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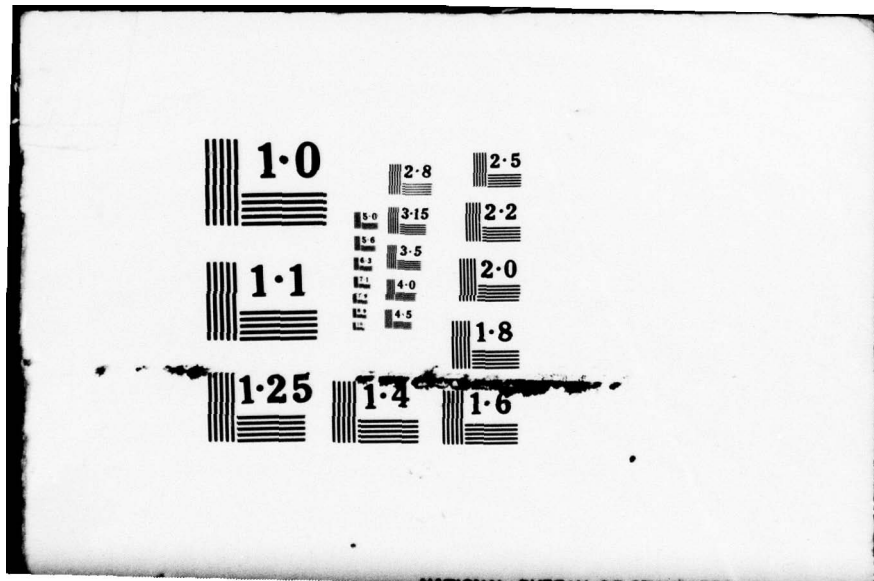
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COMPUTER PROCESSING OF LANDSAT DIGITAL DATA AND SENSOR INTERFACE DEVELOPMENT FOR USE IN NEW ENGLAND RESERVOIR MANAGEMENT.

10 Carolyn J./Merry Harlan L./McKim

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A preliminary analysis of Landsat digital data using the NASA GISS computer algorithms for an 11 February scene of the upper St. John River Basin, Maine, showed that the total radiance of pixels contained in three snow courses varied from 5.34 to 7.74 mW/cm <sup>2</sup> sr for a water equivalent of approximately 24.1 cm (9.5 in.) of water. This correlation between radiance values and water equivalent of the snowpack still needs to be tested. A multispectral signature was developed with an accuracy of 75% for a wetlands category in the Merrimack River		

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estuary. Low-water reservoir and flood water stages were mapped from grayscale printouts of MSS band 7 for 27 October 1972 and 6 July 1973, respectively, for the Franklin Falls reservoir area, New Hampshire. Two snow pillow transducer systems for measuring the water equivalent of the snowpack in northern Maine were interfaced and field tested. A water quality monitor interfaced to the Landsat DCS was field tested in northern Maine and transmitted the following water quality information: pH, dissolved oxygen, river stage, water temperature and conductivity. A thermocouple system was successfully interfaced and field tested at Sugarloaf Mountain, Maine. Temperature data from the surface to a depth of 30 m (100 ft) were transmitted through the Landsat DCS. Also, a tensiometer/transducer system to measure moisture tension and soil volumetric moisture content was successfully interfaced to the Landsat DCS.

PREFACE

This report was prepared by Carolyn J. Merry, Geologist, and Dr. Harlan L. McKim, Research Soil Scientist, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. The study was funded by the Water Control Branch of the U.S. Army Engineer Division, New England, under NASA Landsat-2 Follow-On Investigation 22510, The Use of the Landsat Data Collection System (DCS) and Imagery in Reservoir Management and Operation, Saul Cooper, Principal Investigator.

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CONTENTS

	<u>Page</u>
Introduction . . . . .	1
Background . . . . .	1
Hydrologic parameters. . . . .	1
Part I. Digital Processing of the Landsat CCT's. . . . .	2
Introduction . . . . .	2
Description of the Landsat CCT's . . . . .	2
Description of the computer algorithm . . . . .	2
Computer data handling and analysis . . . . .	5
Snow Cover Analysis. . . . .	6
Literature review . . . . .	6
Approach. . . . .	7
Selection of site. . . . .	7
Snow course data . . . . .	8
Results and discussion. . . . .	11
Wetlands Mapping . . . . .	20
Literature review . . . . .	20
Approach. . . . .	21
Results and discussion. . . . .	21
Mapping of Flooded Areas . . . . .	25
Literature review . . . . .	25
Approach. . . . .	26
Results and discussion. . . . .	26
Part II. DCP Sensor Interface Development . . . . .	30
Introduction . . . . .	30
Snow pillows . . . . .	30
Water quality monitor. . . . .	30
Thermocouple interface . . . . .	34
Tensiometer/transducer system interface. . . . .	35
Summary and Conclusions . . . . .	35
Snow cover analysis . . . . .	35
Wetlands mapping . . . . .	37
Mapping of flooded areas . . . . .	37
DCP sensor interface development . . . . .	37
Recommendations . . . . .	38
Future Plans. . . . .	38
Literature Cited. . . . .	40
Appendix A . . . . .	45
Appendix B . . . . .	47
Appendix C . . . . .	50



## ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	The concept of the four-dimensional "color" space used in the computer classification algorithm.	4
2	Site location map for the imagery analysis.	7
3	Snow depth and water equivalent data for selected snow courses in the Dickey-Lincoln School Lakes Project, Maine, during the 1972-73 winter season.	9
4	Location map of the Allagash B, Beech Ridge and Ninemile B snow courses.	10
5	Computer classification printout of the Allagash B snow course.	12
6	Computer classification printout of the Beech Ridge snow course.	13
7	Computer classification printout of the Ninemile B snow course.	14
8	Computer classification printout showing four snow cover/vegetation classes.	18
9	Location map of the two training sites used in the wetlands mapping analysis.	22
10	Computer classification printout of wetlands for the Merrimack River estuary.	24
11	Grayscale printout of the Franklin Falls reservoir area, 27 October 1972.	28
12	Grayscale printout of the Franklin Falls reservoir area, 6 July 1973.	29
13	Circuit diagram of the snow pillow interface used in the 1975-76 winter season.	31
14	Water equivalent of snow data for the 1975-76 winter season.	32
15	Circuit diagram of the snow pillow interface used in the 1976-77 winter season.	32
16	Water quality data from the St. John River.	33



TABLES

<u>Table</u>		<u>Page</u>
I	Snow course data.	11
II	Average multispectral signatures (mW/cm <sup>2</sup> sr) for the three snow courses.	16
III	Input multispectral signatures (mW/cm <sup>2</sup> sr) for the four snow cover/vegetation classes.	17
IV	Snow cover/vegetation classes mapped from the 11 February 1973 CCT.	17
V	Average multispectral signatures (mW/cm <sup>2</sup> sr) for the wetlands and water categories.	23
VI	Areal extent of water within the Franklin Falls reservoir area on 27 October 1972 and 6 July 1973.	27
VII	Arrangement of the 28 thermocouples in four banks.	34
VIII	Typical data from the tensiometer/transducer inter- face system.	36

## INTRODUCTION

### Background

The U.S. Army Engineer Division, New England (NED) and the Cold Regions Research and Engineering Laboratory (CRREL) have been involved in the Landsat Data Collection System (DCS) and Landsat imagery analysis since the launch of ERTS-1, now known as Landsat-1, in July 1972 (Cooper et al. 1975). During the Landsat-1 experiment CRREL participated in the LCS studies by developing sensor interfaces for the Landsat data collection platforms (DCP's) and evaluating system performance of DCP installations. During the last two years (1975-1977) of the Landsat-2 program CRREL was involved in the digital processing of the Landsat computer compatible tapes (CCT's) and in sensor interface development for the DCP.

The primary objectives of the NED/CRREL Landsat-2 imagery analysis were: 1) to evaluate mapping the extent of snow, and 2) to determine if a relationship exists between the water equivalent of the snowpack and the radiance obtained from Landsat digital data. If a general relationship is identified, the correlation of water equivalent in the snowpack with multispectral signatures developed from the CCT's may be useful in estimating the amount of spring water runoff. Secondary emphasis in the imagery analysis part was on delineation of wetlands and flood waters in New England. Other secondary emphasis in the total Landsat-2 program was on developing and evaluating sensor interfaces for use in obtaining environmental and hydrologic data in near-real time using the Landsat data collection relay system.

Symposia, conferences and other meetings where the results of the Landsat-2 program have been presented are listed in Appendix A.

### Hydrologic parameters

A coordination committee comprising personnel from NED, CRREL and the University of Connecticut originally reviewed the hydrologic parameters that would affect reservoir operation and management. The most significant hydrologic parameters influencing reservoir operation and management are:

- Snow cover (areal extent, water equivalent correlation)
- Soil moisture regimes
- Wetlands delineation
- Slope/topography
- Ice cover
- Flooded areas

The hydrologic parameters selected for detailed Landsat imagery analysis using the Landsat digital data were snow cover and delineation of wetlands and flooded areas.

## PART I. DIGITAL PROCESSING OF THE LANDSAT CCT'S

### INTRODUCTION

#### Description of the Landsat CCT's

The Landsat satellites (Landsat-1 and Landsat-2) circle the earth in a 920-km (572-mile) near-polar orbit once every 103 minutes, each completing approximately 14 orbits per day. The multispectral scanner (MSS) on each satellite is a line scanning device which uses an oscillating mirror to continuously scan perpendicular to the spacecraft (NASA 1976). Six lines are scanned simultaneously in each of four spectral bands for each mirror sweep, and radiation is sensed simultaneously by an array of six detectors in each of four spectral bands from 0.5 to 1.1  $\mu\text{m}$  (NASA 1976). During image data processing at the NASA Goddard Space Flight Center a black and white photographic data product can be produced of an area approximately 185 km (115 miles) on a side for the following spectral regions: MSS band 4 (0.5-0.6  $\mu\text{m}$ ), MSS band 5 (0.6-0.7  $\mu\text{m}$ ), MSS band 6 (0.7-0.8  $\mu\text{m}$ ) and MSS band 7 (0.8-1.1  $\mu\text{m}$ ). This information is also available in digital form on a CCT and can be obtained from NASA.

The standard Landsat CCT was computer-processed to produce a geometrically corrected tape with observations transformed to a UTM (Universal Transverse Mercator) projection. This geometrically corrected CCT comprises 2432 scan lines with each scan line covering 3200 pixels\* (Ungar 1977). Differing levels of radiant energy for each pixel within the scene are registered on a scale from 0 to 127 (minimum to maximum) for bands 4, 5 and 6 and 0 to 63 for band 7 (Thomas 1975).

#### Description of the computer algorithm

The geometric correction of the digital data and the computer classification algorithms used in the analyses were developed at the NASA Goddard Institute for Space Studies (GISS) (Ungar 1977). The geometric correction provides for a 1:24,000 scale computer printout which enables one to more accurately locate test sites. The computer classification algorithms developed for analysis of the digital data allow for both components of the data, each of the four wavelength bands and associated energy value for each pixel, to be evaluated when classifying the Landsat data in various categories. In addition, atmospheric corrections have been applied to the Landsat digital data (Ungar 1977).

The Landsat MSS observation (pixel) may be thought of as a point in a four-dimensional "color" space, where the values along each axis

---

\*Picture element, representing an area on the ground having dimensions of 61 x 76 meters.



represent the radiant energy received by the satellite in one of the four bands (Fig. 1a). Observations lying in a similar direction from the origin in this four-dimensional color space are said to be similar in color regardless of their total radiant energy. The distance (length) of an observation from the origin is a measure of the total radiance associated with that data point. The algorithm is primarily designed to combine observations that are similar in color into the same classification category. There is provision for evaluating brightness differences and for weighting these differences in with the color discrimination when constructing the classification categories.

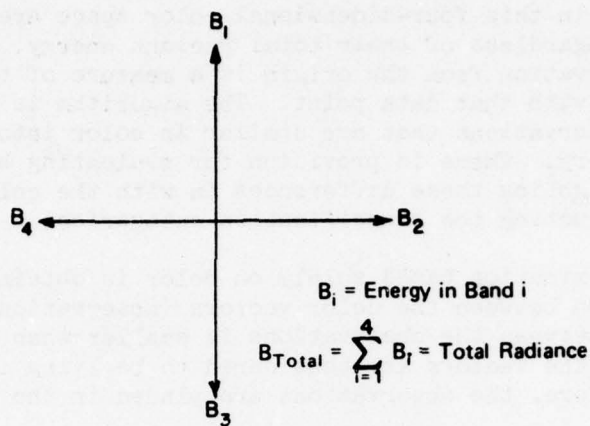
Discrimination based solely on color is obtained when the difference in direction between the color vectors (observations) is examined. If the angle between the observations is smaller than some user-defined *criterion*, the vectors are considered to be lying in the same direction and, therefore, the observations are placed in the same category.

There are two modes in which this classification scheme may be employed: supervised and unsupervised. In the supervised mode the user specifies a *signature* (the energy distribution in the four Landsat bands). If an observation lies within a solid angle smaller than the user-defined criterion,  $\delta_{\max}$ , it is said to belong to the category represented by the multispectral signature (Fig. 1b). Therefore, all vectors lying within a cone of angle  $\delta_{\max}$  about the signature representing category X belong to category X.

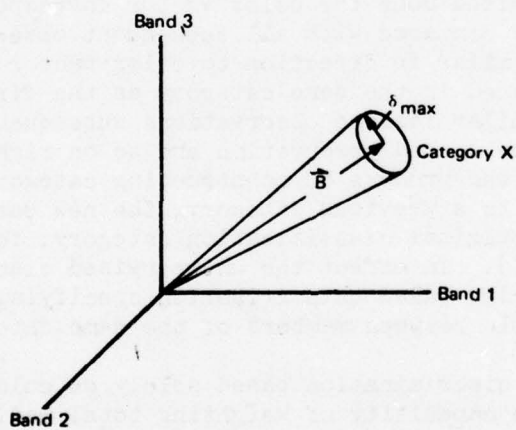
In the unsupervised mode the color vector corresponding to the first observation is compared with all subsequent observations. If color vector 1 is similar in direction to color vector 2 (i.e.  $\delta \leq \delta_{\max}$ ), observation 2 is placed in the same category as the first observation (Fig. 1c). In a similar fashion observations subsequent to observation 2 are compared to the second observation and so on right up to the last observation. If in the process of constructing categories a member is found which belongs to a previous category, the new category is *chained* (or linked) to the original classification category, forming one joint category (Ungar 1977). In effect the unsupervised classification will form several categories based on a criterion specifying maximum color difference permissible between members of the same category.

In addition to discrimination based solely on color, the GISS algorithm provides the capability of weighting total radiance differences into the discriminant equation for classification. The percent difference in brightness between two observations is computed. The calculated normalized difference is then combined with the color difference angle (expressed in steradians) by performing a weighted average in the RMS (root mean square) sense. This brightness-weighted quantity is now compared with the user-defined criterion ( $\delta_{\max}$ ). Thus, in the classification process, a relatively small weighting of brightness allows very



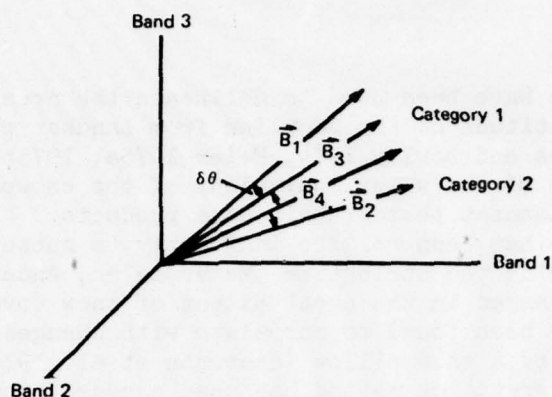


a. A color vector in a four-dimensional space.



- b. Supervised mode. The user-defined criterion,  $\delta_{\text{max}}$ , defines category X about the specified signature  $\vec{B}$ . Any color vector that lies within this cone belongs to category X. This is illustrated for three bands; however, all four Landsat bands are used in the computer classification algorithm.

Figure 1. The concept of the four-dimensional "color" space used in the computer classification algorithm.



- c. Unsupervised mode.  $\vec{B}_3$  is similar in direction to  $\vec{B}_1$  ( $\delta\theta < \delta_{max}$ ) and placed in category 1.  $\vec{B}_4$  is similar in direction to  $\vec{B}_2$  and placed in category 2. However  $\vec{B}_4$  is also similar in direction to  $\vec{B}_3$  (category 1). Therefore, category 1 is merged with category 2.

Figure 1. The concept of the four-dimensional "color" space used in the computer classification algorithm.

large brightness differences to disqualify observations that are similar in color from membership in the same category, thereby adding a second level of discrimination. Discrimination of the classification categories based partially on overall brightness differences plays an important role in the work discussed in this report.

#### Computer data handling and analysis

A Harris 1200 remote job entry terminal was utilized at CRREL for computer data handling and analysis. The remote terminal was used in the analysis of the DCP data cards (hexadecimal format) obtained from NASA and the digital processing of the Landsat CCT's.

Data reduction of the DCP cards was accomplished by using the Infonet computer system located in Chicago, Illinois. The computer programs were developed at CRREL and used for analysis of the data from each interfaced DCP sensor. These data included temperature, using thermocouples, and water equivalent from a snow pillow.

The digital processing of the Landsat CCT's was accomplished through a cooperative agreement with NASA GISS. Computer algorithms for the analysis of the digital data were developed at GISS (Ungar 1977). These algorithms were accessed using the CRREL remote entry terminal to the main computer facility located at GISS in New York City.

## SNOW COVER ANALYSIS

### Literature review

Manual methods have been used to delineate the areal extent of snow and the mean altitude of the snowline from Landsat photographic data products (Barnes and Bowley 1974, Meier 1975a, 1975b). However, a quantitative measure of the water equivalent of the snowpack has not been obtained from Landsat photographic data products. Usually the areal extent of snow has been related indirectly to subsequent watershed runoff occurring during the springtime (Meier 1975c, Anderson et al. 1974). Also, the changes in the areal extent of snow cover measured on Landsat imagery have been found to correlate with changes in water equivalent recorded by a snow pillow (Anderson et al. 1974). Another Landsat manual interpretation method has used a coded snow cover classification scheme to account for vegetation cover, density, aspect, elevation and slope to map the areal extent of snow (Katibah 1975).

A snow mapping experiment comparing the identification of six snow cover types was accomplished using three image processing systems-- LARSYS Version 3, STANSORT-2 and General Electric Image-100 (Itten 1975). In addition, other studies have focused on digital analyses of Landsat data in defining various snow cover types (Bartolucci et al. 1975, Dallam 1975, Luther et al. 1975, Alföldi 1976). In these studies a quantitative estimate of water equivalent content associated with snow cover types was not made. In one case it was suggested that spectral variations within the snowpack area could not be reliably determined because of detector saturation problems (Bartolucci et al. 1975).

Another study used simulated infrared Landsat color composites and snow course data to estimate water equivalent related to the snowpack (Sharp 1975). Sampling units on the Landsat image were mapped to determine the areal extent of snow. An estimation of a snow water content index was calculated using a linear regression equation relating the imagery to ground truth data.

It has been stated that remote sensing of the snow cover may have useful applications since the magnitude and wavelength of reflectance vary with snow types (Mellor 1965). Also, the albedo is high for a layer of new snow and as the new snow grains coalesce and coarsen in texture the albedo falls steadily (Bergen 1975). In addition, a reduction in the spectral reflectance occurs from the combination of densification and increased particle size associated with aging (O'Brien and Munis 1975). Therefore, it is believed that the Landsat CCT's may contain information that can be used to estimate water equivalent in a snowpack. If so, then Landsat digital data can be used for estimating spring runoff (from a watershed area) more accurately than is now possible.



## Approach

Selection of site. The Dickey-Lincoln School Lakes Project, Maine (Fig. 2), currently being evaluated by NED for the generation of hydroelectric power, flood control and recreational purposes, was an ideal site for an analysis of snow cover utilizing the Landsat CCT's. Due to the remoteness and inaccessibility of the area it is impractical to establish an adequate data collection system for evaluating the water equivalent of the snowpack each year.

