

**DIGITAL SNOW MAPPING TECHNIQUE USING LANDSAT DATA AND
GENERAL ELECTRIC IMAGE 100 SYSTEM**

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ABSTRACT

The need for rapid and reliable snow mapping using LANDSAT and future satellite data has been identified. In this study a technique and procedures using General Electric IMAGE 100 system were derived for performing a snow cover analysis of small watersheds for quasi-operational application.

The study area was the Wind River Mountains of west central Wyoming. A small watershed, namely, Dinwoody Creek was selected as a test site. LANDSAT data and U-2 imagery was used in the analysis.

From a minimal snowcover LANDSAT scene, multispectral analysis was performed yielding the distribution of forest, bare rock, grassland, water and snow within the watershed. The forest and bare rock themes were saved and registered with other scenes containing greater snow cover. Likewise, elevation contours from a digitized map were stored and superimposed over the snowpack areas. Analysis of the distribution of the snowcover is facilitated by superimposing the themes and map. For any one watershed the themes (forest, bare rock and grassland) and map are constant.

Different techniques, i.e., contrast stretching, single channel slicing and multispectral signature extraction were investigated to differentiate snow types. Area measurements of the snow classes and other watershed themes were obtained. The technique and procedures derived from the study were applied to the watershed for other dates. From the receipt of the digital LANDSAT tapes, approximately three quarters of an hour have been required for a snowcover analysis.

As a result of this work, it is feasible for small watersheds to have snowcover analysis performed by digital pro-

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cessing in a rapid and reliable manner. The receipt of such timely snowcover analysis by the operational agencies will aid in their management function in the control of reservoirs and in water supply forecasting.

INTRODUCTION

Several agencies participating in operational application of satellite snowcover observations are currently using photographic interpretation. In the future, the processing of satellite digital data may prove to be more economical and reliable. Hence, this study was conducted. The prime purpose of the study was to develop a technique for snowmapping by processing digital satellite data. This has been achieved by using NASA LANDSAT digital data (computer compatible tapes) as a data source, the Dinwoody watershed, Wind River, Wyoming as a test site and the General Electric IMAGE 100 multispectral analyzer as a digital processor. In using the LANDSAT data, its multispectral data provides information in four separate bands. This information when analyzed multispectrally, defines features such as forest, water, snow, grassland and rocks within the LANDSAT imagery. Through the interactive computerized system, rapid and reliable processing of the multispectral data relative to the watershed is obtained. Using the technique developed, several LANDSAT scenes containing the watershed during the snowmelt season (May-June) were analyzed providing area measurements of the snow. These area measurements and analysis time were compared with other techniques using density slicing of single bands and manual photographic interpretation.

OBJECTIVES

Briefly, the objectives of the study were:

- Show the feasibility of using a multispectral analysis technique for snowmapping using LANDSAT digital data
- Define and test a procedure for rapid and reliable snowmapping of watersheds
- Define requirements for improving processing for snowmapping multiple watersheds

STUDY AREA

The Wind River Mountain Range of west central Wyoming has been extensively snowmapped in recent years at the Goddard Space Flight Center (GSFC) (Ref. 1 & 2). Information relative to ground truth, aerial photography, LANDSAT data and analysis was

available thus making this area appropriate to be studied. Within this area, there are seven watersheds (see Figure 1). The selection of the Dinwoody Creek watershed on the northeast slope of the range was the focus of the study. The watershed has an average elevation above 10,000 feet and an area of approximately ninety-two (92) square miles. The geology (Ref. 2) in the Wind River Mountain consists of metamorphic and platonitic rocks of precambrian ages and limestone, sandstone and granitic lithologies. The climate varies with altitude, being semi-arid at the base of the mountains and alpine at the summits. Snowfall fluctuates according to elevation and topography; generally the highest elevations receive in excess of 150 inches (380cm) a year. The vegetation below 10,000 ft. (3050m) is mostly coniferous with Douglas Fir near the base and Lodgepole Pine and Western Spruce Fir forest dominating the higher slopes. Above 10,000 feet (3050m) the vegetation consists of alpine meadows and herbaceous plants and shrubs. In Figure 2, a view looking along Dinwoody Creek depicts the environment within the watershed.

