, thereby enabling more accurate predictions of runoff from mountain watersheds.

Since the methods to be studied may vary in time, cost and practicality of application, parameters must be established to insure that the techniques involved are economically advantageous, i.e., that similar information is provided at less cost than conventional methods or that increased cost is accompanied by additional information. To meet these objectives this analysis has purposely been kept simple and hence does not reflect the most accurate classification possible, i.e., misclassification errors in shadowed areas do occur.

Computer Aided Analysis Techniques

The Animas River watershed above Howardsville, Colorado was selected as the test site for this phase of the study because 1) it is located in the headwaters of the Colorado River, 2) it is wholly contained in the San Juan Mountain Test Site, and 3) good records exist for the gaging station at Howardsville. The watershed boundary was physically located on four USGS 7 1/2' topographic maps (see Figure 1). The boundary was defined by elevations, the stream network and the location of the gaging station in relation to the stream.

Once determined and delineated, the boundary was transferred from the map to a gray scale printout at the same scale (1/24,000), by aligning the stream networks. The watershed was then defined on the LANDSAT imagery, using a series of line and column coordinates as individual "test areas", thus providing an accurate estimation of the total area of the watershed (Figure 2).

The data for frames 1101-17203 (1 November, 1972), 1119-17204 (19 November, 1972), 1173-17202 (12 January, 1973), 1191-17204 (30 January, 1973), 1299-17205 (18 May, 1973) and 1317-17204 (5 June, 1973) were all overlaid, rotated and rescaled thereby eliminating the need for repetition of the outlining process. These frames are cloud free over the Howardsville watershed.