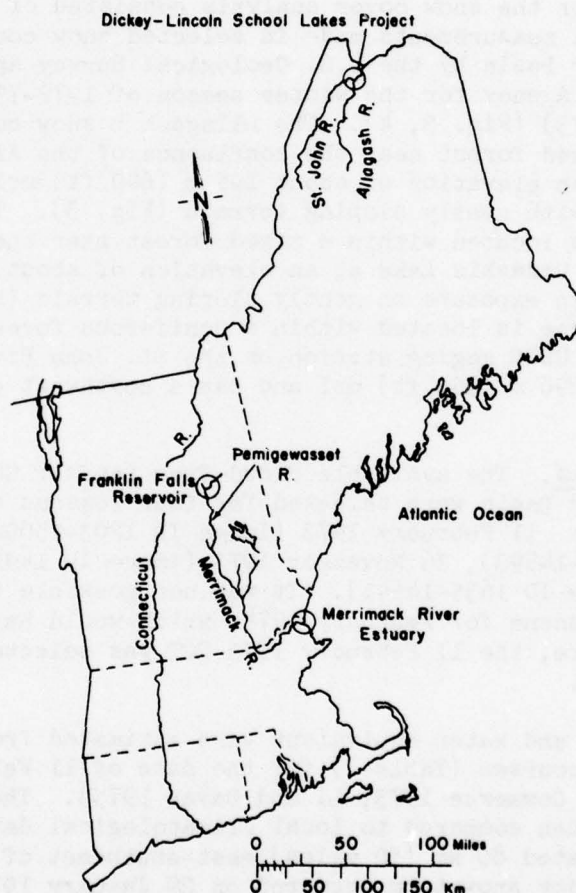


Figure 2. Site location map for the imagery analysis.

The climate of this region is characterized by short, cool summers and long, cold, windy winters. Average annual temperature is 39°F (3.9°C) with extremes of -40°F (-40°C) in the winter and 99°F (37°C) in the summer (New England Division, Corps of Engineers 1967). The average annual precipitation is approximately 91 cm (36 in.) and occurs uniformly



throughout the year with about 30% in the form of snow. The average annual snowfall is about 254 cm (100 in.) which occurs during 8 months of the year (New England Division, Corps of Engineers 1967). Average winter snow depth ranges between 51 and 102 cm (20 and 40 in.), with the upper limit exceeding 127 cm (50 in.). Water equivalent of the snowpack reaches a maximum in late March and usually exceeds 25 cm (10 in.). The geology and vegetation of the Dickey-Lincoln School Lakes Project area was previously mapped and served as a data base of site characteristics in this study (McKim and Merry 1975, McKim 1975).

Ground truth for the snow cover analysis consisted of snow depth and water equivalent measurements made in selected snow courses in the upper St. John River Basin by the U.S. Geological Survey and the Allagash Wilderness Waterway Agency for the winter season of 1972-73 (U.S. Department of Commerce 1973) (Fig. 3, 4). The Allagash B snow course is located within a mixed forest near the confluence of the Allagash and St. John Rivers at an elevation of about 195 m (640 ft) msl and has a southeast exposure with gently sloping terrain (Fig. 3). The Beech Ridge snow course is located within a mixed forest near the Frontier-Churchill Road near Umsaskis Lake at an elevation of about 396 m (1300 ft) msl and has a western exposure on gently sloping terrain (Fig. 3). The Ninemile B snow course is located within a coniferous forest on the floodplain near the USGS gaging station on the St. John River at an elevation of about 290 m (950 ft) msl and has a northwest exposure (Fig. 3).

Snow course data. The available cloud-free Landsat CCT's of the upper St. John River Basin were selected for four seasons and included the following dates: 11 February 1973 (image ID 1203-15002), 23 July 1973 (image ID 1365-14593), 26 November 1973 (image ID 1491-14572) and 19 April 1974 (image ID 1635-14541). It was not possible to obtain a cloud-free Landsat scene for February 1974, which would have been desirable. Therefore, the 11 February 1973 CCT was selected for the snow cover analysis.

The snow depth and water equivalent were estimated from Figure 3 for the three snow courses (Table I) for the date of 11 February 1973 (U.S. Department of Commerce 1973, Li and Davar 1975). These data seemed reasonable when compared to local climatological data obtained at Caribou, Maine, located 80 km (50 miles) east-southeast of the Dickey-Lincoln area. A major snowstorm occurred on 29 January 1973 between the last snow course measurement (28 January 1973) and the date of the CCT (11 February 1973). A total of 23.4 cm (9.2 in.) of snow with a water equivalent of 1.6 cm (0.6 in.) was recorded at Caribou, Maine. In addition, on 8 February 1973 there was a minor snowfall of 4.1 cm (1.6 in.) with a water equivalent of 0.3 cm (0.1 in.). Based on these data, the estimated 24.1 cm (9.5 in.) was assumed to be reasonable.

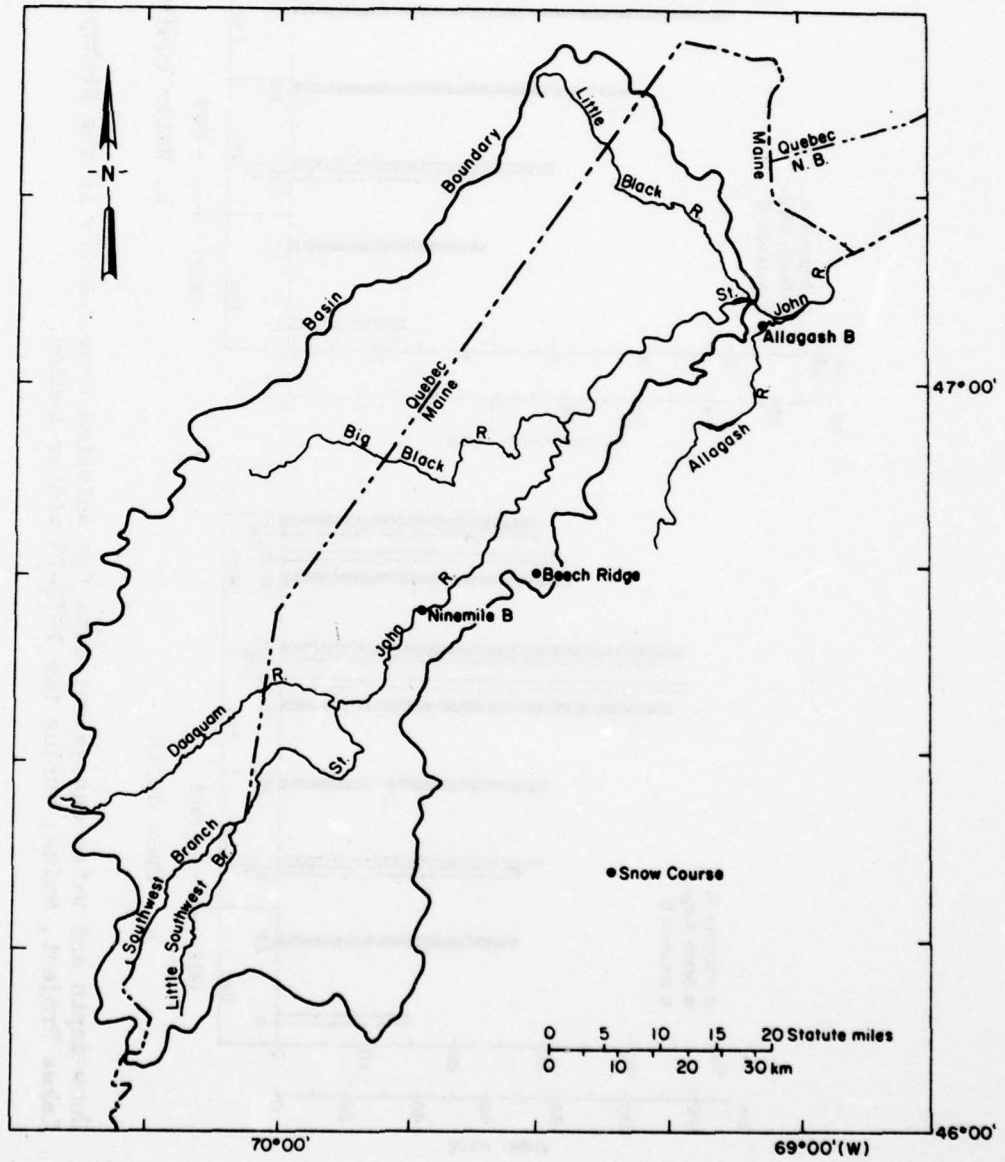


Figure 3. Location map of the Allagash B, Beech Ridge and Ninemile B snow courses.

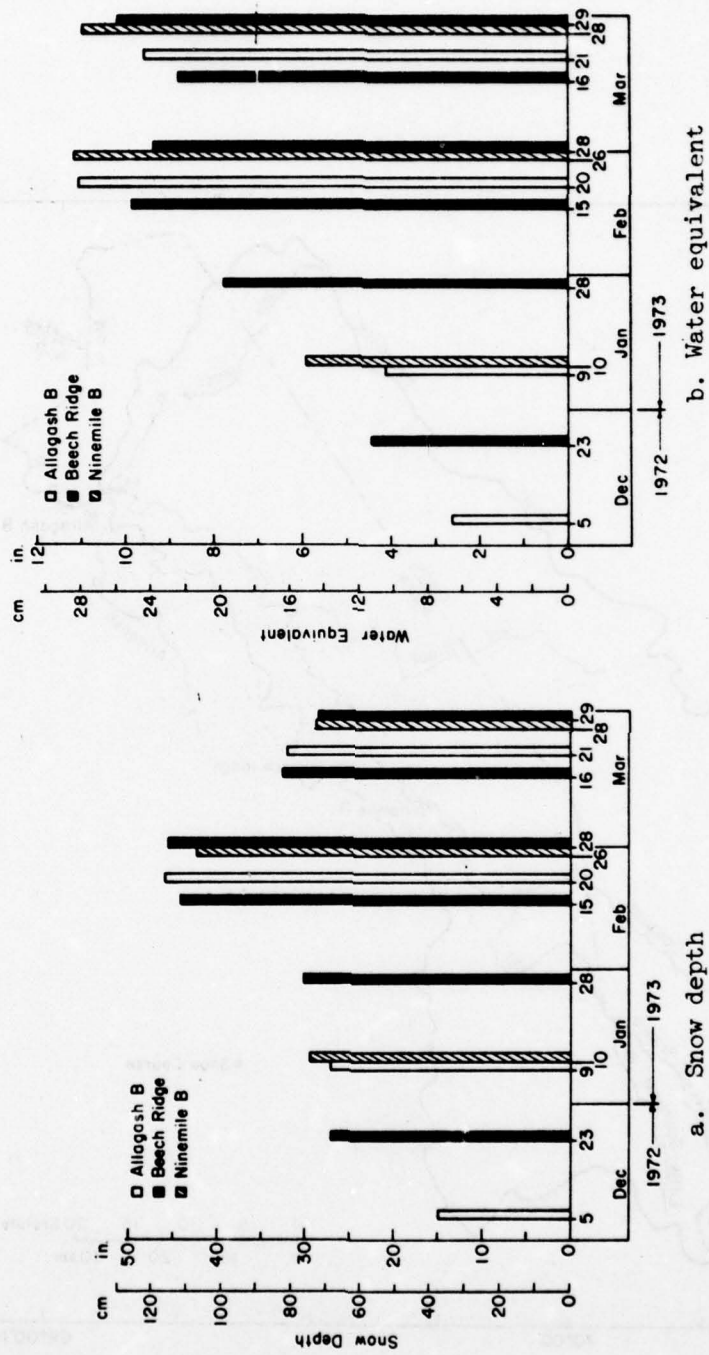


Figure 4. Snow depth and water equivalent data for selected snow courses in the Dickey-Lincoln School Lakes Project, Maine, during the 1972-73 winter season.



Table I. Snow course data (11 February 1973).

<u>Snow course</u>	<u>Location</u>	<u>Length</u> (ft)	<u>Sampling</u> <u>points</u>	<u>Snow</u> <u>depth</u> (in.)*	<u>Water</u> <u>equivalent</u> (in.)*
Allagash E	47°05'N/69°04'W	1000	10	42	9.6
Beech Ridge	46°36'N/69°28'W	-	-	41	9.4
Ninemile B	46°42'N/69°43'W	1000	10	38	9.5

\*1 in. = 2.54 cm

The snow courses were located on each of the CCT's by generating a geometrically corrected, 16-level grayscale computer printout of a 320 by 256 pixel area (380.6 km<sup>2</sup> or 146.9 miles<sup>2</sup>) at a scale of 1:24,000. Each observation was assigned one of 16 levels of gray depending on its radiance value in MSS band 7. The snow course sites were located on the grayscale printouts using available topographic maps for orientation.

The computer test site containing each snow course is 40 by 32 pixels for a total area of 6.0 km<sup>2</sup> (2.3 miles<sup>2</sup>). The snow course was located in the center of each computer test site. The computer algorithm described previously was applied to extract information concerning the spectral characteristics of the snow cover/vegetation within the snow course computer test sites.

#### Results and discussion

Unsupervised classifications were performed on the three snow course sites for the 11 February 1973 CCT for a range of  $\delta_{\max}$  (delmax) values between 0.02 and 0.04 with several brightness weightings (for example, 0.1, 0.2, 0.3) for initial classification of the digital data. Computer runs which produced large numbers of categories were selected so that several signatures could be extracted for the pixels contained within the snow course areas. This allowed for an evaluation of signature variation within each snow course. The sun elevation angle (23°) of the scene was corrected to zenith to account for seasonal variations in irradiance.

The three snow course computer classification printouts for 11 February 1973 are shown in Figures 5, 6 and 7 (Merry et al. 1977). The location of the snow course is shown outlined on the computer test site. The radiance values associated with each pixel within the snow course are indicated by the arrows within the *categorization summary* shown in Figures 5, 6 and 7. In this summary the two left-hand columns are the category symbol and the number of pixels (*num*) within each classification category, respectively. The *tol* column is a measure of the variation among the signatures within a category, with the smaller numbers indicating little variation. The *normalized radiances* in each band





CATEGORIZATION SUMMARY

NUM.	TOL.	NORMALIZED RADIANCES / TRUE RADIANCES				TOTAL RADIANCE
		81'	82'	83'	84'	
7	1.0	0.18	0.15	0.09	0.11	0.06
8	0.5	0.16	0.14	0.08	0.09	5.74
9	0.5	0.14	0.12	0.07	0.08	5.84
10	1.0	0.12	0.10	0.06	0.07	0.50
11	0.5	0.10	0.09	0.05	0.06	5.34
12	0.5	0.08	0.07	0.04	0.05	5.54
13	0.5	0.06	0.05	0.03	0.04	5.14
14	0.5	0.04	0.03	0.02	0.03	5.60
15	0.5	0.02	0.02	0.01	0.02	5.60
16	0.5	0.01	0.01	0.00	0.01	5.41
17	0.5	0.01	0.01	0.00	0.01	5.44
18	0.5	0.01	0.01	0.00	0.01	5.69
19	0.5	0.01	0.01	0.00	0.01	6.04
20	0.5	0.01	0.01	0.00	0.01	5.97
21	0.5	0.01	0.01	0.00	0.01	5.43
22	0.5	0.01	0.01	0.00	0.01	4.96
23	0.5	0.01	0.01	0.00	0.01	5.11
24	0.5	0.01	0.01	0.00	0.01	6.02
25	0.5	0.01	0.01	0.00	0.01	6.50
26	0.5	0.01	0.01	0.00	0.01	6.50
27	0.5	0.01	0.01	0.00	0.01	6.04
28	0.5	0.01	0.01	0.00	0.01	5.97
29	0.5	0.01	0.01	0.00	0.01	5.43
30	0.5	0.01	0.01	0.00	0.01	4.96
31	0.5	0.01	0.01	0.00	0.01	5.11
32	0.5	0.01	0.01	0.00	0.01	6.02
33	0.5	0.01	0.01	0.00	0.01	6.50
34	0.5	0.01	0.01	0.00	0.01	6.50
35	0.5	0.01	0.01	0.00	0.01	6.04
36	0.5	0.01	0.01	0.00	0.01	5.97
37	0.5	0.01	0.01	0.00	0.01	5.43
38	0.5	0.01	0.01	0.00	0.01	4.96
39	0.5	0.01	0.01	0.00	0.01	5.11
40	0.5	0.01	0.01	0.00	0.01	6.02
41	0.5	0.01	0.01	0.00	0.01	6.50
42	0.5	0.01	0.01	0.00	0.01	6.50
43	0.5	0.01	0.01	0.00	0.01	6.04
44	0.5	0.01	0.01	0.00	0.01	5.97
45	0.5	0.01	0.01	0.00	0.01	5.43
46	0.5	0.01	0.01	0.00	0.01	4.96
47	0.5	0.01	0.01	0.00	0.01	5.11
48	0.5	0.01	0.01	0.00	0.01	6.02
49	0.5	0.01	0.01	0.00	0.01	6.50
50	0.5	0.01	0.01	0.00	0.01	6.50
51	0.5	0.01	0.01	0.00	0.01	6.04
52	0.5	0.01	0.01	0.00	0.01	5.97
53	0.5	0.01	0.01	0.00	0.01	5.43
54	0.5	0.01	0.01	0.00	0.01	4.96
55	0.5	0.01	0.01	0.00	0.01	5.11
56	0.5	0.01	0.01	0.00	0.01	6.02
57	0.5	0.01	0.01	0.00	0.01	6.50
58	0.5	0.01	0.01	0.00	0.01	6.50
59	0.5	0.01	0.01	0.00	0.01	6.04
60	0.5	0.01	0.01	0.00	0.01	5.97
61	0.5	0.01	0.01	0.00	0.01	5.43
62	0.5	0.01	0.01	0.00	0.01	4.96
63	0.5	0.01	0.01	0.00	0.01	5.11
64	0.5	0.01	0.01	0.00	0.01	6.02
65	0.5	0.01	0.01	0.00	0.01	6.50
66	0.5	0.01	0.01	0.00	0.01	6.50
67	0.5	0.01	0.01	0.00	0.01	6.04
68	0.5	0.01	0.01	0.00	0.01	5.97
69	0.5	0.01	0.01	0.00	0.01	5.43
70	0.5	0.01	0.01	0.00	0.01	4.96
71	0.5	0.01	0.01	0.00	0.01	5.11
72	0.5	0.01	0.01	0.00	0.01	6.02
73	0.5	0.01	0.01	0.00	0.01	6.50
74	0.5	0.01	0.01	0.00	0.01	6.50
75	0.5	0.01	0.01	0.00	0.01	6.04
76	0.5	0.01	0.01	0.00	0.01	5.97
77	0.5	0.01	0.01	0.00	0.01	5.43
78	0.5	0.01	0.01	0.00	0.01	4.96
79	0.5	0.01	0.01	0.00	0.01	5.11
80	0.5	0.01	0.01	0.00	0.01	6.02
81	0.5	0.01	0.01	0.00	0.01	6.50
82	0.5	0.01	0.01	0.00	0.01	6.50
83	0.5	0.01	0.01	0.00	0.01	6.04
84	0.5	0.01	0.01	0.00	0.01	5.97
85	0.5	0.01	0.01	0.00	0.01	5.43
86	0.5	0.01	0.01	0.00	0.01	4.96
87	0.5	0.01	0.01	0.00	0.01	5.11
88	0.5	0.01	0.01	0.00	0.01	6.02
89	0.5	0.01	0.01	0.00	0.01	6.50
90	0.5	0.01	0.01	0.00	0.01	6.50
91	0.5	0.01	0.01	0.00	0.01	6.04
92	0.5	0.01	0.01	0.00	0.01	5.97
93	0.5	0.01	0.01	0.00	0.01	5.43
94	0.5	0.01	0.01	0.00	0.01	4.96
95	0.5	0.01	0.01	0.00	0.01	5.11
96	0.5	0.01	0.01	0.00	0.01	6.02
97	0.5	0.01	0.01	0.00	0.01	6.50
98	0.5	0.01	0.01	0.00	0.01	6.50
99	0.5	0.01	0.01	0.00	0.01	6.04
100	0.5	0.01	0.01	0.00	0.01	5.97

NUM. POINTS CLASSIFIED = 1938 NO. POINTS UNCLASSIFIED = 480  
 RELMAX = 0.0110 BRIGHTNESS WEIGHTING = 0.300

INDICATOR PREFIX OF BAND 1 USED IN ALBEDO CALC.  
 INDICATOR PREFIX OF BAND 2 USED IN ALBEDO CALC.  
 INDICATOR PREFIX OF BAND 3 USED IN ALBEDO CALC.