DATA SOURCES

The data sources for this study consisted of four LANDSAT scenes, U-2 high altitude infrared photography (1974, 1975) and Soil Conservation Service snow survey measurements (1973, 1974, 1975). The four LANDSAT scenes are identified as:

July 27, 1974	-	ID1734-17271
May 16, 1974	-	ID1667-17283
June 21, 1974	-	ID1698-17283
May 29, 1975	-	ID5040-17145

This LANDSAT information was received in digital form on computer compatible tapes (CCTs). The information on the tape is in four multispectral ranges. These ranges are two visible bands $.5-.6\mu m$ and $.6-.7\mu m$ and two near infrared bands $.7-.8\mu m$ and $.8-1.1\mu m$.

APPROACH

Multispectral Analysis

The General Electric IMAGE 100 multispectral image processing and analysis system was used in this study to perform the digital data processing. The prime concept of the IMAGE 100 system design is the operation of a man-machine interface.



WIND RIVER MOUNTAIN, WYOMING
 LANDSAT-AUG. 6, 1972 (REF. 2) WATERSHEDS

FIGURE 1.



WORKING SCENE, MINIMAL SNOWCOVER,
 JULY 27, 1974, DINWOODY WATERSHED

FIGURE 4.



WIND RIVER MOUNTAIN RANGE, DINWOODY
CREEK

FIGURE 2.

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A DEC PDP-11 computer, with standard peripherals is used as the system process controller. The system has the capability of storing 4 eight-bit video channels of imagery, and in addition, eight theme channels. The IMAGE 100 uses a television compatible format of 512 x 512 picture elements (pixels) to put the storage requirements at approximately 10 million bits. LANDSAT digital data can be entered from computer compatible tapes into the refresh memory, or photographic transparency data can be entered via the video scanner and analog to digital converter subsystem. A variety of preprocessing, multispectral analysis, and theme synthesis functions are accomplished under interactive operator-computer control.

In operation, a user specified training area is delineated on the displayed image through the use of an adjustable electronic cursor. The multispectral gray levels within the training area are automatically measured and their limits are used to define a four-dimensional parallelepiped in spectral space. The entire image is scanned pixel by pixel and compared to the parallelepiped limits. All pixels which are located within the bounds defined by the training data are classified or alarmed and displayed on the monitor as a color map. If after a few iterations of the basic training and classification procedure, the operator is not satisfied with the results, other sophisticated procedures may be used. One of these is the histogram analysis. Each time the system performs a parallelepiped training, it stores complete histogram data for each of the four spectral channels. The operator can call these data to be displayed on the graphics terminal and alter any of the parallelepiped limits as defined on the histograms.

Once the classification results have been achieved, they are stored on one of the eight binary theme channels to form a thematic map. The operator can proceed to a new area by loading the refresh memory with new data. For subsequent analysis, he can rely on spectral signatures or parallelepiped limits previously derived by recalling them from storage or reentering them.

METHODOLOGY

Presently, operational snowmapping techniques require the determination of the snowline elevation of the determination of the snowcovered area of a watershed. Little emphasis has been placed upon mapping classes of snow and surface features of a watershed relative to operational snowmapping. Currently, work is being performed on the latter (Ref. 4). Knowledge of the distribution of these land use types; forests, bare rock areas, grassland, and water and shadow areas, may be useful in solving interpretation problems encountered in snowmapping. In addition,

if runoff equation or models become more refined in future years, it might be useful to know what percent of a given land use type is snowcovered.