Figure 1. Animas River Watershed at Howardsville, Colorado

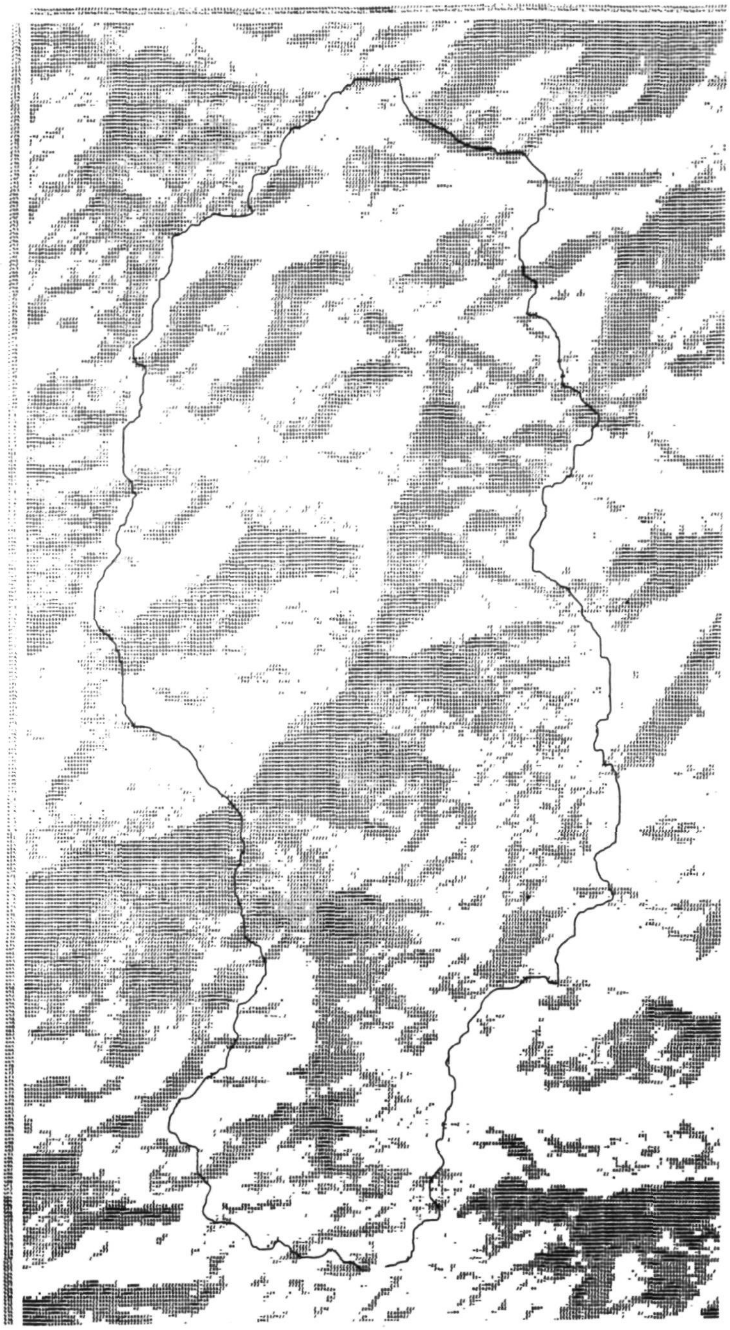

Figure 2. Location of Animas Watershed on LANDSAT Imagery

In order to ascertain the accuracy of this type of areal calculation, the relative size of a printer element must be known. Previous investigations have indicated that each LANDSAT element contains .43 hectares. Furthermore, a total of 32,405 elements was contained within the watershed, so the area was calculated to be 147 square kilometers. Since the U.S. Geological Survey had estimated the area to be 55.9 square miles (145 square kilometers) (see WSP 1925) and this coincided with an estimate obtained by planimetering the area, the error introduced by the computer tabulation and human errors in outlining the boundary was 1.5%. Band five digital display imagery for one of the frames (1119-17204) which contains the watershed is shown in Figure 3. This image consists of sixteen gray levels defined by the computer program, based on relative reflectance histograms of the area.

Figure 3. Digital Display Photograph of LANDSAT Frame 1119-17204, Band Five.

To determine the areal extent of the snow cover, two channels, (one in the visible (.6-.7μm) and one in the IR (.8-1.1μm), were used in conjunction with LARSYS. LANDSAT MSS channels four and five were generally saturated by the snow cover and the information provided by each resulted in a singular correlation matrix. This required the elimination of one of these channels in order to implement the LARSYS processor.

Two classes, "snow" and "other", were then requested from the clustering processor, to generate the statistics for these classes which are shown below in Table 1.

TABLE 1. Spectral Response of Snow

		Snow		Other	
Date	LANDSAT Band	Mean Relative Reflectance	Std. Dev.	Mean Relative Reflectance	Std. Dev.
1 Nov. 1972	5	124.73	7.01	37.29	18.21
	7	56.75	9.23	13.15	7.11
19 Nov. 1972	5	123.43	9.21	32.21	10.35
	7	54.34	10.66	18.22	6.96
12 Jan. 1973	5	121.73	11.17	31.36	10.31
	7	52.32	11.13	18.59	7.03
30 Jan. 1973	5	122.45	10.32	30.04	17.21
	7	52.70	10.78	10.34	6.72
18 May 1973	5	125.33	11.02	50.44	18.83
	7	53.50	17.42	21.12	5.50
5 June 1973	5	125.98	10.30	45.89	18.66
	7	51.72	15.26	22.30	5.90

These numbers are dimensionless and indicate the relative reflectance of each class. Note that the mean of the class snow does not vary significantly between dates and approaches the saturation level, which is 128 for band five and 64 for band seven.

Each frame was then classified separately into two classes, snow and other according to these statistics. Display maps of the classification results were obtained, along with a table showing the number of resolution elements within the watershed that were classified as snow and the percentage of snow cover (an example of this type of output is shown in Figure 4). By multiplying the number of resolution elements classified as snow by the .43 hectares represented by each resolution element or by multiplying the percentage of snow cover, the areal extent of the snowpack can be quickly and easily calculated by this computer analysis procedure.