**BEECH RIDGE SNOW COURSE  
 1300' ELEVATION ASPECT: WEST  
 WATER EQUIV. 9.4"  
 SNOW DEPTH 41"**

Figure 6. Computer classification printout of the Beech Ridge snow course (11 February 1973).

NINE-MILE BRIDGE SNOW COURSE  
 950' ELEVATION ASPECT: NORTHWEST

WATER EQUIV. 9.5"  
 SNOW DEPTH 38"

CATEGORIZATION SUMMARY

CATEGORIZATION SUMMARY

DIGITIZED OUTPUT OF SUBSEQUENT(S) 770,  
 SHOWING 40 CATEGORIES

NORMALIZED RADIANCES / TRUE RADIANCES		NORMALIZED RADIANCES / TRUE RADIANCES					
NUM.	TOL.	R1'	R2'	R3'	R4'	TOTAL RADIANCE	
G	5	1.	0.28	0.74	1.58	7.04	11.00
H	4	1.	0.51	0.46	0.82	3.74	6.52
J	4	1.	0.09	0.93	0.14	0.76	24.21
K	4	0.	0.24	0.04	0.11	0.37	20.10
L	4	0.	0.23	0.08	0.13	0.39	9.61
Z	4	1.	0.12	0.08	0.14	0.70	19.48
X	4	1.	0.28	0.11	0.12	0.49	9.47
C	3	1.	0.24	0.10	0.14	0.52	6.47
E	3	1.	0.14	0.04	0.14	0.66	11.67
V	3	0.	0.24	0.09	0.13	0.48	10.00
B	3	1.	0.25	0.04	0.12	0.55	12.35
C	3	1.	0.24	0.04	0.14	0.53	5.68
M	3	1.	0.51	0.52	0.87	3.55	6.30
M	3	1.	0.20	0.12	0.16	0.58	13.46
F	3	1.	0.20	0.07	0.11	0.22	13.40
I	3	1.	0.04	0.03	0.02	0.78	20.51
Z	3	1.	0.24	0.08	0.14	0.50	6.30
S	3	1.	0.24	0.09	0.11	0.54	16.81
A	3	1.	0.24	0.04	0.14	0.50	9.31
S	3	1.	0.23	0.08	0.13	0.55	6.75

NORMALIZED RADIANCES / TRUE RADIANCES		NORMALIZED RADIANCES / TRUE RADIANCES					
NUM.	TOL.	R1'	R2'	R3'	R4'	TOTAL RADIANCE	
U	225	3.	0.17	0.04	0.15	0.52	6.87
A	163	2.	0.10	0.07	0.15	0.54	5.45
S	151	3.	0.17	0.06	0.13	0.44	16.70
S	93	2.	0.20	0.04	0.16	0.37	4.95
Q	93	3.	0.15	0.05	0.13	0.47	28.22
M	89	2.	0.14	0.07	0.16	0.59	5.69
J	65	2.	0.19	0.37	0.83	2.96	5.16
E	24	2.	0.14	0.05	0.14	0.52	12.68
R	19	2.	0.15	0.05	0.13	0.31	21.42
T	17	2.	0.20	0.16	0.14	0.54	4.67
V	17	1.	0.14	0.04	0.15	0.71	13.45
U	16	1.	0.14	0.05	0.15	0.60	10.63
I	13	1.	0.24	0.07	0.17	12.11	16.34
O	10	1.	0.24	0.06	0.14	0.43	11.11
S	10	1.	0.19	0.04	0.13	0.76	12.49
P	10	1.	0.23	0.07	0.13	0.53	10.65
A	9	1.	0.15	0.05	0.13	0.47	23.00
S	6	1.	0.24	0.07	0.14	0.50	22.84
D	6	1.	0.23	0.04	0.14	0.70	6.63
F	6	1.	0.23	0.04	0.14	0.57	11.49

NUM. POINTS CLASSIFIED = 1116 NO. POINTS UNCLASSIFIED = 164  
 DELTA = 0.0225 BRIGHTNESS WEIGHTING = 0.300

100.00 PERCENT OF BAND 1 USED IN ALBEDO CALC.  
 100.00 PERCENT OF BAND 2 USED IN ALBEDO CALC.  
 100.00 PERCENT OF BAND 3 USED IN ALBEDO CALC.  
 100.00 PERCENT OF BAND 4 USED IN ALBEDO CALC.

Figure 7. Computer classification printout of the Minemile B snow course (11 February 1973).



(B1', B2', B3' and B4') always total one and are listed for each category. Also, the *true radiances* are listed for each band (B1, B2, B3 and B4); these values sum to the *total radiance* ( $\text{mW/cm}^2 \text{sr}^*$ ) listed in the extreme right-hand column. The *delmax* and the *brightness weighting* used in the unsupervised classification are shown at the bottom of the categorization summary.

The Allagash B snow course computer classification printout is shown in Figure 5. The total radiance of pixels contained in the snow course area varied from 6.93 to 7.74  $\text{mW/cm}^2 \text{sr}$  (categories: E T & P 2 6), which corresponded to a water equivalent of 24.4 cm (9.6 in.) obtained from the snow course data. An important observation was that the radiance for MSS band 7 was consistently 2.99 or 3.18  $\text{mW/cm}^2 \text{sr}$ , a difference of only one energy level.

The Beech Ridge snow course computer classification printout is shown in Figure 6. The total radiance of pixels contained in this snow course varied from 5.34 to 6.54  $\text{mW/cm}^2 \text{sr}$  (categories: \* . + Q W U I O G) and corresponded to a water equivalent of 23.9 cm (9.4 in.) obtained from the snow course data. The Ninemile B snow course computer classification printout is shown in Figure 7. The total radiance for the pixels contained in the site varied from 5.45 to 6.87  $\text{mW/cm}^2 \text{sr}$  (categories: / \* W C) and corresponded to a water equivalent of 24.1 cm (9.5 in.) obtained from the snow course data.

The radiance varied from 5.34 to 7.74  $\text{mW/cm}^2 \text{sr}$  over the three sampled snow course areas, which corresponded to a water equivalent value of approximately 24.1 cm (9.5 in.) (Merry et al. 1977). The range in radiance values from 5.34 to 7.74  $\text{mW/cm}^2 \text{sr}$  may be attributed to variations in vegetative cover, slope and aspect among these snow course areas.

The greatest radiance occurred in cleared areas such as fields and river channels. As an example, the snow cover on the St. John River (Fig. 4 and 6) showed the highest total radiance, which ranged from 20.23 to as high as 29.21  $\text{mW/cm}^2 \text{sr}$ . These high radiance values occurred in areas where there was a minimal vegetative cover. The important factors to be considered in the snow cover mapping and assessment of the water equivalent analysis based on radiance values obtained from the Landsat CCT's in the Dickey-Lincoln School Lakes area are probably the vegetation cover, slope, aspect, geomorphic position and, to a lesser degree, elevation.

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\*Milliwatts per square centimeter per steradian.

A preliminary analysis of the 11 February 1973 CCT using the GISS computer algorithm showed that the radiance of the snow cover/vegetation varied from approximately 20 mW/cm<sup>2</sup> sr in non-vegetated areas to less than 4 mW/cm<sup>2</sup> sr for densely covered forested areas. Comparison of the digital data from three snow courses in the Dickey-Lincoln School Lakes area with the radiance value of the snowpack at these sites indicated that the radiance of the pixels contained in the snow courses varied from 5.34 to 7.74 mW/cm<sup>2</sup> sr, with the average radiance value being 6.4 ± 0.6 mW/cm<sup>2</sup> sr. The water equivalent of the snowpack for this range of radiance values was approximately 24.1 cm (9.5 in.) of water.

Average multispectral signatures were extracted for the three snow course sites from the four-band energy values for the dates of 11 February 1973 and 23 July 1973 to evaluate seasonal variations in radiance. The multispectral signatures from these dates are shown in Table II.

Table II. Average multispectral signatures (mW/cm<sup>2</sup> sr) for the three snow courses.

<u>Snow Course</u>	<u>Date</u>	<u>MSS 4</u>	<u>MSS 5</u>	<u>MSS 6</u>	<u>MSS 7</u>	<u>Total radiance</u>
Allagash B	11 Feb 73	1.741	1.189	1.209	3.084	7.223
	23 Jul 73	0.518	0.247	0.603	1.760	3.128
Beech Ridge	11 Feb 73	1.053	0.600	0.720	1.927	4.300
	23 Jul 73	0.507	0.233	0.561	1.705	3.006
Ninemile B	11 Feb 73	1.428	0.534	0.975	4.033	6.970
	23 Jul 73	0.550	0.282	0.591	1.879	3.302

The area where the three snow courses are located showed relatively the same radiance value (3 mW/cm<sup>2</sup> sr) for the month of July. This low value would be anticipated due to the absence of snow. The minor differences observed in the four MSS bands can be attributed to the difference in vegetative cover. The Allagash B and Beech Ridge sites have a mixed forest cover and their multispectral signatures are similar. The Nine-mile B site is in a coniferous forest and the four-band multispectral signatures are slightly different from those of the other two sites.

Figure 8 shows the computer classification of snow cover/vegetation classes for the 11 February scene of a selected area (90 km<sup>2</sup> or 35 miles<sup>2</sup>) near the confluence of the St. John and Allagash Rivers with the correlative USGS topographic map. The multispectral signatures (Table III) for a supervised classification were derived from Table II for the three

snow course sites during February and another multispectral signature was derived from the four-band energy values for the Allagash and St. John River channels. The four snow cover/vegetation classes are shown in Table IV.

Table III. Input multispectral signatures ( $\text{mW}/\text{cm}^2 \text{ sr}$ ) for the four snow cover/vegetation classes.

<u>Symbol on map</u>	<u>Delmax</u>	<u>Multispectral Signatures</u>				<u>Total radiance</u>	<u>W2</u>
		<u>MSS 4</u>	<u>MSS 5</u>	<u>MSS 6</u>	<u>MSS 7</u>		
1	0.25	1.74	1.19	1.21	3.08	7.22	0.3
2	0.25	1.05	0.60	0.72	1.93	4.30	0.3
3	0.50	1.43	0.53	0.98	4.03	6.97	0.3
4	0.25	5.22	4.23	3.43	7.52	20.40	0.3

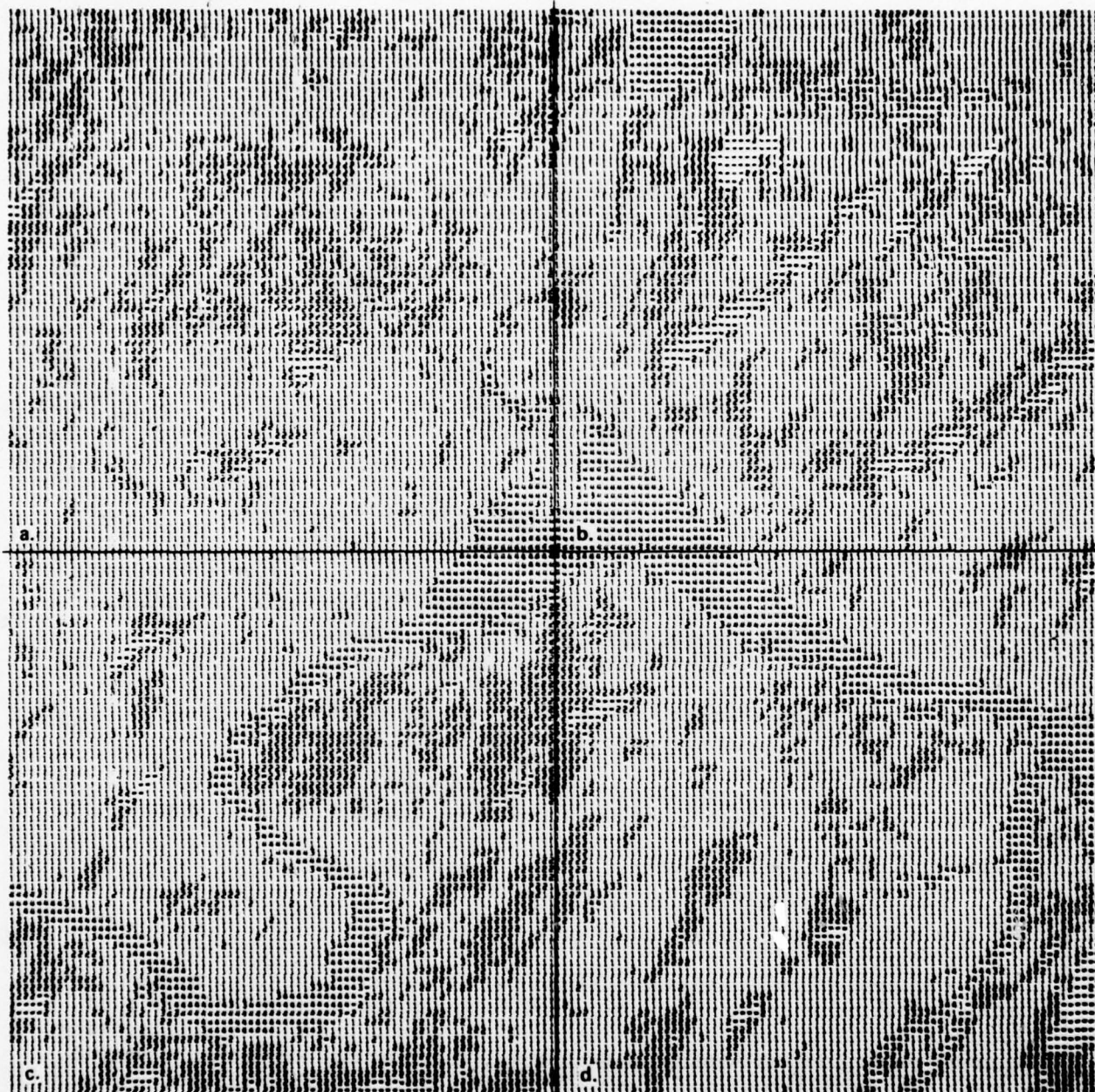
Table IV. Snow cover/vegetation classes mapped from the 11 February 1973 CCT.

<u>Symbol on map</u>	<u>Snow cover/vegetation characteristics</u>	<u>Water equivalent (in.)*</u>
1	Mixed forest, 195 m (640 ft) msl elevation, southeast exposure, gently sloping	9.6
2	Mixed forest, 396 m (1300 ft) msl elevation, western exposure, gently sloping	9.4
3	Coniferous forest, 290 m (950 ft) msl elevation, northwest exposure, level	9.5
4	Open nonvegetated areas, lowest elevations, level	-

\*1 in. = 2.54 cm

Patterns of snow radiance values can be observed on the computer classification printout (Fig. 8) which suggests the interrelationship of vegetation, slope and aspect. The 1 and 2 symbols predominate, indicating mixed forest land at various elevations. The 3 symbol occurs in isolated areas such as hilltops and along the river channels. The 4 symbol occurs as expected along the Allagash, St. John and part of the Little Black Rivers. Also, there were a number of unclassified pixels (the dashes) which can be seen in Figure 8. This was as anticipated due to other snow cover/vegetation classes that were not defined during this exercise. It is suggested that these undefined snow cover/vegetation classes would be for areas that have water equivalent values either greater or less than 24.1 cm (9.5 in.) and/or other types of site characteristics.





a. Actual signature table						b. Actual signature table						c. Actual signature table						d. Actual signature table									
Sym	Num	B1	B2	B3	B4	Albedo	Sym	Num	B1	B2	B3	B4	Albedo	Sym	Num	B1	B2	B3	B4	Albedo	Sym	Num	B1	B2	B3	B4	Albedo
1	3797	1.60	1.06	1.05	2.62	6.33	1	3228	1.72	1.14	1.11	2.75	6.71	1	3235	1.60	1.06	1.05	2.64	6.35	1	3479	1.54	1.01	1.01	2.57	6.14
2	1020	1.17	0.68	0.69	1.66	4.20	2	945	1.18	0.68	0.67	1.61	4.14	2	1107	1.16	0.67	0.67	1.63	4.12	2	849	1.16	0.66	0.66	1.61	4.09
3	155	3.16	2.43	2.11	4.95	12.65	3	441	3.16	2.45	2.14	5.07	12.82	3	168	3.14	2.41	2.08	4.86	12.48	3	148	3.22	2.47	2.11	4.90	12.69
4	97	4.94	3.94	3.24	7.19	19.31	4	430	5.02	4.03	3.28	7.32	19.65	4	505	5.13	4.12	3.35	7.41	20.00	4	515	5.02	4.04	3.28	7.29	19.63

No. points classified = 5069  
No. points unclassified = 51

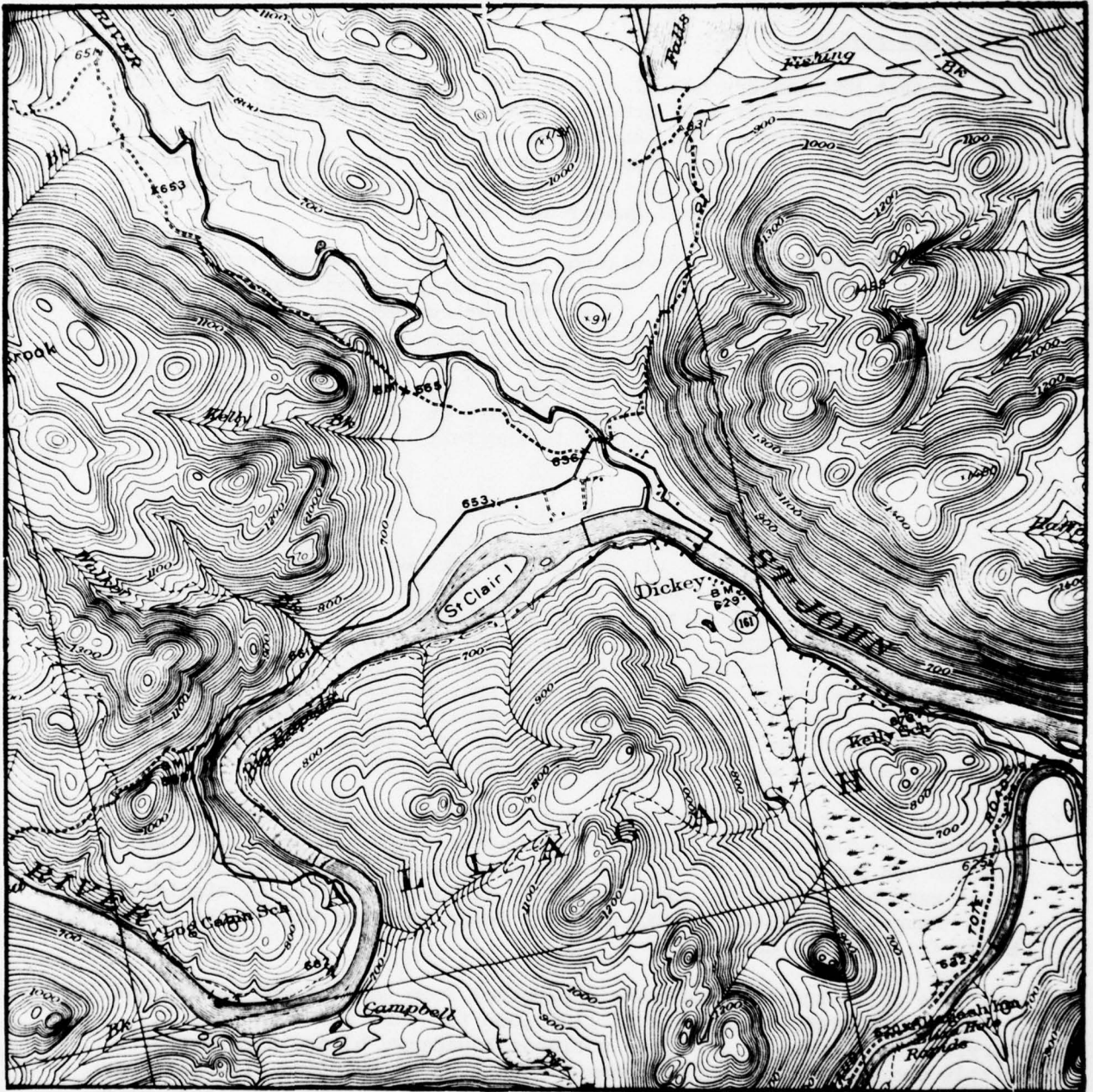
No. points classified = 4944  
No. points unclassified = 176

No. points classified = 5015  
No. points unclassified = 105

No. points classified = 4991  
No. points unclassified = 129

a. The computer classification printout with multispectral signature data.