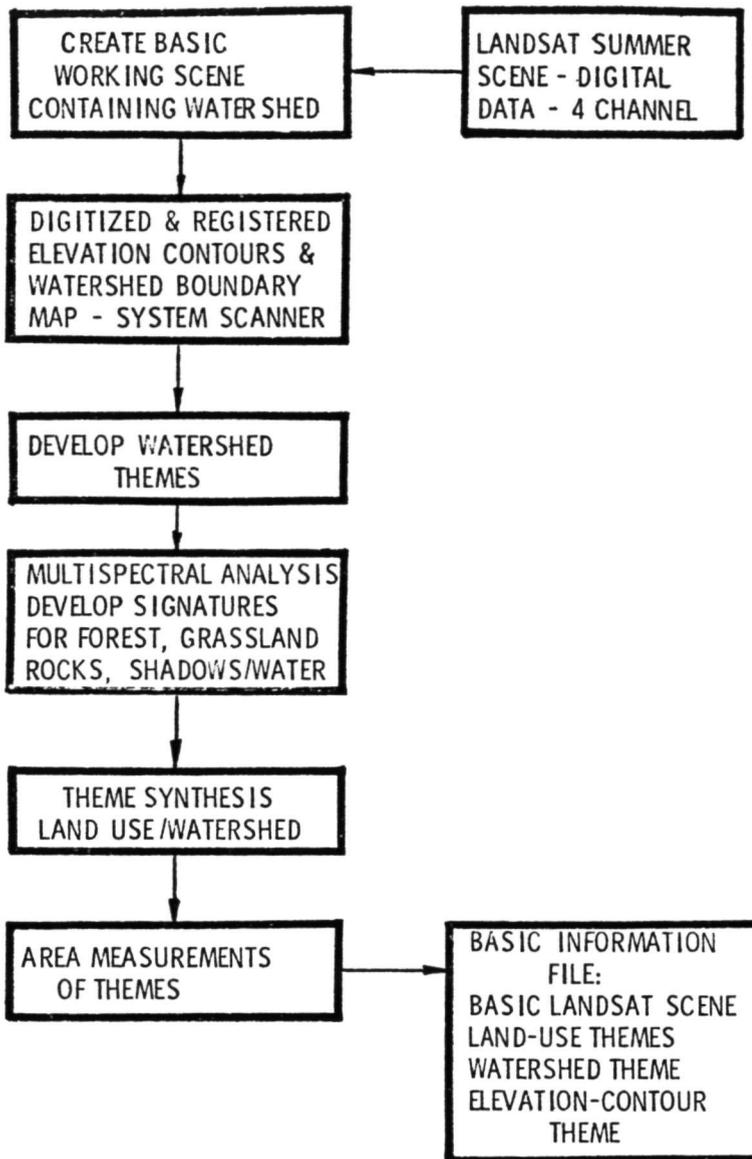
Based upon the above considerations, the technique for digital snowmapping was devised to have two parts. The first part of the technique has a permanent (basic) part and the second part an operational (quasi-operational) part. The basic part is accomplished only once for a watershed. It will remain constant and be used repetitively with the quasi-operational part for snowmapping. Items included in the basic part are digitized watershed boundary maps with elevation contours and watershed surface feature themes (forest, rocks, meadows, shadows/water). The quasi-operational procedures deals primarily with determination of snow area and the snow line.

Basic Part--In Figure 3, the basic part of the technique is schematically shown. A LANDSAT scene having a minimum of snowcover was selected for extracting multispectral signatures of surface features within the watershed. The LANDSAT data source used was dated July 27, 1974, ID1734-17271. A working scene was created using the data from LANDSAT computer compatible tapes (CCT). This working scene, Figure 4, contained the Dinwoody watershed. Elevation contours and watershed boundaries from a tracing were digitized and registered with the working scene Figure 5. This tracing was made from a 1:250,000 USGS map having contour intervals at 200 feet. Two themes were developed, the elevation contours Figure 5 and the watershed Figure 6.

Signature extraction of surface features in the watershed using multispectral analysis was performed. Signatures for forest, grassland, rocks and shadow/water were obtained, classified and assigned as themes. Extraction of the signatures was aided by information from U-2 high altitude photography. This photography assisted in selection of training areas containing surface features to be classified. Verification of the working scene classification was accomplished by comparing with the U-2 photography.

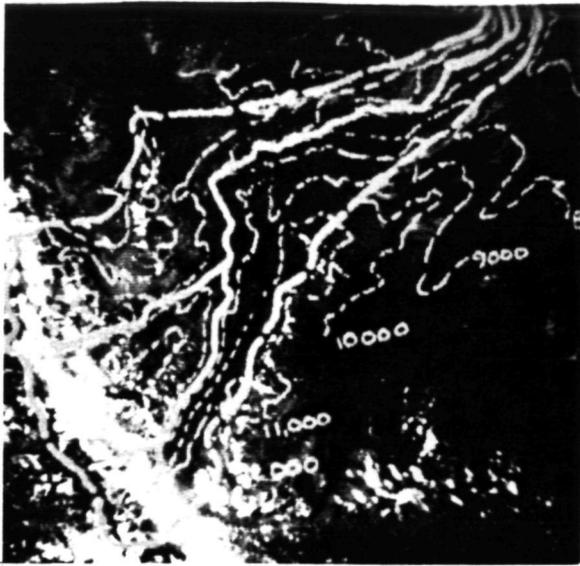
Theme synthesis provided surface feature themes relative to the watershed. Area measurements for these themes were obtained and their percentages to the watershed calculated.