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AUG 13,1975
07 48 41 PM
LARSYS VERSION 3

CLASSIFICATION STUDY 325548065 CLASSIFIED SEPT 12,1973

CLASSIFICATION TAPE/FILE NUMBER ... 59/ 6

CHANNELS USED

CHANNEL 2	SPECTRAL BAND 0.60 TO 0.70 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 4	SPECTRAL BAND 0.80 TO 1.10 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0

CLASSES

	CLASS	WEIGHT		CLASS	WEIGHT
1	NS- 1/	0.000	2	NS- 2/	0.000

TEST CLASS PERFORMANCE

GROUP	NO OF SAMPS	PCT. CORCT	NUMBER OF SAMPLES CLASSIFIED INTO NS- 1/	NS- 2/
1 NS- 1/	32367	76.2	24654	7713
TOTAL	32367		24654	7713

OVERALL PERFORMANCE(24654/ 32367) = 76.2

AVERAGE PERFORMANCE BY CLASS(76.2/ 1) = 76.2

Figure 4. Snow Cover Calculation

Table 2 gives a summary of the areal fluctuations of the snowpack.

TABLE 2. Snow Acreage Fluctuations

Date	Percent Snow Cover	Total Area (hectares)
1 Nov. 1972	76.1	11189
19 Nov. 1972	68.3	10037
12 Jan. 1973	62.6	9203
30 Jan. 1973	65.1	10023
18 May 1973	81.0	12471
5 June 1973	87.5	13471

Figure 5 shows the last two classification results taken from the digital display. These include that portion of the area surrounding the Howardsville watershed.

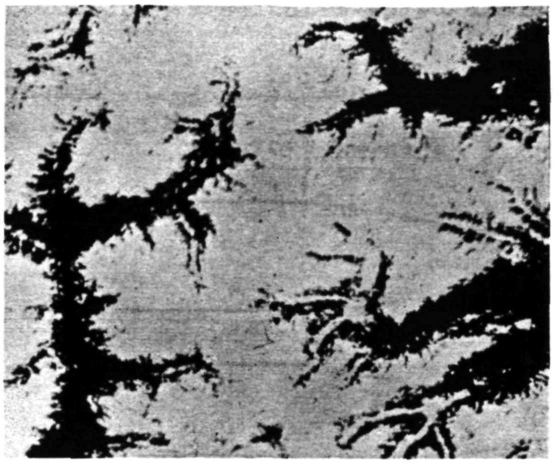
The relationship between area, snowpack density and total water content of the snowpack requires much additional study. However, LANDSAT can provide accurate, rapid measurements of the areal extent of the snowpack.

Several intervening dates between January 30, 1973 and May 18, 1973 have not been included in this investigation due to cloud conditions. Thus, this study clearly indicated that LANDSAT-1 frequency of coverage can rapidly decrease from once to every 18 days to once every 36 or 54 days, a totally unacceptable condition for studying hydrological and other dynamic phenomena.

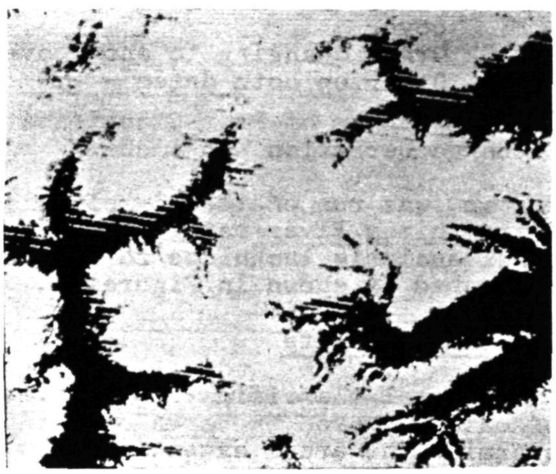
Temporal Analysis

The general technique for determining ground cover changes between two dates is known as change detection. There are at least four change detection methods; Delta Transformation, Spectral/Temporal Concurrent Classification, Spectral/Temporal Layered Classification and Post-Classification Comparison.

For this study classifications were made for the area on the various dates and then these classifications were compared. Before the classifications were attempted an overlay was made which aligned the data so a ground point could be located by the same line and column coordinates. Channels 1-4 are the first date and channels 5-8 are the second date so that two classifications exist for the same run number, the same area, but different sets of channels.