Figure 8. Computer classification printout showing four snow cover/vegetation classes (11 February 1973).



b. The correlative USGS topographic map.

Figure 8. Computer classification printout showing four snow cover/vegetation classes (11 February 1973).



## WETLANDS MAPPING

### Literature review

Landsat MSS imagery has also been used to delineate the extent of wetlands. The wetlands maps produced have generally resulted from a visual interpretation of the Landsat photographic data products. Mapping accuracies between 70 and 85% have been achieved using Landsat MSS photography (Seevers et al. 1975, Anderson et al. 1973a, 1973b, Higer et al. 1975, Rehder and Quattrochi 1976).

Accurate inventories of wetlands larger than ten acres were made in Nebraska for four categories: open water, subirrigated meadows, marshes, and seasonally flooded basins. The inventories were made by using imagery from two seasons and an electronic image-enhancing system. Positive print enlargements of MSS bands 5 and 7 at a scale of 1:250,000 (acquired in the spring) as well as band 7 (acquired in late summer) were used to delineate all wetlands (Seevers et al. 1975). Electronic enhancement of MSS band 6 (acquired in the fall) was used as an aid to differentiate marshes.

A wetlands map of Wisconsin was prepared at a scale of 1:500,000 using Landsat MSS bands 5 and 7 and an additive color viewer as a data analysis system (Frazier et al. 1975). Wetland areas in this investigation were defined as those which had enough water during June to adversely affect the infrared reflectance of growing plants. These included areas with wetland cover types (marsh, sedge meadow, shrub-carr and lowland forest) and poorly drained agricultural cropland areas. The primary criteria for delineation of wetlands were the reduced infrared reflectance of broad-leafed plants growing in wet areas, the dark red tone of spruce bogs, and the black color of organic soil areas observed when using the additive color viewer (Frazier et al. 1975).

Significant changes occurred in the size of wetlands because of seasonal fluctuations in vegetation characteristics and precipitation (Rehder and Quattrochi 1976). The dynamic characteristics of the wetlands were not attributed exclusively to seasonal factors, as significant changes in wetland morphology were found to occur within the MSS bands for the same date.

The following features were determined from Landsat MSS band 5 and 7 imagery enlarged to a scale of 1:250,000 for test sites located in Maryland and Georgia: a) upper wetlands boundary; b) drainage patterns within the wetlands; c) plant communities such as *Spartina alterniflora*, *Spartina patens*, *Juncus roemerianus*; d) drainage ditches associated with agriculture; and e) lagoons for waterside home development (Anderson et al. 1973a, 1973b). Mapping at a scale of 1:250,000 was adequate for the general delineation of large marshes and for rather gross wetland species associations.



In addition, digital processing of Landsat MSS imagery has been used to map wetlands (Anderson et al. 1973b, Cartmill 1973, Flores et al. 1973, Klemas et al. 1973). Mapping accuracies ranging generally from 78 to 99% have been achieved using digital processing techniques.

Seven categories of marsh vegetation and marsh features were identified at an approximate scale of 1:20,000 (Anderson et al. 1973b). These categories included water, sandy mudflat, sparsely vegetated organic mudflat, spoil, *Iva frutescens*, *Spartina patens* and *Spartina alterniflora*.

Seventeen to thirty spectrally homogeneous land use classes were defined in the Texas coastal zone using two clustering algorithms available from the NASA Johnson Space Center (Flores et al. 1973). Many classes were identified as being homogeneous features such as water masses, salt marsh, beaches, pine, hardwoods, and exposed soil or construction materials, with most classes identified as mixtures.

Eight vegetation and land use discrimination classes were selected to map and inventory the significant ecological communities in the coastal zone of Delaware (Klemas et al. 1973). These classes were: *Phragmites communis* (giant reed grass), *Spartina alterniflora* (salt marsh cord grass), *Spartina patens* (salt marsh hay), shallow water and exposed mud, deep water (>2 m or 76 ft), forest, agriculture, and exposed sand and concrete. The *Spartina alterniflora* was discriminated with an accuracy of 94-100%, the *Phragmites communis* showed a classification accuracy of 83%, but the discrimination of *Spartina patens* was only 52%.

#### Approach

The site selected for the wetlands mapping analysis was a 124-km<sup>2</sup> (48-mile<sup>2</sup>) area of the Merrimack River estuary (Fig. 2). This area contained the largest variety of land use and vegetation classification units to be found in the Merrimack River Basin. In addition, the Merrimack River Basin had been a primary test site for the NED-CRREL Skylab Earth Resources Experiment Package (EREP) project (McKim et al. 1975b). Land use maps prepared from satellite and aircraft photographic data products were available for this site.

#### Results and discussion

The CCT's were obtained of the Merrimack River estuary for 6 July 1976 (image ID 5444-14082). A grayscale computer printout of the Merrimack River estuary was obtained for the purpose of locating potential training sites for wetlands. In addition, a 1:24,000 NASA RB-57/RC-8 photograph and a USGS topographic map of the study area were available for ground truth comparison to the computer printout. An overlay was

prepared from the photograph showing the delineation of the water and the extent of wetlands. Two training sites were located on the north side of the estuary for use in the wetlands analysis (Fig. 9).

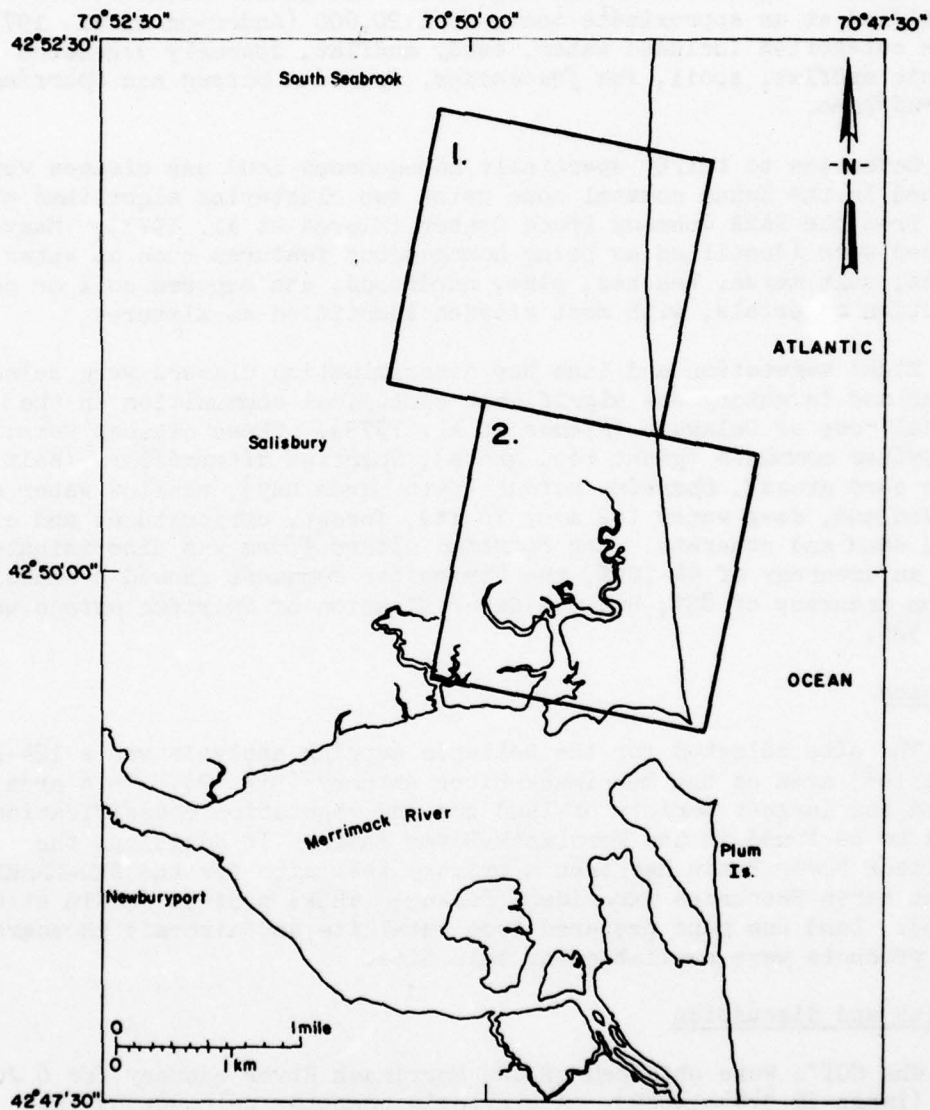


Figure 9. Location map of the two training sites used in the wetlands mapping analysis.

A "ground truth" computer algorithm developed at GISS was used to determine an average multispectral signature for the wetlands and the water classification categories. This computer program allows one to "tag" certain pixels of a category into a 32 by 40 array; these specified pixels in the array are then used in the computation of an average multispectral signature.

The wetlands overlay that was prepared from a photointerpretation analysis of the 1:24,000 photograph was placed over the grayscale computer printout (scale 1:24,000) of the Merrimack River estuary. The pixels that were within the boundaries of the delineated wetlands and the water classification categories were tagged as the pixels to be used in the specified array for the ground truth computer program. The ground truth computer program determined the average multispectral signatures for the two specified categories (Table V).

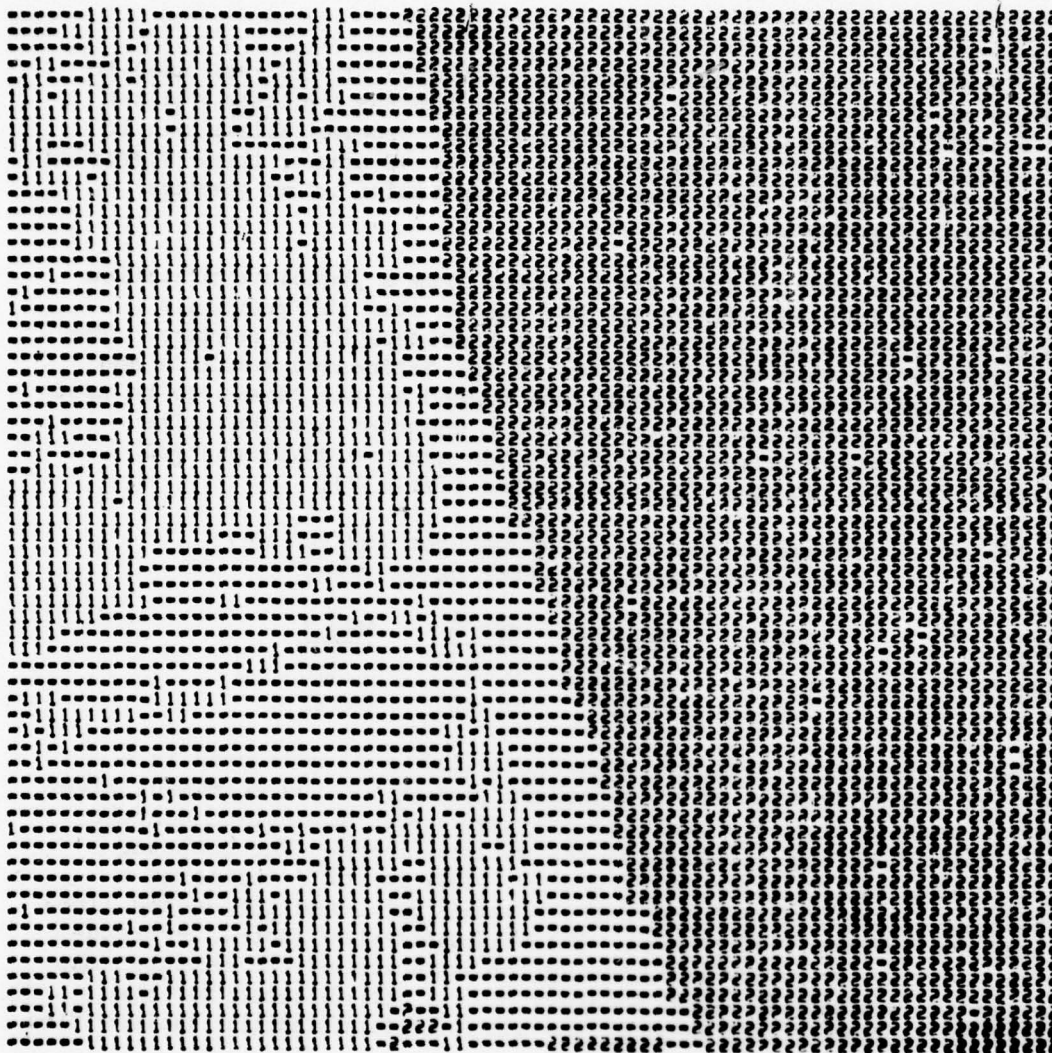
Table V. Average multispectral signatures ( $\text{mW}/\text{cm}^2 \text{ sr}$ ) for the wetlands and water categories.

<u>Category</u>	<u>MSS 4</u>	<u>MSS 5</u>	<u>MSS 6</u>	<u>MSS 7</u>
Wetlands	0.584	0.326	0.581	1.510
Water	0.551	0.237	0.140	0.131

The multispectral training signatures (Table V) were used in a supervised classification of the northern portion of the Merrimack River estuary. Various values of delmax were used until an optimum computer classification map was obtained of the wetland areas. The computer classification map is shown in Figure 10. The symbol 1 indicates a wetlands unit, the symbol 2 indicates a water unit, and the dashed lines (-) indicate unclassified pixels. The wetlands/water photointerpretation map overlay was used in comparing the accuracy of the computer map of wetlands. A classification accuracy of 75% was obtained for the wetlands unit, taking into account the misclassified and the unclassified wetlands pixels.

The reason for the 75% accuracy may be the variability of wetland species, because it was assumed that all the wetlands contained the same vegetation type. If there was a large variability in species, there would be different multispectral responses. Also, changes in moisture conditions and tidal fluctuations would contribute to multispectral variations. This would prevent the wetland areas from being classified in one broad category.





Input signature table

Sym	Num	Delmax	B1	B2	B3	B4	Albedo	W2
1	1172	0.150	0.58	0.33	0.58	1.51	3.00	0.20
2	2565	0.200	0.55	0.24	0.14	0.13	1.06	0.20

Actual signature table

B1	B2	B3	B4	Albedo
0.74	0.42	0.69	1.77	3.82
0.60	0.25	0.15	0.12	1.12

No. points classified = 3737 No. points unclassified = 1383

Figure 10. Computer classification printout of wetlands for the Merrimack River estuary (image ID 5444-14082).

## MAPPING OF FLOODED AREAS

### Literature review

Landsat MSS data have been used for flood observations because of the relatively high resolution, cartographic fidelity and the near infrared sensors (Rango 1975). Flood area measurements for areas of 100 km<sup>2</sup> (39 miles<sup>2</sup>) or more have been made with less than a 5% error (Rango and Salomonson 1974).

Flood-prone areas have been shown to have multispectral signatures indicating categories of natural vegetation, soil characteristics and cultural features which are different from the signatures of surrounding non-flood-prone areas (Rango and Anderson 1974). These differences have developed over a period of time in response to increased flooding frequency which enabled the signatures to be distinguished from the non-flood-prone areas (Rango 1975). The areas subject to flooding along the Mississippi River were identified by observation of various floodplain indicators such as natural and artificial levee systems, soil differences, agricultural pattern and vegetation differences, upland boundaries, backwater areas and special flood alleviation measures in urban areas.

Landsat imagery has also been used to trace the details of inundation and drainage of flood areas and deltaic lowlands (Burgy 1973). An overall lightening of tone observed on MSS band 7 imagery of the Andrus Island flood area in California was attributed to an increase of bottom reflection with the lowering of the water level.

Flood inundation mapping has been accomplished on MSS band 7 imagery enlarged to a scale of 1:250,000 acquired one week to 10 days after a flood (Hallberg et al. 1973, Rango and Salomonson 1974, Morrison and Cooley 1973, Schwertz et al. 1976). The inundated areas showed sharply reduced infrared reflectance on MSS band 7 because of standing surface water, excessive soil moisture and stressed vegetation (Hallberg et al. 1973). These data compared favorably with flood extent mapping accomplished on low altitude aircraft photography. Also, areas affected by severe sand and gravel erosion and sediment deposition were detected on MSS band 5 (Morrison and Cooley 1973).

Color enhancement techniques were used to produce a variety of multispectral color composites at a scale of 1:250,000 of flooding along the Mississippi River in the spring of 1973 (Deutsch et al. 1973, Deutsch and Ruggles 1974). Two color composites of MSS bands 6 and 7 were enlarged and registered to 1:250,000 scale topographic maps and used as the data base for preparation of flood image maps. Specially filtered 3-color composites of MSS bands 5, 6 and 7 and 4, 5 and 7 were used to aid in the data interpretation. In addition, two-color temporal com-

posites of pre-flood and post-flood MSS band 7 images were used in interpretation. These indicated that flooding caused changes in surface reflectance characteristics, making it possible to map the flooded areas after the flood waters had receded. Also, Landsat MSS data have been digitally processed to produce water distribution maps and map overlays that show the areal extent of flooding during the 1973 flood of the lower Mississippi River (Williamson 1974, 1975).

Landsat MSS band 7 digital data were superimposed on a digital image display and manipulation system (IDAMS) developed at Goddard Space Flight Center (Rango and Anderson 1974). This enabled a quantitative change detection analysis for determining normal surface water area and areas susceptible to flooding. Also, the General Electric Multispectral Information Extraction System (GEMS) was used to classify and measure water areas according to differences in reflectance resulting from physical differences in depth and/or sediment load (Rango and Anderson 1974). Therefore, in general, preliminary digital Landsat flood and flood-prone area maps have been produced at a scale of 1:62,500; however, most mapping has been done on a regional basis at a scale of 1:250,000.

#### Approach

The site selected for the flooded areas mapping analysis was the Franklin Falls reservoir, New Hampshire (Fig. 2). During the last four days of June 1973, a strong, moist tropical airflow in conjunction with a stationary frontal system resulted in moderate to heavy rain over much of New England. For example, the total rainfall was 13.0 cm (5.1 in.) for the three-day period ending at 0800 hours 1 July 1973 in the Franklin Falls reservoir. In the northern portions of the Merrimack River Basin this storm caused the largest summer flood on record.

Sixty-six percent of the storage capacity at Franklin Falls was utilized in controlling the flood waters. Large areas were inundated for periods of one to two weeks (McKim et al. 1975a). This flood was unusual because of its magnitude, the extremely high concentration of suspended sediment in the flood waters, and the fact that it occurred at the height of the growing season. On 6 July 1973 a Landsat pass occurred over the New Hampshire area at peak flood conditions. Due to partial cloud cover the entire surface area of the flood waters could not be accurately delineated; however, the satellite imagery did provide a look at peak flood conditions in the Franklin Falls reservoir.