A basic file consisting of four channels of LANDSAT July 27, 1974 data and one channel of themes (elevation contour/surface features/watershed) were stored on magnetic tape. This file is



BASIC INFORMATION PART

FIGURE 3



DIGITIZED ELEVATION CONTOUR AND
WATERSHED BOUNDARY, DINWOODY WATERSHED
FIGURE 5.



DINWOODY WATERSHED
FIGURE 6.

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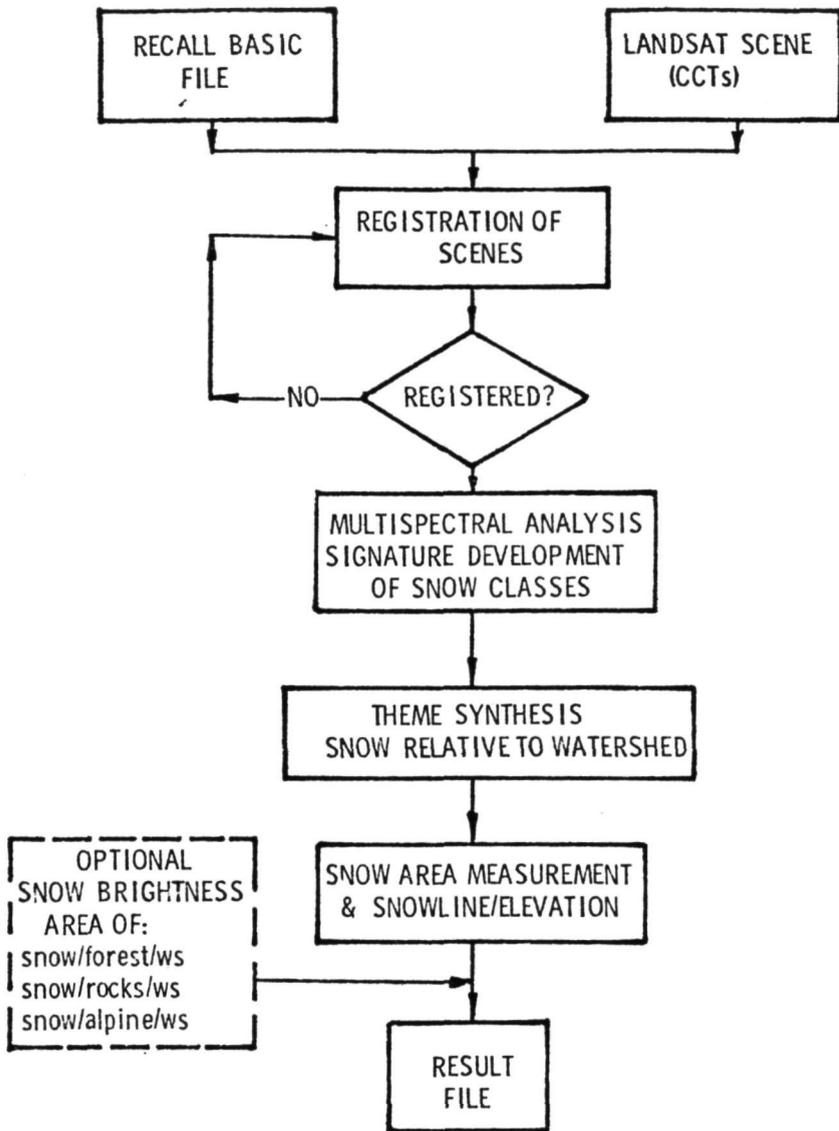
permanent, containing information constant to the watershed. This information is the reference for registration of other LANDSAT data sources and for recalling surface feature themes.

Quasi-Operational Part -- In Figure 7, the quasi-operational part of the technique is shown. Initially, the basic file information is recalled into the system. This included the original LANDSAT scene and the themes (surface features, watershed map). Registration of the two LANDSAT scenes is accomplished in an iterative mode. Registration of a single point of a working scene can be obtained by a pixel. For the complete working scene, experience has shown that registration accuracy varies from 2 to 10 pixels. Once registration is complete, All LANDSAT information for the scene to be analyzed is called into the system. Basic themes are saved. The next step is the analysis of the snowcover by multispectral analysis. The training sites were selected for areas of the snow-pack having different spectral signatures. They are located in bright or heavy snow areas, in mottled areas where the forest is concealing most of the snow, in areas where the snow is melting, and in areas where bare rock or ground is protruding through the snowcover. Classes of snow area determined from these training sites using all four channels of LANDSAT data. After the determination of the classes, the total snow class is obtained. By performing theme synthesis, snowcover classes are acquired within the watershed. As an option, snow in forested areas, snow over rocks or snow in shadows/water can be obtained. At this point, area measurements of the snow classes are obtained. Another option is selecting particular snowcover sites and obtaining brightness values of snow (in all four LANDSAT bands). If the option is not selected, a result file is made with the snow classes on magnetic tape.