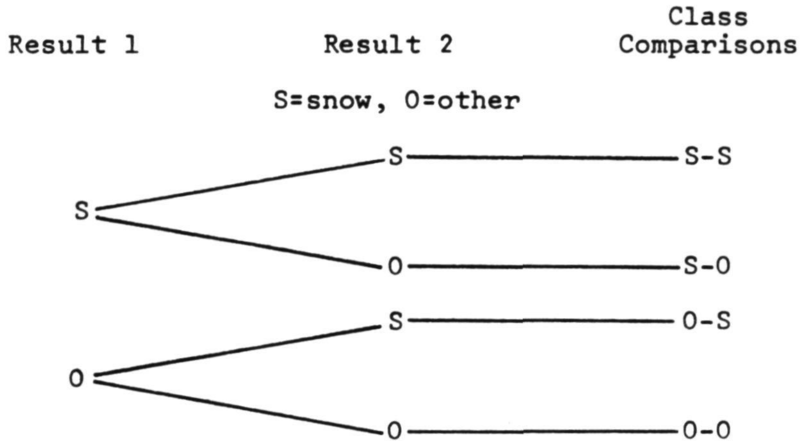
A. May 18, 1973



B. June 5, 1973

Figure 5. Classification Results

This program was used to analyze the snow classification results as an aid to analyzing redistribution patterns of snow within watersheds and to display the results as a third 4-class classification. Figure 6 below illustrates this process.



S-S Snow cover on both dates
S-O Snow cover changing to non-snow cover
O-S Other changing to snow cover
O-O Other on both dates

Figure 6. Flow Diagram of Post-Classification Change Detection Technique

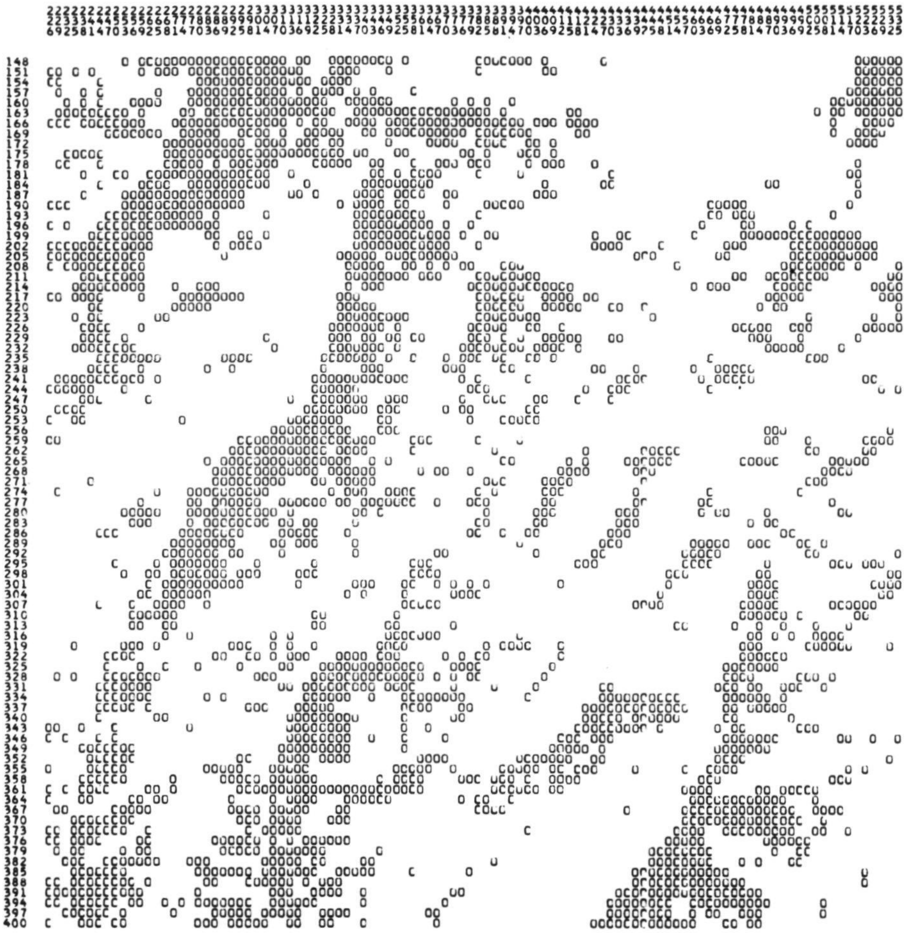
This program, was run on the six classification results from the Animas River watershed. An example of this temporal analysis technique for a portion of the Animas watershed is shown in Figures 7, 8 and 9.