#### Results and discussion

The areal extent of water was best displayed in the near infrared band, MSS 7. Therefore, MSS band 7 grayscale printouts at a scale of 1:24,000 were obtained of the Franklin Falls reservoir area for the



dates of 27 October 1972 (image ID 1096-15065) at low-water stage and 6 July 1973 (image ID 1348-15064) during flood stage. The MSS band 7 grayscale overprint symbols representing energy intensity levels were used in differentiating the reservoir water from the land.

Figure 11 shows the Franklin Falls reservoir area on 27 October 1972. The extent of water is delineated on the grayscale printout by a solid line. The dotted line indicates the outline of the Pemigewasset River (elevation ranging from 98 to 110 m (320 to 360 ft)) obtained from USGS topographic maps. Both outlines show very good agreement of the areal extent of water at the low-water reservoir stage.

Figure 12 shows the Franklin Falls area on 6 July 1973. The extent of water is delineated by a solid line on the grayscale printout and the dashed line indicates the extent of water in the northern part of the reservoir area, which had to be estimated because of cloud cover. The dotted line shows the maximum inundation level of 112.6 m (369.5 ft) for 6 July 1973 delineated from USGS topographic maps. Again, the agreement of the areal extent of water between the computer printout and the ground truth data is extremely good.

The number of acres of water was quantified for the 27 October and 6 July Landsat scenes. Table VI shows the total number of pixels and acreage determined to be water within the reservoir area for both dates. It shows approximately 60% more water in the Franklin Falls reservoir on 6 July 1973 than on 27 October 1972, which was as expected (McKim et al. 1975a).

Table VI. Areal extent of water within the Franklin Falls reservoir area on 27 October 1972 and 6 July 1973.

<u>Date</u>	<u>Pixels (no.)</u>	<u>Area (acres)*</u>
27 October 1972	790	1011.2
6 July 1973	1333†	1706.2

\*1 acre = 4046 m<sup>2</sup>

†Estimated

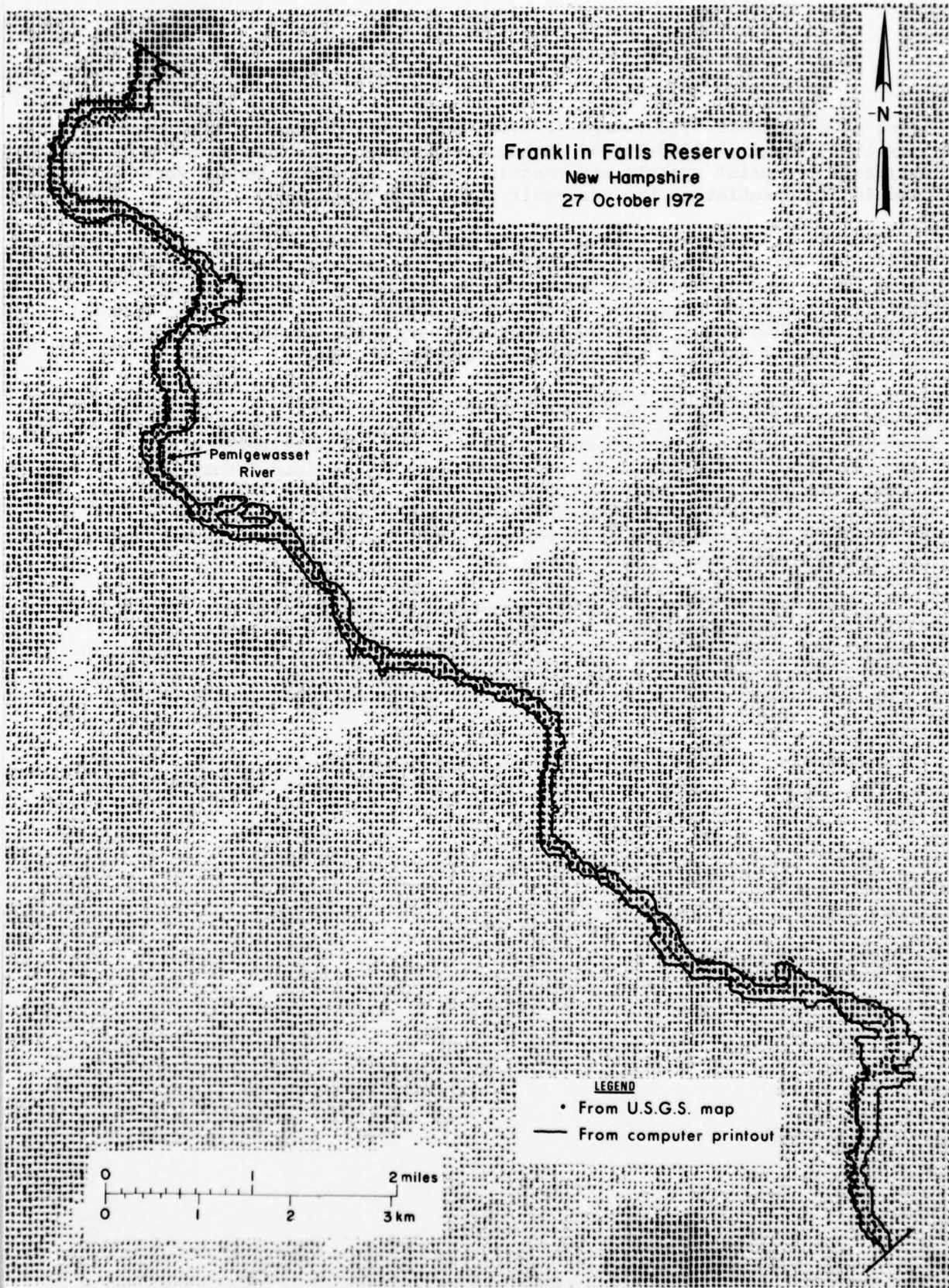


Figure 11. Grayscale printout of the Franklin Falls reservoir area, 27 October 1972.



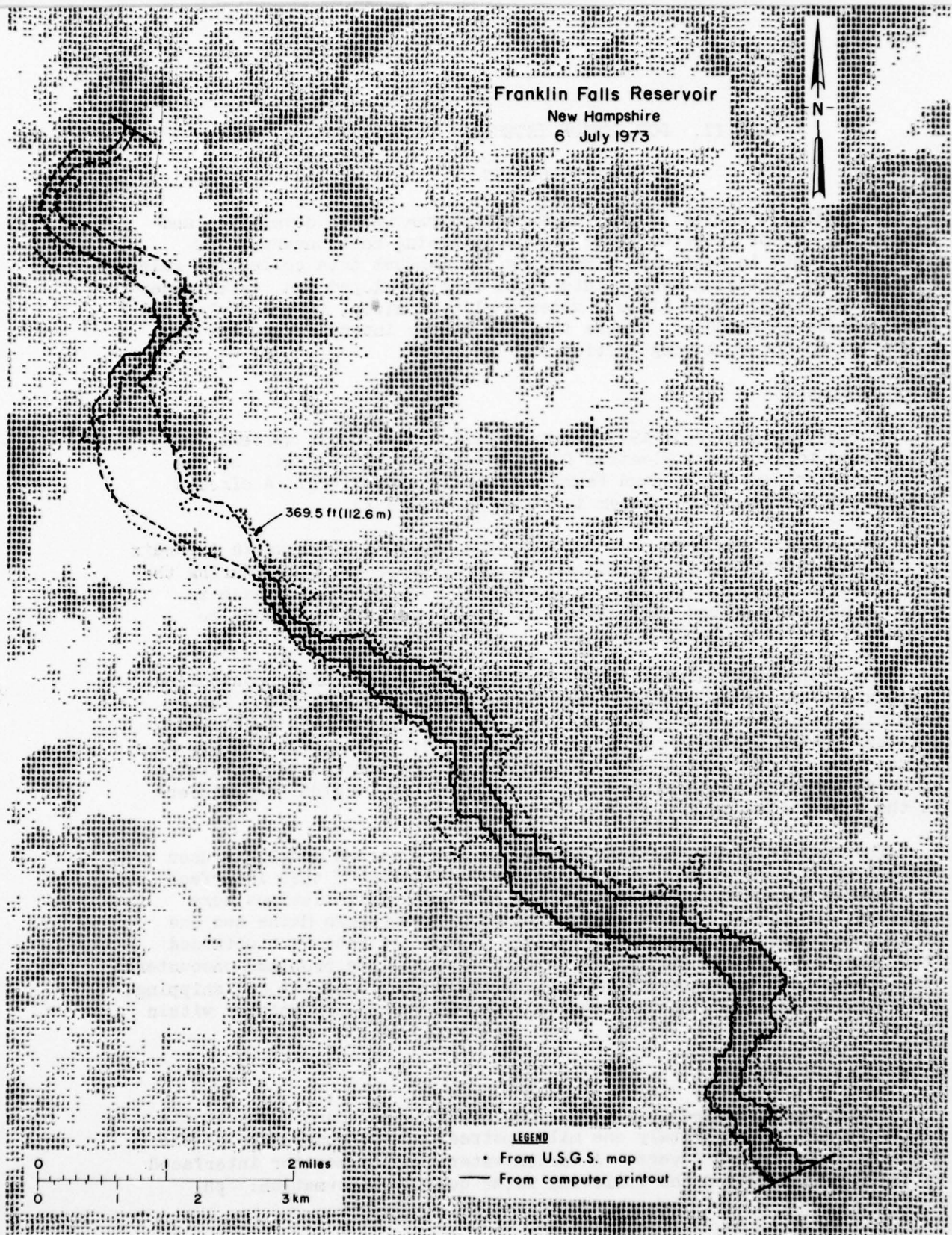


Figure 12. Grayscale printout of the Franklin Falls reservoir area, 6 July 1973.



## PART II. DCP SENSOR INTERFACE DEVELOPMENT

### INTRODUCTION

Secondary emphasis in the Landsat-2 program was on developing and evaluating sensor interfaces for use in obtaining environmental and hydrologic data in near-real time using the Landsat data collection relay system. The following sensor interfaces were developed and tested under field conditions: snow pillow, water quality monitor, thermocouples and a tensiometer/transducer. These four DCP sensor interface systems are described in the following sections.

#### Snow pillows

During the summer of 1975 two snow pillow transducer systems were interfaced to a General Electric DCP and installed at Ninemile on the St. John River and at Michaud Farms on the Allagash River. A circuit diagram of the interface system is shown in Figure 13.

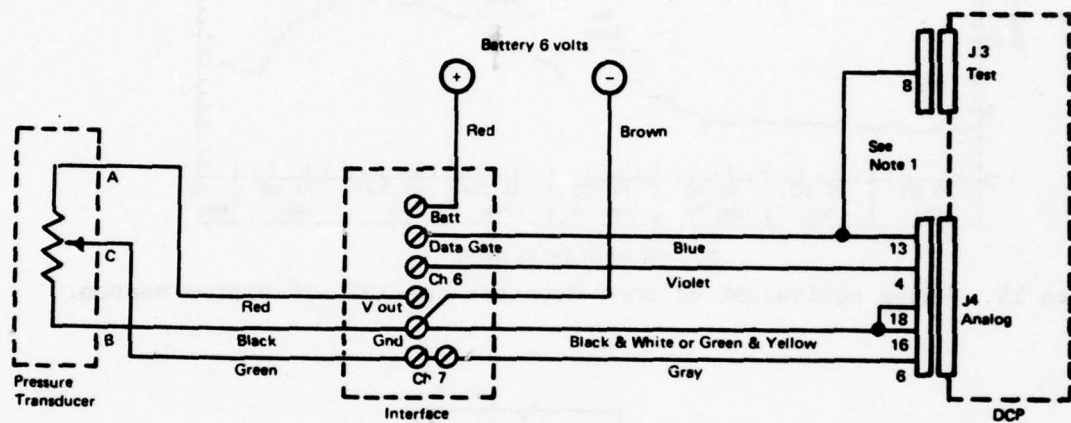
The computer program used for decoding the data is shown in Appendix B. A graph of the water equivalent data from these two sites during the 1975-76 winter season is shown in Figure 14. The sudden increase in water equivalent around early April for the Ninemile site cannot be explained and is probably not real.

The transducers used in the interface were tested under controlled temperature and pressure conditions during the summer of 1976. The resulting temperature calibration curve for the transducers indicated that the system became erratic below 0°C (32°F). Therefore, a CRREL in-house study on the reliability of a number of transducers was initiated and a different transducer was used to replace the original transducer in the snow pillow interface.

The snow pillow transducer system using the second model was used during the 1976-77 winter season. A circuit diagram of this interface is shown in Figure 15. Two snow pillow interface installations were emplaced, one at the Allagash Falls location in northern Maine and one at NED, Waltham, Massachusetts. However, incorrect data were obtained from these two systems during the 1976-77 season. The problems encountered were inadvertent breakage of the transducers during handling and shipping, and unexplained, questionable data telemetered by the transmitter within the DCP.

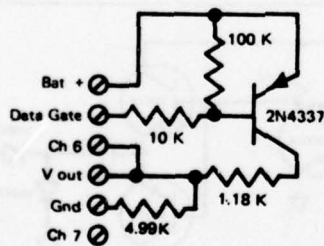
#### Water quality monitor

A DCP was installed on the St. John River in northern Maine at the Dickey Bridge, approximately one mile upstream of the confluence of the St. John and Allagash Rivers. A Martek water quality monitor interfaced to the DCP transmitted the following water quality information: pH,



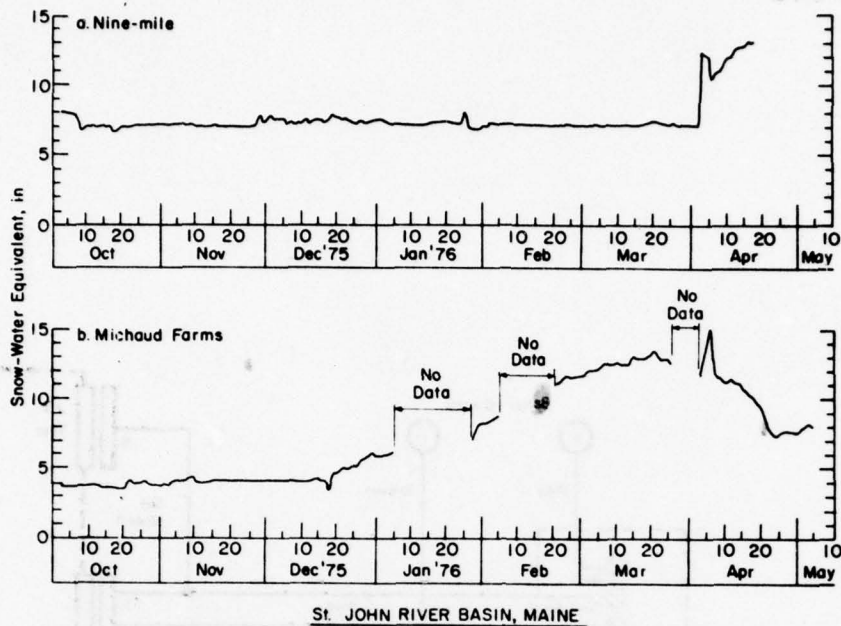
Note 1: On some DCP's, data gate is not wired to pin 13, J4; in which case connect data gate lead to pin 8, J3.

a. INTERCONNECTION DIAGRAM - Snow pillow transducer to interface to DCP



b. CIRCUIT DIAGRAM - Interface

Figure 13. Circuit diagram of the snow pillow interface used in the 1975-76 winter season.



ST. JOHN RIVER BASIN, MAINE

Figure 14. Water equivalent of snow data for the 1975-76 winter season.

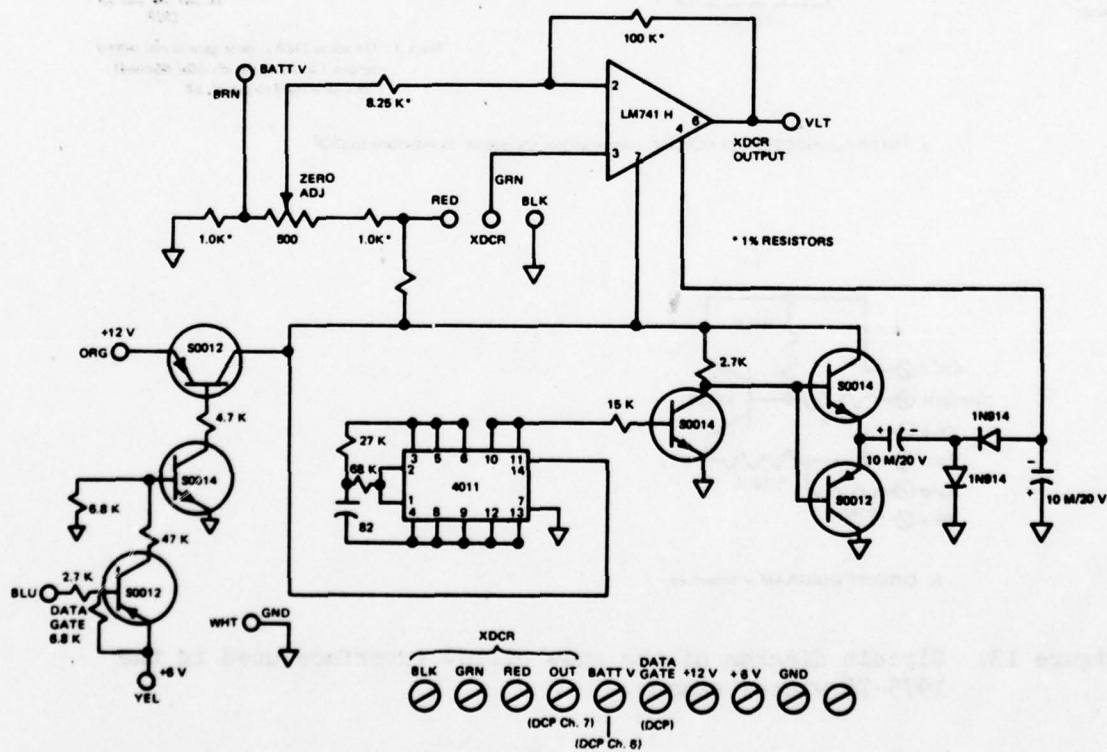


Figure 15. Circuit diagram of snow pillow interface used in the 1976-77 winter season.



dissolved oxygen, river stage, water temperature and conductivity. The sensor interface was developed and the computer program used to decode the data written during the Landsat-1 experiment (Cooper et al. 1975, McKim et al. 1975c).

The water quality data from this exercise are shown in Figure 16. The dissolved oxygen probe operated intermittently and the river stage measured less than 61 cm (2 ft); therefore, these data were not included in Figure 16. The data from the pH probe between 10-17 August probably did not fluctuate as indicated on the graph. The water quality data compared favorably with on-site analysis of these parameters during the first week of operation. The water quality information will serve as part of the baseline data for the upper St. John River.