Brightness values (spectral reflectance recorded by LANDSAT multispectral scanner) may be useful in discriminating snow classes along the snowline. It has been considered that snow which appeared less reflective near the snowline was indicative of "melting". In Ref. 3, it was noted that further research is required to confirm melting snow. In lieu of this, the availability of brightness values relative to characteristic of the snow may have little value but they do help in defining the snow edges.

RESULTS

- LANDSAT digital data of July 27, 1974, Figure 3, (minimal snowcover) of the Wind River Mountain Range, Wyoming was processed by the General Electric IMAGE 100 system. This processing by multispectral analysis defined the surface feature signatures such as forest, rock, grassland



SNOWMAPPING QUASI-OPERATIONAL ANALYSIS

FIGURE 7

and shadows/water within the Dinwoody watershed. Through the system scanner, an elevation contour and watershed boundary map was digitized and registered with the LANDSAT scene. Theme synthesis provided the surface features relative to the watershed. Area measurements of these surface features and the watershed are shown in Table 1.

- The LANDSAT data of July 27, 1974, the surface feature themes, the elevation contour map theme and the watershed theme were used as reference for processing other LANDSAT data during the snowmelt season (May-June) for the Dinwoody watershed. Multispectral analysis of four dates of LANDSAT data has provided estimates of total snow area within the Dinwoody watershed (Figures 8, 9, and 10). Several classes of snow were obtained by the multispectral analysis. In this study, no attempt was made to correlate the physical significance of these snow classes. At this time, significance is placed on two classes of snow; the main snowpack and the snow edges. In Figure 11, classes of snow are shown. In Table 2, the snow area and percentage of snow in the watershed is shown and compared with area measurements derived by manual interpretation. The manual interpretation, is based upon mapping the snowline and measuring the area of the snow above the snowline with a planimeter.
- In Figure 5, the elevation - contour map theme is superimposed over the LANDSAT May 16, 1974 scene. This capability allows for the quick estimate of the snow line location relative to the elevation contour lines. For the LANDSAT May 16, 1974 scene, the snowline is observed between the 8000 - 10,000 foot contours and is estimated to be at 9000 feet.
- From this study, an estimate of the amount of snowcover within the watershed surface features is possible. In the case of the LANDSAT, May 16, 1974 scene, the estimate of the snowcover within forested areas in the watershed is 3511 pixels or 6.6% of the watershed. See Table 3 for other snowcover/surface feature percentages.
- A quasi-operational technique has been developed to snow map the Dinwoody watershed, Wyoming. This technique requires thirty to forty-five (30 to 45) minutes to obtain the basic information of:

DINWOODY WATERSHED
WIND RIVER MOUNTAIN RANGE, WYOMING

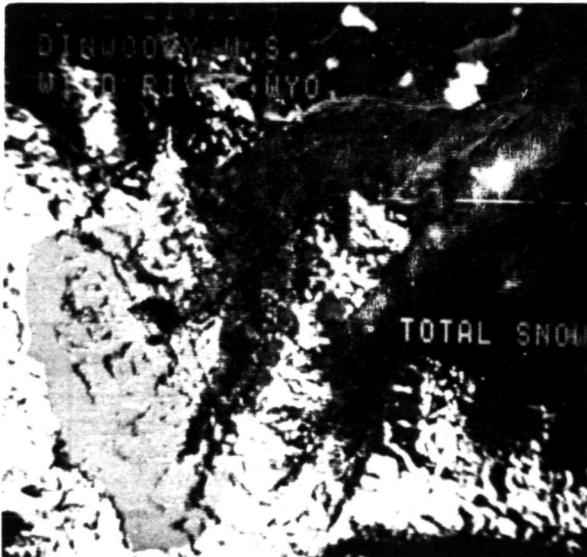
LANDSAT SCENE: JULY 27, 1975

TABLE 1

THEMES	AREA MEASUREMENTS			PERCENT OF WATERSHED
	pixels	miles ²	kilometers ²	
WATERSHED	52650	92.5	239.6	
BARE ROCK	28031	49.2	127.5	53.2
FOREST	6213	10.9	28.3	11.8
GRASSLAND	2699	4.7	12.3	5.1
SNOW	8920	15.7	40.6	16.9
SHADOWS/WATER	1301	2.3	5.9	2.5



SNOWCOVER - MAY 16, 1974
DINWOODY WATERSHED
FIGURE 8.