Classification Sampling Rate

The multispectral classification of enormous quantities of data gathered by earth orbiting satellites (to determine the areal extent of snow cover), requires a relatively large amount of computer CPU (Central Processing Unit) time. The purpose of this phase of the investigation was to compare the accuracy of the multispectral classification of snow cover using different data sampling rates in order to reduce the amount of computer processing time.

CLASSES

SYMBOL	CLASS	WEIGHT		SYMBOL	CLASS	WEIGHT	
	NS- 1/	C.000	Snow	0	NS- 2/	0.000	Other

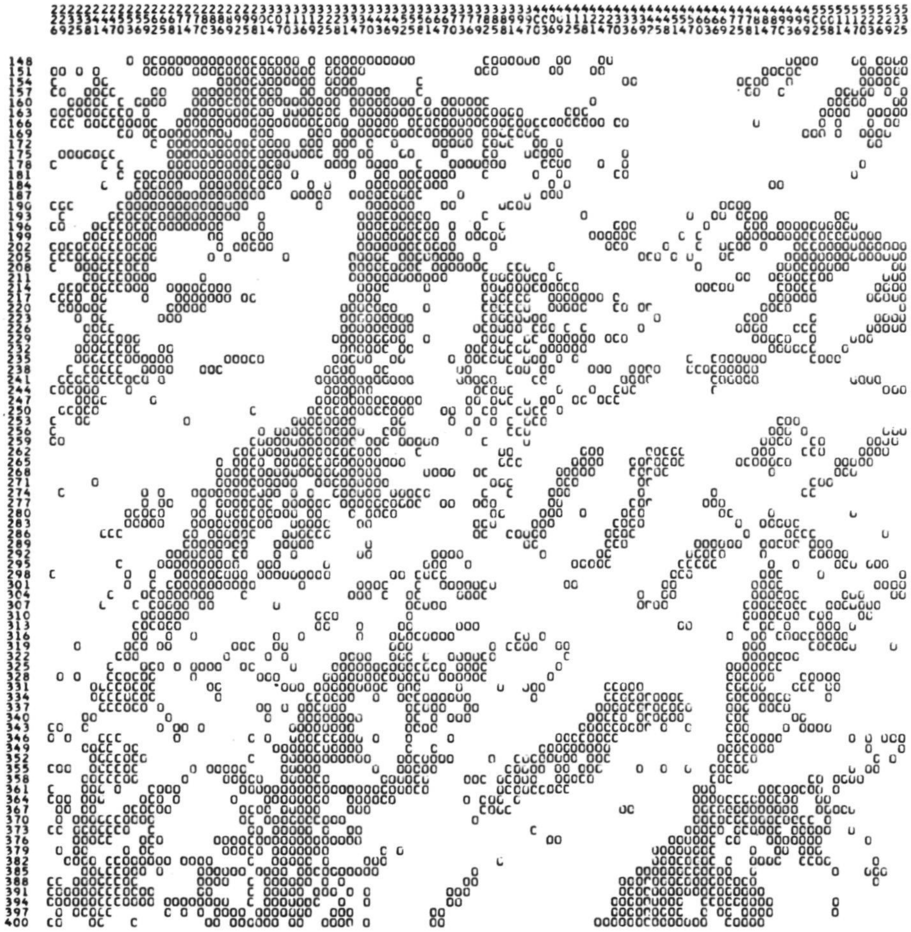


NUMBER OF POINTS DISPLAYED IS 9435

Figure 7. Snow Map for November 1, 1973

CLASSES

SYMBOL	CLASS	WEIGHT		SYMBOL	CLASS	WEIGHT	
	NS- 1/	0.000	Snow	0	NS- 2/	0.000	Other

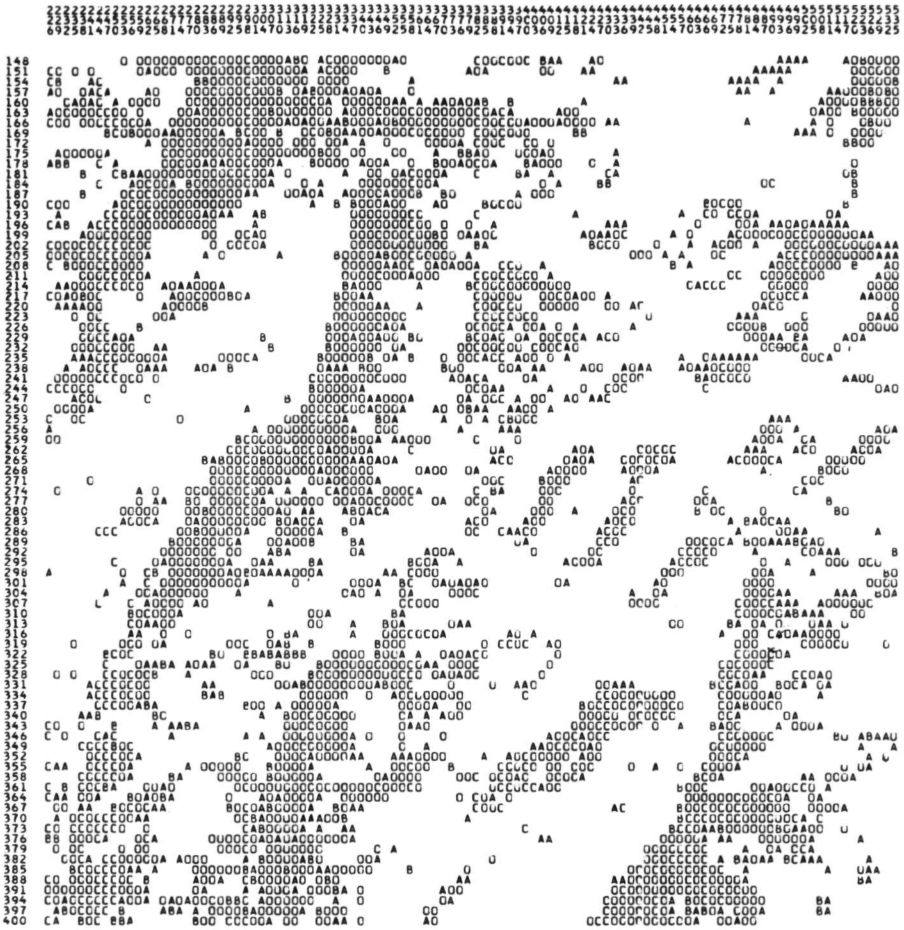


NUMBER OF POINTS DISPLAYED IS 9435

Figure 8. Snow Map for November 19, 1973

CLASSES

SYMBOL	CLASS	WEIGHT	SYMBOL	CLASS	WEIGHT
	SNO-SNO	0.000	B	OTH-SNO	-.000
C	OTH-OTH	0.000	C	*CHANGE*	0.000
A	SNO-OTH	0.000			



NUMBER OF POINTS DISPLAYED IS 9435

Figure 9. Change Detection Map for November 1-19, 1973

Approximately 60% of a LANDSAT-1 MSS frame (scene ID 1317-17204) was classified into four spectral classes (one snow class and three non-snow classes) using bands 5 and 6. In essence, five classifications of the area were performed each at a different data sampling rate. Then, the areal extent of the snow cover was computed for each one of the five classifications. Table 3 shows the percent of the area classified as snow cover and the corresponding CPU time used by each one of the five different data sampling rate classifications. Note in Table 3 that the difference between the area of snow for the 1x1 and 16x16 sampling rates is only 0.4 of one percent.

TABLE 3. Determination of Areal Extent of Snow Cover from LANDSAT MSS Data using Different Sampling Intervals

Sample Interval	Number Data Points	Number of Points Classified as Snow	% of Area in Snow	Classification CPU* Time (minutes)
1 x 1	4,330,561	1,385,126	31.99	54.34
2 x 2	1,083,681	345,417	31.87	13.20
4 x 4	271,441	86,433	31.84	4.21
8 x 8	68,121	21,646	31.78	1.52
16 x 16	17,161	5,422	31.60	0.65

*IBM 360 Model 67

Figure 10 shows a graph of the CPU time involved in the classification of snow cover versus the data sampling rates.