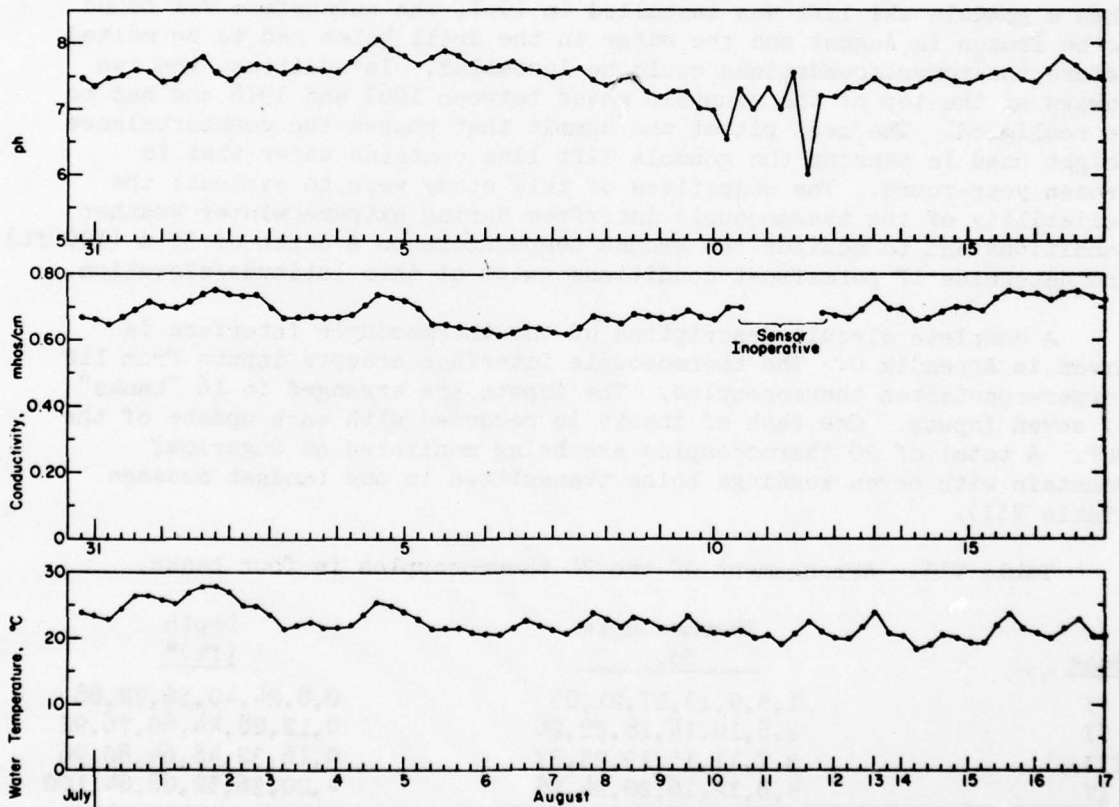


Figure 16. Water quality data from the St. John River (summer 1976).

### Thermocouple interface

A site for testing a thermocouple interface to monitor air and ground temperatures was located at Sugarloaf Mountain, Maine (45°02'56"N, 70°23'21"W). This was the first time the thermocouple interface was tested under field conditions. The data are presently being evaluated for accuracy. The emplacement and interfacing techniques developed during this field experiment will be used for installation of thermocouples in Alaska. When validated, this temperature measurement system could be used in reservoirs to monitor water temperature on a daily basis.

There is evidence of permafrost on the upper 305 m (1000 ft) of Sugarloaf Mountain. The summit of the mountain is veneered with active, turf-banked terraces which have moved downslope during the past five years at a rate of approximately 5.1 cm/yr (2 in./yr) (Borns 1975). When a gondola ski lift was installed in 1967, the subsurface was found to be frozen in August and the water in the drill holes had to be melted before the tower foundations could be installed. In addition, the two towers at the top of the mountain moved between 1967 and 1976 and had to be realigned. The deep pit at the summit that houses the counterbalance weight used in tensing the gondola lift line contains water that is frozen year-round. The objectives of this study were to evaluate the reliability of the thermocouple interface during extreme winter weather conditions and to monitor the ground temperature to a depth of 30 m (100 ft) and determine if permafrost conditions exist at this latitude/elevation.

A complete circuit description of the thermocouple interface is given in Appendix C. The thermocouple interface accepts inputs from 112 copper-constantan thermocouples. The inputs are arranged in 16 "banks" of seven inputs. One bank of inputs is recorded with each update of the DCP. A total of 28 thermocouples are being monitored at Sugarloaf Mountain with seven readings being transmitted in one Landsat message (Table VII).

Table VII. Arrangement of the 28 thermocouples in four banks.

<u>Bank</u>	<u>Thermocouple No.</u>	<u>Depth (ft)*</u>
I	1,5,9,13,17,21,25	0,8,24,40,56,72,88
II	2,6,10,14,18,22,26	0,12,28,44,60,76,92
III	3,7,11,15,19,23,27	0,16,32,48,64,80,96
IV	4,8,12,16,20,24,28	4,20,36,52,68,84,100

\*1 ft = 0.3 m

The temperature measurement range of the thermocouple interface unit is -34 to +32°C (-29 to +90°F). The resolution of a DCP data word is  $\pm 0.25^\circ\text{C}$  ( $\pm 0.5^\circ\text{F}$ ), or 10  $\mu\text{V}$ , and the copper-constantan wire is

guaranteed to be accurate within 0.5 to 0.75°C (0.9 to 1.35°F). Therefore, the accuracy of the temperature data is  $\pm 0.5^\circ\text{C}$  (0.9°F). The results from this experiment will be reported after the field interfacing techniques have been successfully tested.

#### Tensiometer/transducer system interface

A tensiometer/transducer system has been successfully interfaced to the Landsat data collection system (McKim et al. 1975a). The interface system enables moisture tension and soil volumetric moisture content data to be obtained in near-real time.

The instrument is currently being tested under simulated field conditions at CRREL. Preliminary results indicate that tension as low as 10 cm (4 in.) and as high as 900 cm (354 in.) of water can be obtained.

Typical data for a soil that has a bulk density of 1.37 g/cm<sup>3</sup> with a specific gravity of 2.63 and a volume of voids of 47.9% are shown in Table VIII. In the initial series of tests, tensiometer values could be obtained that ranged from about 10 to 150 cm (4 to 59 in.) of water. Previously it has been very difficult to get accurate and reliable numbers on field moisture tension less than 300 cm (118 in.). It is suggested that this method will not only give reliable data for this range of values, but supply the information in near-real time. The precision and accuracy of the data are being evaluated.

#### SUMMARY AND CONCLUSIONS

##### Snow cover analysis

Preliminary analysis of the Landsat digital data using the GISS computer algorithms for the 11 February 1973 scene showed that the radiance of the snow cover/vegetation varied from approximately 20 mW/cm<sup>2</sup> sr in non-vegetated areas to less than 4 mW/cm<sup>2</sup> sr for densely covered forested areas. Comparison of the digital data from three snow course sites in the Dickey-Lincoln School Lakes area with the radiance value of the snowpack at these sites indicated that the total radiance of the pixels contained in the snow courses varied from 5.34 to 7.74 mW/cm<sup>2</sup> sr with the average radiance value being 6.4 + 0.6 mW/cm<sup>2</sup> sr. The water equivalent of the snowpack for this range of radiance values was approximately 24.1 cm (9.5 in.) of water. Since data from only three snow courses were available, the correlation between radiance values and water equivalent of the snowpack still needs to be tested. However, if the relationship holds with more extensive ground truth data in the Dickey-Lincoln area, it is anticipated that extrapolation of radiance values for snow cover/vegetation in large areas of the watershed may prove useful in mapping the extent of snow cover vegetation related to a water equivalent value. This relationship would need to be verified to test the accuracy of using satellite imagery in predicting spring runoff.



Table VIII. Typical data from the tensiometer/transducer interface system.

USA CRREL Test Set  
Hanover, New Hampshire  
DCP 7110

Date	Time	Tensiometer (cm of water)	Error	Calculations	
				% Water (volume)	% Voids filled with air
2/22	1752	-10.7	27	40.0	17.0
2/23	622	-10.7	07	40.0	17.0
2/23	1801	-22.5	07	40.0	17.0
2/24	628	-22.5	07	40.0	17.0
2/24	1804	-22.5	86	40.0	17.0
2/25	633	-28.3	07	39.5	17.5
2/25	814	-22.5	07	40.0	17.0
2/26	638	-28.3	07	39.5	17.5
2/26	820	-28.3	07	39.5	17.5
2/27	644	-34.2	07	38.5	19.7
2/27	829	-34.2	07	38.5	19.7
3/1	1832	-40.1	07	37.8	21.1
3/2	702	-40.1	07	37.8	21.1
3/2	844	-40.1	07	37.8	21.1
3/3	1703	-51.9	07	36.0	24.8
3/3	2030	-57.8	80	35.4	26.1
3/4	856	-57.8	07	35.4	26.1
3/6	1721	-81.3	07	30.2	37.0
3/6	1859	-81.3	80	30.2	37.0
3/7	911	-87.2	07	29.2	39.0
3/8	735	-93.1	07	28.8	39.9
3/8	924	-99.0	07	27.9	41.8
3/9	741	-110.7	07	26.6	44.5
3/9	924	-110.7	07	26.6	44.5

The different changes in radiance for the 23 July 1973 ( $3 \text{ mW/cm}^2 \text{ sr}$ ) and 11 February 1973 ( $5.34 - 7.74 \text{ mW/cm}^2 \text{ sr}$ ) Landsat scenes for the three snow course sites were attributed to the presence of snow and vegetation changes in the 11 February scene. Multispectral training signatures for four snow cover/vegetation classes were derived from the four-band energy values for the 11 February 1973 Landsat scene. These signatures were applied to the digital data and four snow cover/vegetation classes were mapped.

#### Wetlands mapping

Landsat digital data were used in a wetlands analysis of the Merrimack River estuary for the date of 6 July 1976. A multispectral signature was developed for a wetlands category from two training sites located on the north side of the Merrimack River estuary. Wetlands were mapped with an accuracy of 75% when compared to ground truth information.

#### Mapping of flooded areas

Landsat digital data were also used to delineate flood waters in the Franklin Falls reservoir area, New Hampshire, for the 6 July 1973 scene. Low-water reservoir and flood water stages were mapped from grayscale printouts of MSS band 7 for 27 October 1972 and 6 July 1973, respectively. Comparison with ground truth information indicated very good agreement with the Landsat digital data. Approximately 60% more water was observed on the 6 July 1973 scene than on 27 October 1972, which was as expected.

#### DCP sensor interface development

Snow pillow transducer systems for measuring the water equivalent of the snowpack in northern Maine were interfaced and field tested. Problems with temperature sensitivity of the transducers were encountered during the first testing period (1975-76). Problems were also encountered during the second testing period (1976-77) with inadvertent breakage of the transducers and questionable data from a DCP transmitter.

A water quality monitor interfaced to the DCS was also field tested in northern Maine. The water quality data compared favorably to on-site chemical analysis. The water quality data obtained will be used as baseline information for the Dickey-Lincoln School Lakes Project.

A thermocouple system was successfully interfaced and field tested at Sugarloaf Mountain, Maine. Temperature data from the surface to a depth of 30 m (100 ft) were transmitted through the Landsat DCS. The emplacement and interfacing techniques developed during this experiment will be used for future installation of thermocouples at Alaskan sites. In addition, this temperature measurement system could be used in reservoirs to monitor water temperature on a daily basis.

A tensiometer/transducer system was successfully interfaced to the Landsat DCS. Laboratory results indicated that tension as low as 10 cm (4 in.) and as high as 900 cm (354 in.) of water can be obtained. Presently the system is being tested under field conditions.

#### RECOMMENDATIONS

The following recommendations are made based on the results of the Landsat-2 investigation.

1. The Landsat CCT's for specific areas of interest in New England should be furnished to the user on a timely basis (within three days) for use in evaluating the snow cover of a watershed during critical spring runoff periods (March through May). The 9-day coverage provided by the Landsat satellites is not adequate for the operational needs of the NED Control Center. However, in times of critical spring flooding the timely use of the available Landsat imagery and CCT's would be extremely valuable for a regional evaluation of the extent of snow cover.

2. The MSS band 7 digital data should be used for mapping the extent of flood waters since this multispectral band provided the most information in the delineation of the water/land boundary.

3. When a mapping accuracy of 75% is required, the Landsat digital data should be used in regional evaluation of wetlands.

4. In remote locations the Landsat DCS can be used on an operational basis for monitoring hydrologic and environmental parameters.

#### FUTURE PLANS

The snow cover analysis work will continue with the FY78 Civil Works sponsored work unit entitled, "Snow Cover Analysis in New England Using Landsat Digital Data." Site selection based on vegetation, slope, aspect and elevation will be accomplished in the Dickey-Lincoln School Lakes project area and other selected watersheds. Ground truth measurements of snow depth and water equivalent at the selected sites will be taken in conjunction with times of the Landsat imagery acquisition. A meteorological station will be installed to obtain data on local climatic conditions. As available, cloud-free Landsat CCT's will be acquired for the 1977-78 winter season and analyzed.

Cloud-free Landsat CCT's may also be obtained over the Sleepers River Watershed in Danville, Vermont, for the 1972-77 winter seasons. Detailed measurements of the snow cover are available at this site from December 1968 to present. This watershed was chosen because it is hydrologically representative of most of the glaciated upland areas in New England and is extensively instrumented.



Results from these two areas will be developed to further evaluate the method of obtaining the water equivalent of the snow cover using Landsat digital data.

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APPENDIX A

Presentations

Tenth International Symposium on Remote Sensing of Environment, Environmental Research Institute of Michigan, Ann Arbor, Michigan, 6-10 October 1975, "Applications of Remote Sensing for Corps of Engineers Programs in New England"\* by H.L. McKim#, C.J. Merry, S. Cooper, D.M. Anderson and L.W. Gatto.

International Telemetering Conference, Silver Spring, Maryland, 14-16 October 1975, "Application of the Landsat Data Collection System in Alaska"\* by D.M. Anderson# and H.L. McKim.

Eastern Snow Conference, Belleville, Ontario, Canada, 3-4 February 1977, "Preliminary Analysis of Water Equivalent/Snow Characteristics Using LANDSAT Digital Processing Techniques"\* by C.J. Merry#, H.L. McKim, S. Cooper and S.G. Ungar.

Seminar, NED, Waltham, Massachusetts, 19 March 1975, "Remote Sensing Programs in New England" by H.L. McKim# and C.J. Merry#.

Atlantic Fisheries Biologists Meeting, Newagen, Maine, 10-12 October 1975, "Remote Sensing Program Capabilities" by H.L. McKim#.

Meteorological Satellite Workshop on Data Collection Systems, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico, 26 April 1977, "New England Division Use of Landsat Satellite" (C.J. Merry#).

Seminar, University of Maine, Institute of Quaternary Studies, Department of Geological Sciences, 12 May 1977, "Permafrost in New England with Special Emphasis on Sugarloaf Mountain, Maine" by C.J. Merry#.

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\*Published report appears in the Proceedings for the Symposium  
#Individual presenting paper

### Meetings

Meeting held at CRREL to discuss cooperative remote sensing programs between NASA GISS and CRREL, 8 January 1976 (McKim, Merry).

Demonstration of Landsat DCS bank held at the Boston, Massachusetts, USGS Regional office, 10 February 1976 (McKim, Merry).

Consultation on the use of Landsat imagery for detection of red tide with CRREL/NED personnel by Mr. Jerry McCall (Massachusetts Department of Environmental Quality Engineering), 8-12 April 1976 (McKim, Merry, Buckelew, Cooper).

Meeting held at Sugarloaf Mountain, Maine, to discuss with Dr. Harold Borns (University of Maine) and Mr. Hazen McMullen (Sugarloaf Mountain Corporation) the emplacement of a DCP interfaced to a 100-ft thermocouple cable, 24 June 1976 (McKim, Cooper, Hetu, Merry).

NASA Interview/Briefing held at NASA GSFC, Greenbelt, Maryland, 19 October 1976 (McKim, Merry, Buckelew).

Meeting held at NASA GISS, New York City, New York, to discuss ongoing Landsat digital analysis with Dr. Stephen Ungar (Director, Earth Resources Program), 20 October 1976 (McKim, Merry).

Participation by CRREL in an Informal Earth Resources Program Review Meeting held at NASA GISS, 2 November 1976 (Merry).

APPENDIX B. Computer programs used to convert the DCP hexadecimal data cards into real numbers.

```

5. FILE APPEND WIDTH(132,132) #2="DCPUUT"
10. DIM E(12),D(16)
20. FILE #1="DATAIN"
40. MAT READ E
90. DATA 31,28,31,30,31,30,31,31,30,31,30,31
204. PRINT #2, "1"
210. PRINT #2, TAB(18)"NEW ENGLAND DIVISION"
215. PRINT #2, TAB(18)"WALTHAM, MASS"
220. PRINT #2, TAB(21)"SNOW PILLOW DATA"
230. PRINT #2,
240. PRINT #2, " DATE TIME RSID ENR/QUAL SNOW WATER"
245. PRINT #2, " CONTENT (IN)"
250. PRINT #2,
260. L ##/## ### # ## ##
265. LET Z=0
270. IF END # 1 THEN 1000
280. INPUT #1, I$
290. IF VAL(I$(1,4)) < 7325 THEN 270
330. LET D1=VAL(I$(7,3))
340. LET M1=VAL(I$(10,2))
350. LET M1=VAL(I$(12,2))
360. IF M1 < 7 THEN 390
370. LET M1=M1*7
380. GO TO #10
390. LET M1=M1+17
400. LET D1=D1+1
410. LET T1=M1+M1/60
420. IF ABS(T1-T2) < 1 THEN 270
430. LET T3=T1-T2
440. IF T3 > 0 THEN 460
450. LET T3=T3+24
460. LET T2=T1
465. LET T3=T2
470. LET T4=M1+100+M1
500. FOR I= 1 TO 12
510. IF D1 <= E(I) THEN 540
520. LET D1=D1+E(I)
530. NEXT I
540. LET D2=I
550. IF D1 <= D9 THEN 570
560. PRINT #2,
570. LET D9=D1
580. GOSUB 5000
590. LET A=16*D(12)+D(11)
600. LET H=16*D(14)+D(13)
610. LET P=185*B/A/407
611. LET P=P*2
620. PRINT #2 USING 2=0, 02.01,T4,I$(16,1),I$(18,2),P
630. GO TO 270
1000. REM
1010. STOP
5000. FOR I= 1 TO 16
5010. LET JS=TS(20+I,1)
5020. IF JS="A" THEN 5100
5030. IF JS="B" THEN 5120
5040. IF JS="C" THEN 5140
5050. IF JS="D" THEN 5160
5060. IF JS="E" THEN 5180
5070. IF JS="F" THEN 5200
5080. LET D(I)=VAL(JS)
5090. GO TO 5210
5100. LET D(I)=10
5110. GO TO 5210
5120. LET D(I)=11
5130. GO TO 5210
5140. LET D(I)=12
5150. GOTO 5210
5160. LET D(I)=13
5170. GO TO 5210
5180. LET D(I)=14
5190. GO TO 5210
5200. LET D(I)=15
5210. NEXT I
5220. RETURN
5230. END

```

Figure B1. Computer program to decode the hexadecimal data cards for the snow pillow interface located at Allagash Falls, Maine.



```

5.      FILE APPEND WIDTH(132,132) #2="DCPUOT"
10.     DIM E(12),D(16)
20.     FILE #1="DATATN"
80.     MAT HEAD E
90.     DATA 31,28,31,30,31,30,31,31,30,31,30,31
204.    PRINT #2, "1"
210.    PRINT #2, TAB(18)!"DICKY=LINCULN, MAINE"
215.    PRINT #2, TAB(19)!"ALLAGASH FALLS"
220.    PRINT #2, TAB(21)!"SNOW PILLOW DATA"
230.    PRINT #2,
240.    PRINT #2, " DATE      TIME      WSTD      ERR/DUAL      SNOW WATER"
245.    PRINT #2, "                                CUNENT (IN)"
250.    PRINT #2,
260.    I ###          ###          #          ##          ###.#
265.    LET Z=0
270.    IF END # 1 THEN 1000
280.    INPUT #1, I3
290.    IF VAL(I3(1,4))<= 7147 THEN 270
330.    LET D1=VAL(I3(7,3))
340.    LET M1=VAL(I3(10,2))
350.    LET M1=VAL(I3(12,2))
360.    IF M1< 7 THEN 390
370.    LET M1=M1*7
380.    GO TO 410
390.    LET M1=M1+17
400.    LET D1=D1+1
410.    LET T1=M1+M1/60
420.    IF ABS(T1-T2)<1 THEN 270
430.    LET T3=T1-T2
440.    IF T3> 0 THEN 460
450.    LET T3=T3+24
460.    LET I2=T1
465.    LET T3=12
470.    LET T4=M1+100+M1
500.    FOR I= 1 TO 12
510.    IF D1 <= E(I) THEN 540
520.    LET D1=D1+E(I)
530.    NEXT I
540.    LET D2=T
550.    IF D1#D9 THEN 570
560.    PRINT #2,
570.    LET D9=D1
580.    GOSUB 5000
590.    LET A=16*D(12)+D(11)
600.    LET B=16*D(14)+D(13)
610.    IF A=0 THEN 270
610.    LET P=185*B/A/355
611.    LET P=P*Z
620.    PRINT #2 USING 260, D2,D1,T4,I3(16,1),I3(18,2),P
630.    GO TO 270
1000.   REM
1010.   STOP
5000.   FOR I= 1 TO 16
5010.   LET JS=I3(20+I,1)
5020.   IF JS="A" THEN 5100
5030.   IF JS="B" THEN 5120
5040.   IF JS="C" THEN 5140
5050.   IF JS="D" THEN 5160
5060.   IF JS="E" THEN 5180
5070.   IF JS="F" THEN 5200
5080.   LET D(I)=VAL(JS)
5090.   GO TO 5210
5100.   LET D(I)=10
5110.   GO TO 5210
5120.   LET D(I)=11
5130.   GO TO 5210
5140.   LET D(I)=12
5150.   GOTO5210
5160.   LET D(I)=13
5170.   GO TO 5210
5180.   LET D(I)=14
5190.   GO TO 5210
5200.   LET D(I)=15
5210.   NEXT I
5220.   RETURN
5230.   END