SNOWCOVER - JUNE 21, 1974
DINWOODY WATERSHED
FIGURE 9.

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SNOWCOVER, MAY 29, 1975 DINWOODY
WATERSHED

FIGURE 10



TWO CLASSES OF SNOW, MAY 29, 1975
DINWOODY WATERSHED

FIGURE 11

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DINWOODY WATERSHED
WIND RIVER MOUNTAIN RANGE, WYOMING
SNOW AREA MEASUREMENTS

TABLE 2

LANDSAT DATA SOURCE	TOTAL SNOW AREA MEASUREMENTS			PERCENT OF WATERSHED *	MANUAL INTERPRETATION % OF WATERSHED •
	pixels	miles ²	kilometer ²		
May 29, 1975	44155	77.6	200.9	83.9	88.
June 21, 1974	15466	27.2	70.4	29.4	52.
May 16, 1974	37484	48.3	125.1	71.2	85.
July 27, 1974	8920	15.7	40.6	16.9	

DINWOODY W. S. AREA = 52650 PIXELS

- Based on count of pixels defined multispectrally as snow.
- Interpretation based on mapping the snow line and measuring the percentage of the basin above the snow line.

DINWOODY WATERSHED
WIND RIVER MOUNTAIN RANGE, WYOMING
LANDSAT SCENE: MAY 16, 1974

TABLE 3

SNOW RELATIVE TO WATERSHED SURFACE FEATURE	AREA MEASUREMENTS			PERCENT OF SNOW COVER
	pixels	miles ²	kilometers ²	
SNOW/FOREST	3511	6.1	15.8	9.4
SNOW/ROCK	22095	38.8	100.5	58.9
SNOW/GRASSLAND	2527	4.4	11.5	6.7

TOTAL SNOW COVER: 37484 pixels

- classes of snow and snow areas/watershed
- total snow area/watershed
- snow line elevation estimate

The technique also allows for estimating the amount of snow over watershed surface features.

The Wind River Mountain Range contains several watersheds. In Figure 1, seven watersheds are shown. Applying this quasi-operational technique, an estimate of fifteen hours (15) of processing time would be required to provide basic snow information for all seven watersheds.

At the present time, General Electric, Beltsville, has implemented a bulk processing relative to LANDSAT data. This capability, with other software refinements, is estimated to reduce the processing time to approximately five (5) hours for the Wind River Mountain Range watersheds.

CONCLUSIONS

A digital snowmapping technique using LANDSAT data and the General Electric IMAGE 100 system has been implemented. This technique was tested several times on snowmapping the snow areas and snow lines of the Dinwoody watershed in the Wind River Mountain Range in Wyoming. Signatures of snow classes were rapidly determined by multispectral analysis. Area measurements of snow classes were instantaneously achieved by electronically counting the classified snow pixels. Greater detail in area measurement is obtained through the multispectral analysis rather than manual interpretation. This is because there are snow free areas within the snowpack which are too numerous and minute to measure accurately with a compensating planimeter, but these small melt areas or wind blown areas can be accounted for with the automatic planimeter function of the GE IMAGE 100 system. As compared to the manual technique, machine processing is less laborious and tedious. The average time required to process a single LANDSAT working scene to obtain snowcover and the snowline was three quarters of an hour. Repetitive processing of the Dinwoody watershed would reduce this processing time.

In addition to snow areas and snow lines, this technique has devised methods of estimating the snow distribution over watershed surface features. Presently, this distribution is not needed in operations but may prove to be of value with development of

sophisticated snowmelt models. Other possible uses of this technique is in conjunction with snow surveys. Data derived from the analysis of the snowpack may assist in location of new snow course or modifications to existing courses. Correlation studies could be performed by superimposing snow courses over working scenes and obtaining radiance values at the course locations. These radiance values and snow course measurement could be correlated.

This technique has been referred to as quasi-operational. In the true sense of an operational technique, bulk processing of LANDSAT scenes and the methods described in this paper must be incorporated into the IMAGE 100 system. The bulk processing has been implemented. Software development to expedite watershed boundary delineation and registration is required. This capability will reduce the processing time significantly; with the Wind River Mountain Range (seven watersheds) a conservative estimate of five hours will be required for acquisition of snowcover areas.

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