Statistical analysis of the results shown in Table 3 has indicated that the percent area of snow-cover determined by the 16x16 data sampling rate is not significantly different from the percent area covered by snow as determined by the 1x1 data sampling rate at both a 95% and 99% confidence level. In other words, the 31.60% area (in Table 3) is not statistically different from the 31.99% area, even though the sample number was decreased from over 4 million points to just over five thousand data points.

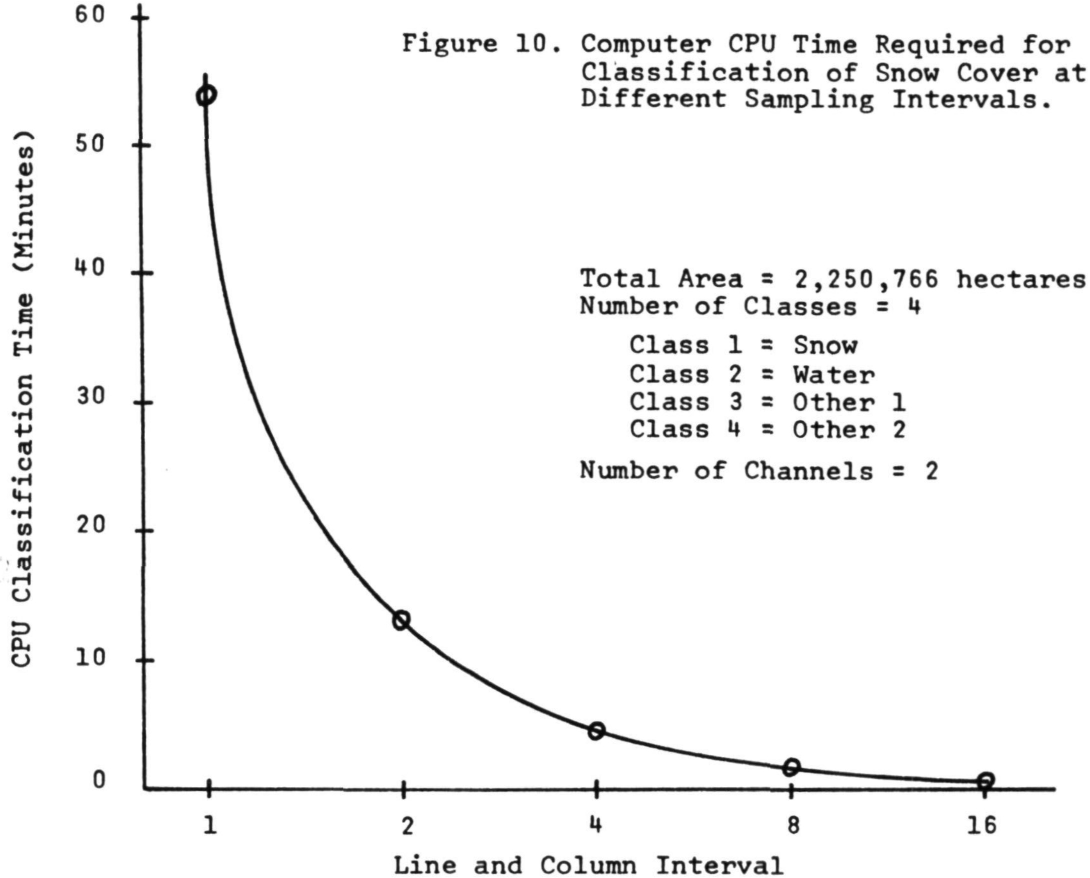


Figure 10. Computer CPU Time Required for Classification of Snow Cover at Different Sampling Intervals.

Conclusions

Six LANDSAT frames over the test site were overlaid, geometrically corrected and rescaled. The dates ranged from November 1, 1972 through June 5, 1973. Computer processing techniques were utilized to make an accurate determination of snow cover within a watershed at a scale of 1:24,000. A post-classification change detection processing technique determined and located changes in snow cover. For large geographic areas, snow cover can be accurately mapped without incurring the cost of classifying every data sample.