```

Figure B2. Computer program to decode the hexadecimal data cards for the snow pillow interface located at NED, Waltham, Massachusetts.

```

5. FILE APPEND "TOTM(132,132) 020DCP00T"
10. DIM C(12),D(16),U(20),X(20)
20. LET A33=805102E+2
30. LET P390=2700939E4
40. MAT HEAD C
45. REM FOR NON LEAP YEARS CHANGE THE 20 TO A 28 BELOW
50. DATA 31,20,31,30,31,30,31,30,31,30,31
60. LET P982=3.14159/3.
70. LET G00=113/27
80. GO SUB 100
90. GO TO 210
100. PRINT #2, "1"
110. PRINT #2,
120. PRINT #2, TAB(25)"GROUND TEMPERATURE DATA"
130. PRINT #2, TAB(25)"SUGARLOAF MOUNTAIN MAINE"
140. PRINT #2,
150. PRINT #2,
160. PRINT #2, "MSID DATE TIME CHN"
170. PRINT #2, " DEPTH TEMP C TEMP F ERN"
180. PRINT #2,
190. LET L=0
200. RETURN
210. MAT HEAD U
220.
230. DATA 0,6,24,40,50,72,80,0,12,20,40,60,76,92
240. DATA 0,16,32,40,64,80,96,4,20,36,52,60,84,100
250. DATA 1,9,13,17,21,25,2,6,10,14,18,22,26
260. DATA 3,7,11,15,19,23,27,4,8,12,16,20,24,28
270. 1 5 00/00 0000 00
280. 1 500 0000.0 0000.0 00
290. FILE #10"DATA1"
300. IF END #1 THEN 1030
310. INPUT #1, I5
320. IF VAL(I5(1,4)) <= 7125 THEN 300
330. LET D20=VAL(I5(7,3))
340. LET T20=VAL(I5(10,4))
350. IF T2<500 THEN 370
360. LET T2=T2-500
370. GO TO 590
380. LET D2=D2*1900
390. LET D2=D2*1
400. FOR I=1 TO 12
410. IF D2=C(I) THEN 430
420. NEXT I
430. LET D2=D2+100*02
440. IF D2=09 THEN 470
450. PRINT #2,
460. LET L=L+1
470. LET D9=D2
480. LET D5=INT(D2/100)
490. LET D6=D2-05*100
500. IF ABS(I2-T9)<100 THEN 300
510. LET T9=I2

```

```

520. FOR I=1 TO 14
530. LET J9=I5(20+1,1)
540. IF J9="A" THEN 620
550. IF J9="B" THEN 640
560. IF J9="C" THEN 660
570. IF J9="D" THEN 680
580. IF J9="E" THEN 700
590. IF J9="F" THEN 720
600. LET D(I)=VAL(J9)
610. GO TO 730
620. LET D(I)=10
630. GO TO 730
640. LET D(I)=11
650. GO TO 730
660. LET D(I)=12
670. GO TO 730
680. LET D(I)=13
690. GO TO 730
700. LET D(I)=14
710. GO TO 730
720. LET D(I)=15
730. NEXT I
740. LET B0(1)
750. LET PAB=INT(I5(18)/A100)
760. LET P=P+1
770. LET P1=(P*1)07+1
780. LET P2=P1*6
790. LET I=35
800. FOR J=1 TO P2
810. LET YAD=INT(I5(11)/A100)
820. LET I=I+2
830. IF Y2=128 THEN 845
840. LET V=V+Y
850. GO TO 850
860. LET V=V+28
870. LET Y=INT(I5(11)/100)
880. IF Y=40 THEN 890
890. IF X(J)=20 THEN 950
900. LET CS=80R((I+37755E10*(.00907508E00V))1(2)/4)/.4054735E19)
910. LET PAB=INT(I5(18)/A100)
920. LET X1=2*80R(.4920027/3)*C08(P6/3+.209039E1)
930. LET YX1=P5/3
940. LET V1=V+9/5*32
950. PRINT #2 USING 270, I5(16,1), 05, D6, 12, X(J), I
960. PRINT #2 USING 280, U(J), V, V1, I5(16,2)
970. LET L=L+1
980. IF L=58 THEN 1000
990. GO TO 1010
1000. GO SUB 100
1010. NEXT J
1020. GO TO 300
1030. END

```

Figure B3. Computer program to decode the hexadecimal data cards for the thermocouple cable interface located at Sugarloaf Mountain, Maine.

## APPENDIX C

### CIRCUIT DESCRIPTION OF THERMOCOUPLE INTERFACE

#### Thermocouple interface

The thermocouple unit was designed to accept inputs from up to 112 copper-constantan thermocouples which are arranged in 16 "banks" of 7 inputs. Each bank of inputs is recorded with an individual update of the data collection platform (DCP). There were 28 thermocouples (four banks) used at the Sugarloaf Mountain installation.

The reference thermocouple junction is compensated to within  $\pm 0.3^{\circ}\text{C}$  over a temperature range of  $-50^{\circ}$  to  $+40^{\circ}\text{C}$  using a combination of five thermistors. The normal measurement temperature range is  $-34^{\circ}$  to  $+32^{\circ}\text{C}$  with a resolution of  $\pm 0.25^{\circ}\text{C}$  or  $10\ \mu\text{V}$ . It is possible to trade range for resolution, or vice versa, by selecting different groups of data bits from the analog-to-digital converter.

The thermocouple unit is designed to operate with a LaBarge Electronics Convertible Data Collection Platform (C/DCP) which has a memory capability. Power requirements are  $+12\ \text{V}$  (nominal) at  $0.5\ \text{ampere}$  and  $5\ \text{V}$  at  $1.0\ \text{milliampere}$ . The  $12\text{-V}$  power is applied only while the C/DCP is acquiring new data.

#### Circuit Description

The electronic components are arranged on nine circuit cards that are identified as follows (Fig. C1):

- Input multiplexer, group I (MX I)
- Input multiplexer, group II (MX II)
- Input multiplexer, group III (MX III)
- Input multiplexer, group IV (MX IV)
- Amplifier and channel multiplexer (AMPL/CHANNEL MUX)
- Analog-to-digital converter (A/D CONV)
- Power supply and reference junction compensator (P.S./REF JCT COMP)
- Latch (LATCH)
- Interface (INTERFACE)

Thermocouple signals are routed through the input multiplexer, consisting of cards MX I, MX II, MX III and MX IV (Fig. C2, C3, C4, C5). Seven input signals are read during one C/DCP update sequence. The 16 banks are numbered 0 through 15. When an update occurs, the next highest numbered bank is read. Thus, after 16 updates a total of 112 inputs have been sampled.



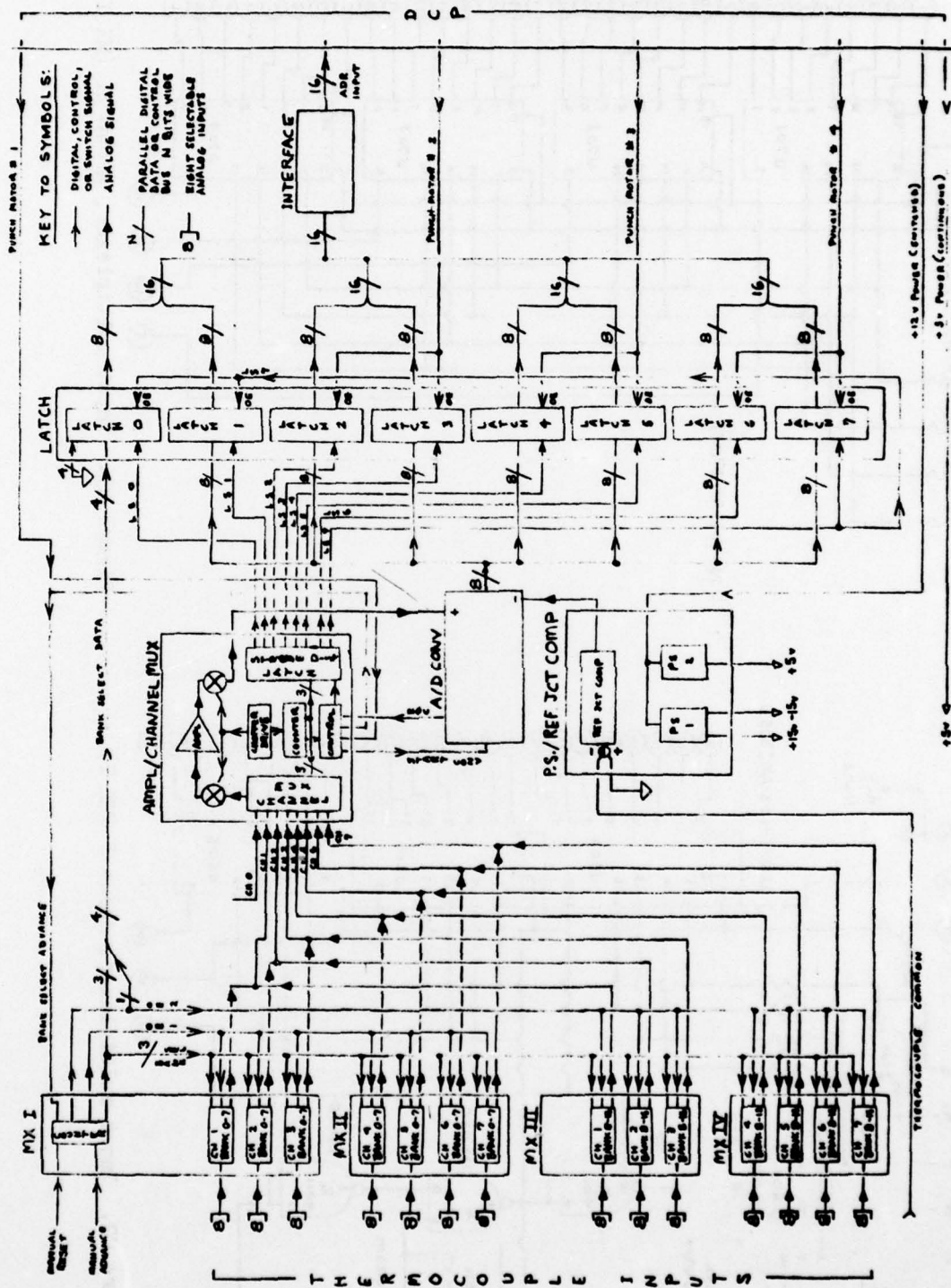


Figure C1. Functional diagram of thermocouple interface arranged on nine circuit cards.

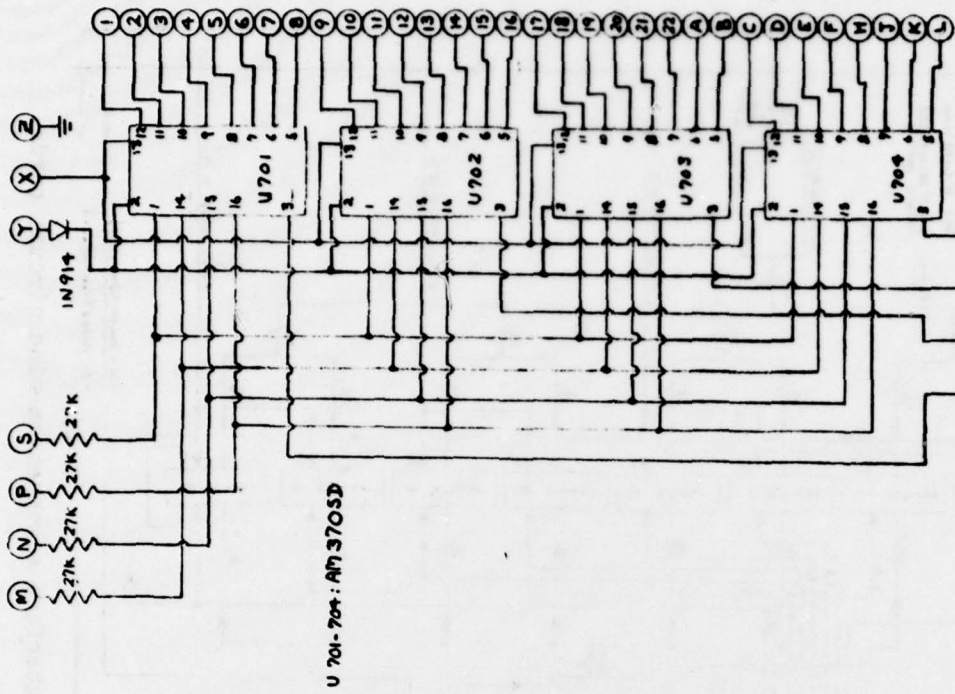


Figure C3. Input multiplexer, group II (MX II).

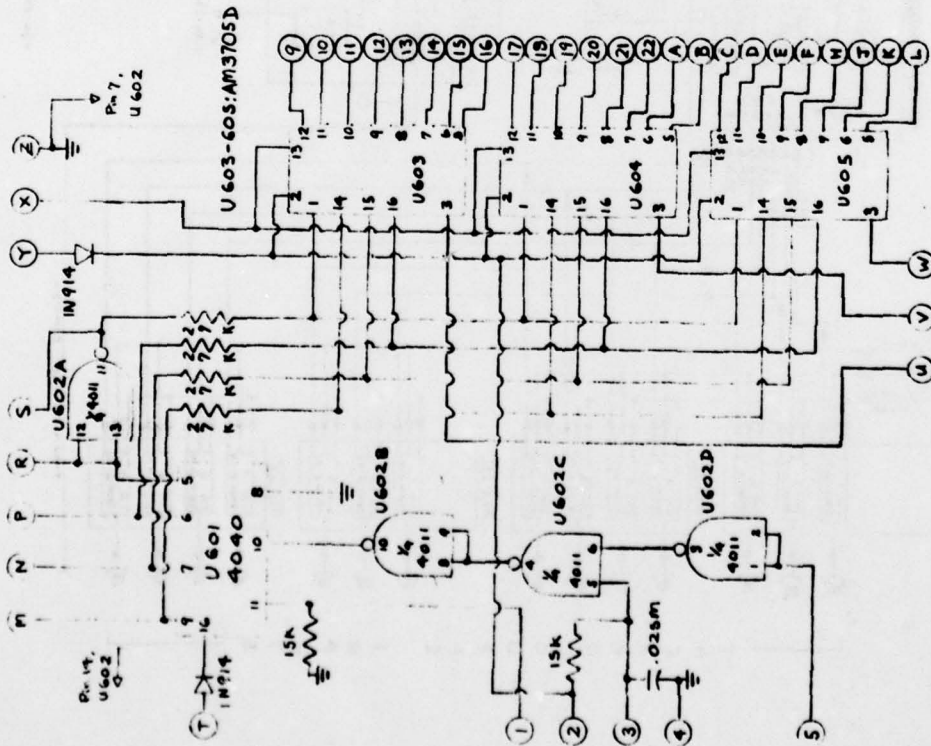


Figure C2. Input multiplexer, group I (MX I).

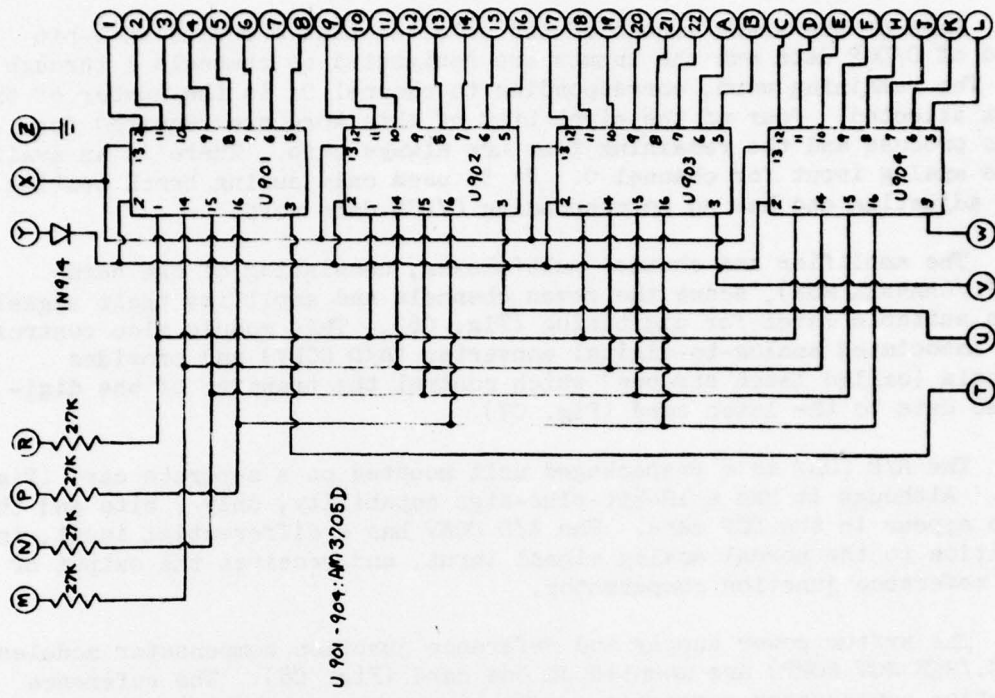


Figure C5. Input Multiplexer, group IV (MX IV).

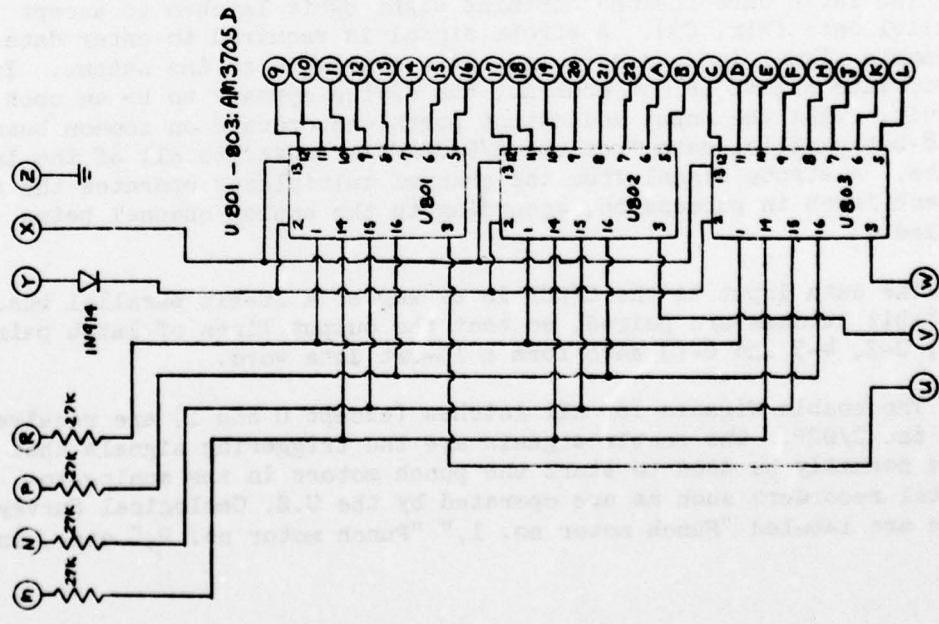


Figure C4. Input multiplexer, group III (MX III).



Each of the seven inputs of the selected bank occupies an 8-bit word of C/DCP data and the inputs are designated as channels 1 through 7. The remaining word, corresponding to channel 0, is the number of the bank selected. Four of the eight bits of this word are required for this process and the remaining four are always zero. There is an available analog input for channel 0. It is used only during bench testing and adjusting and has no corresponding C/DCP data word.

The amplifier and channel multiplexer, consisting of one card (AMPL/CHANNEL MUX), scans the seven channels and amplifies their signals to a suitable level for digitizing (Fig. C6). This module also controls the associated analog-to-digital converter (A/D CONV) and provides signals (called latch strobes) which control the transfer of the digitized data to the latch card (Fig. C7).

The A/D CONV is a prepackaged unit mounted on a separate card (Fig. C7). Although it has a 12-bit-plus-sign capability, only 7 bits and the sign appear in the DCP data. The A/D CONV has a differential input, in addition to the normal analog signal input, and receives the output of the reference junction compensator.

The system power supply and reference junction compensator modules (P.S./REF JCT COMP) are mounted on one card (Fig. C8). The reference junction compensator generates a voltage which matches that produced by the reference junction itself over the temperature range of  $-50^{\circ}$  to  $+40^{\circ}\text{C}$ . The compensating voltage is introduced to the A/D CONV at the same level as the amplifier output. The compensating voltage is the reference junction voltage multiplied by the gain of the amplifier.

The latch card (LATCH) contains eight 8-bit latches to accept parallel data (Fig. C9). A strobe signal is required to enter data and an enable signal is needed to make data available at the output. If the appropriate signal is not present, the device appears to be an open circuit. Thus the input and output ports can operate on common busses. The 8-bit parallel data from the A/D CONV is bussed to all of the latch inputs. A strobe signal from the channel multiplexer operates the input of each latch in succession, according to the analog channel being sampled.

The data input to the C/DCP is by way of a 16-bit parallel bus. The 8-bit latches are paired, so that the output lines of latch pairs (0-1, 2-3, 4-5 and 6-7) each form a 16-bit data word.

The enable signals for all latches (except 0 and 1) are received from the C/DCP. The enable signals are the triggering signals that would normally be used to start the punch motors in the analog-to-digital recorders such as are operated by the U.S. Geological Survey. These are labeled "Punch motor no. 1," "Punch motor no. 2," etc., in all

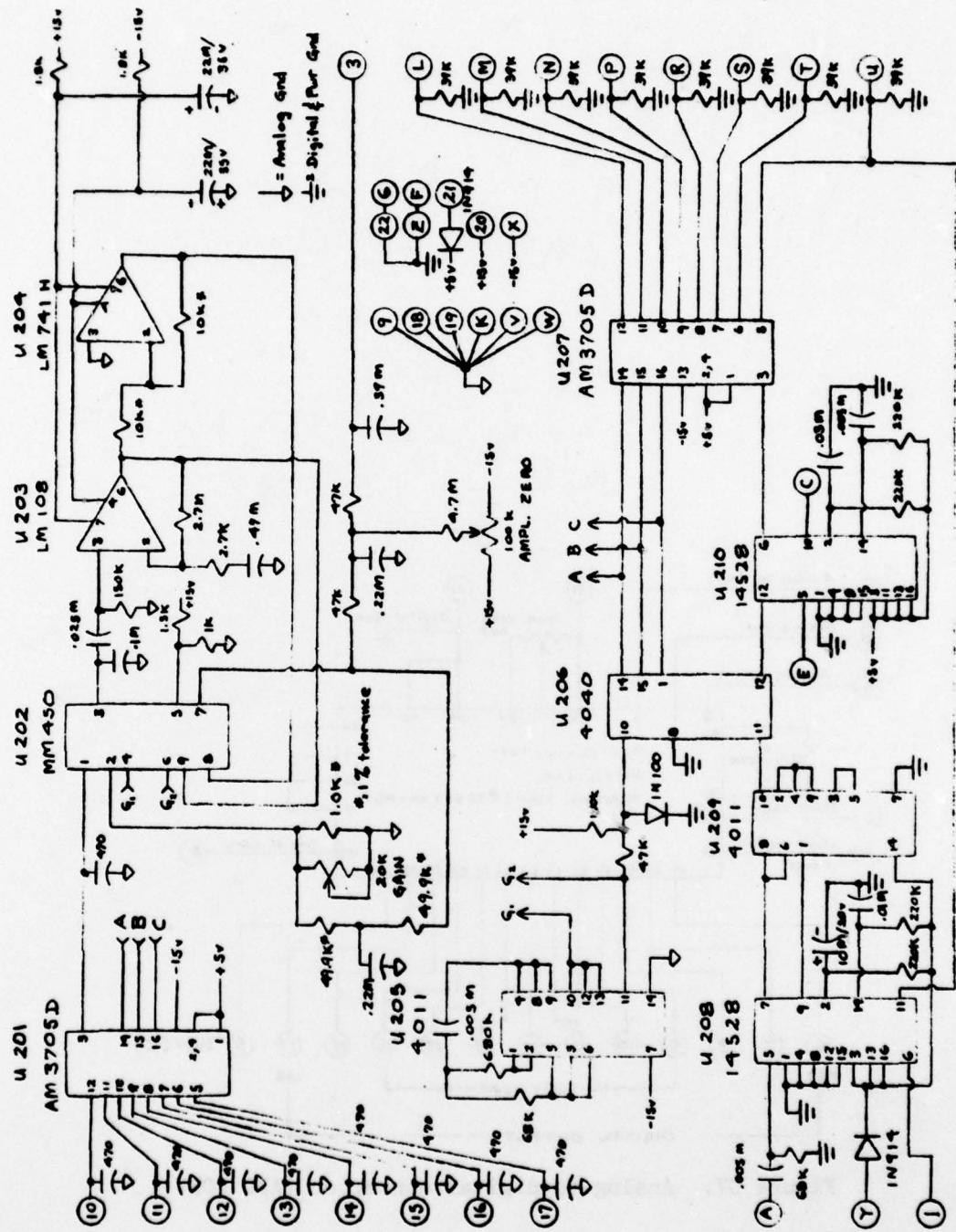


Figure C6. Amplifier and channel multiplexer (AMPL/CHANNEL MUX).

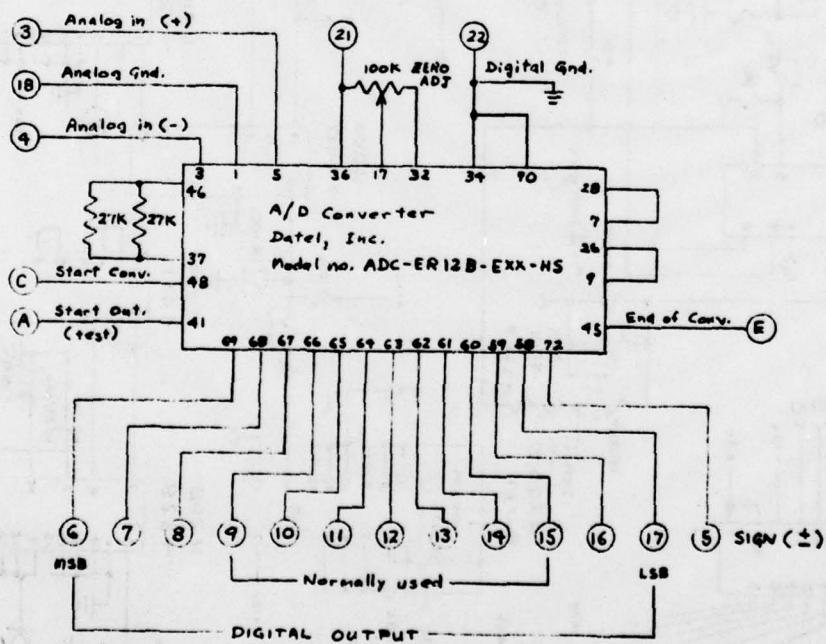


Figure C7. Analog-to-digital converter (A/D CONV).



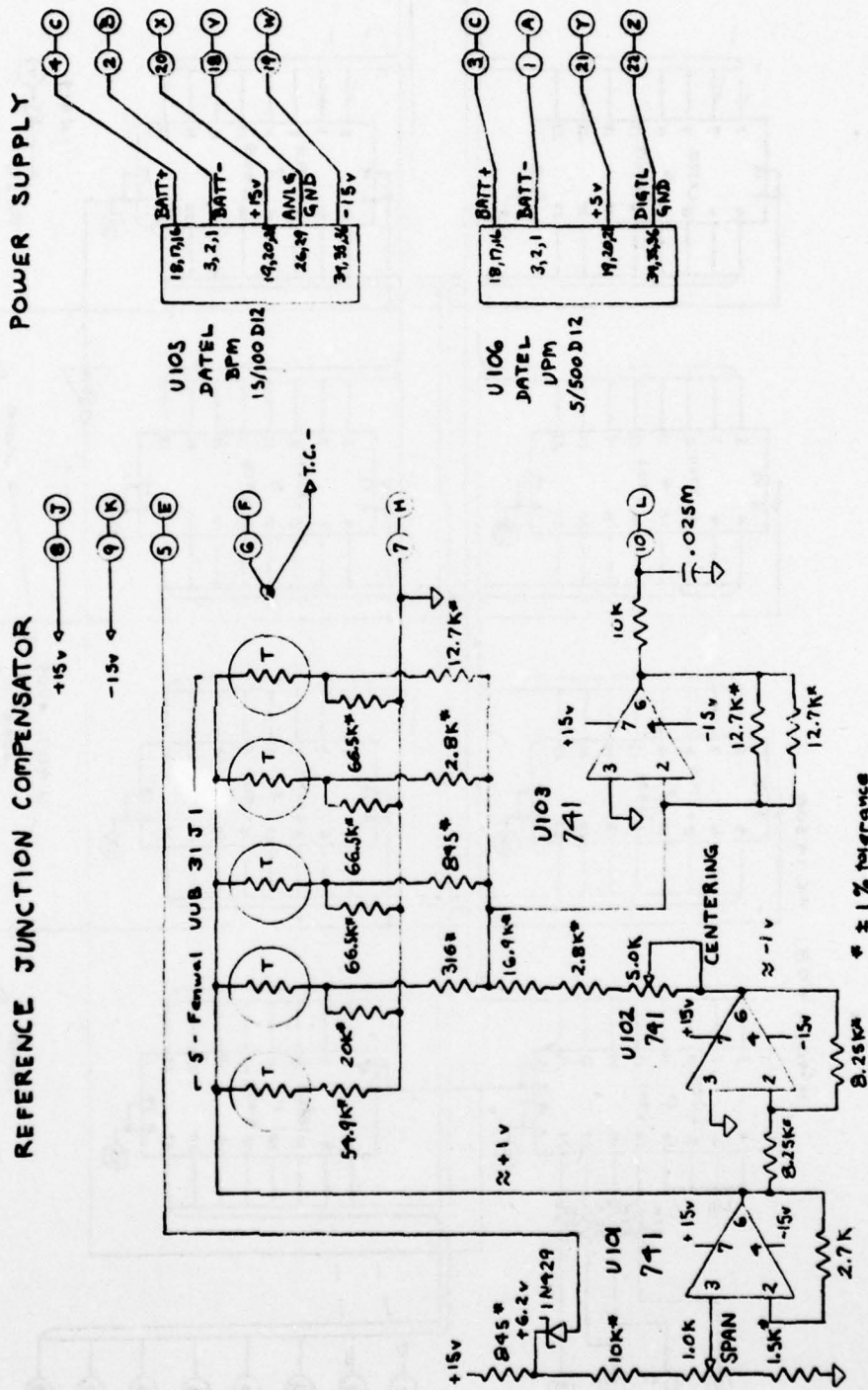


Figure C8. Power supply and reference junction compensator (P.S./REF JCT COMP).

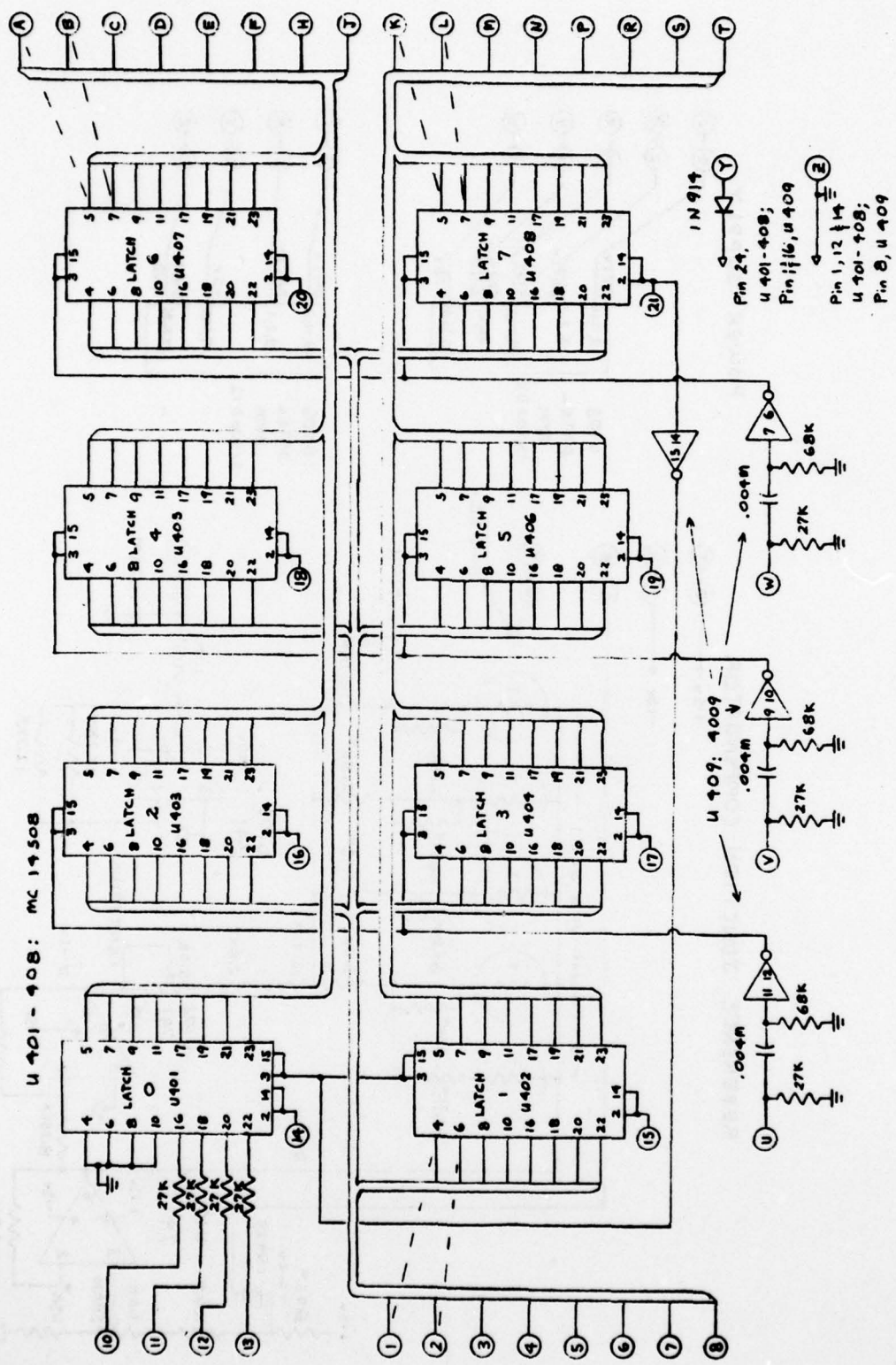


Figure C9. Latch (LATCH).

instructions and diagrams (Fig. C1). Punch motor no. 1 initiates a scan by the channel multiplexer. Punch motor signals 2, 3 and 4 enable latch pairs 2-3, 4-5 and 6-7, respectively, to be started. Since Punch motor no. 1 arrives before latches 0 and 1 can be supplied with data, the input strobe signal for latch 7 also serves as the output enable signal for latches 0 and 1.

Latches 1 through 7 carry thermocouple data, which consist of 7 magnitude bits and one sign bit. Latch 0 carries a 4-bit word to indicate which of the 16 banks of inputs is being scanned. The remaining 4 bits in latch 0 are not presently utilized.

The 16-bit output from the latches goes through a transistor switch array (INTERFACE) to the C/DCP (Fig. C10). The transistors invert the polarity of the data signals and also simulate the grounding-type signal that would come from an analog-to digital recorder.

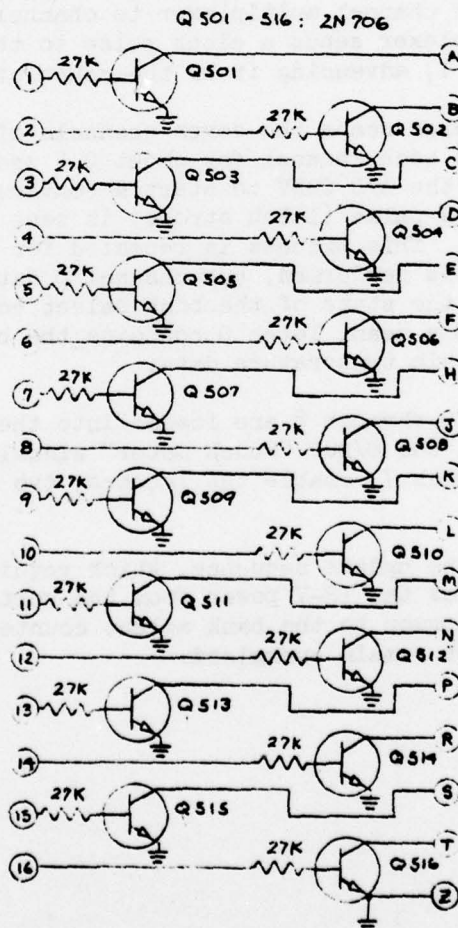


Figure C10. Interface (INTERFACE).



The primary power supply is 12 V DC, supplied from the battery that powers the C/DCP, and is turned on during an update sequence by a semiconductor switch in the C/DCP. The switched 12-V supply powers a +15-V and a +5-V supply which are electrically isolated from each other to avoid current loops. The bank select counter and certain parts of the control portion of the amplifier/channel multiplexer require +5 V continuously. The voltage comes from a regulated supply within the C/DCP.

#### Operating Sequence

The operating sequence is as follows:

1. The C/DCP begins an update sequence, by applying a 12-V input to the +15-V and +5-V power supplies; and initializing a "Punch motor no. 1" trigger pulse to the control portion of the amplifier and channel multiplexer. This resets the channel multiplexer to channel 0. At the same time, the channel multiplexer sends a clock pulse to the bank select counter, which is on MX I, advancing it by the count of one.
2. The channel multiplexer scans the seven channels of the bank selected. It remains on each channel for about 0.5 second, during which time a pulse is sent to the A/D CONV to start a conversion. When the conversion is complete, a pulse (latch strobe) is sent to the proper latch to enter the data. This process is repeated for all channels. On channel 0, a conversion is performed, but channel 0 data are not entered into a latch. Instead, the state of the bank select counter is entered. Thus, upon completion of a scan, latch 0 contains the bank number, while latches 1 through 7 contain temperature data.
3. The data in latches 0 through 8 are loaded into the C/DCP memory. As previously described, the C/DCP "Punch motor" signals, together with the strobe signal for latch 7, enable the latches, two at a time, to operate.
4. Upon completion of the update sequence, which requires about 90 seconds, the C/DCP removes the 12-V power from the unit. The C/DCP continues to supply 5-V power to the bank select counter and certain other circuits which must remain energized.

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