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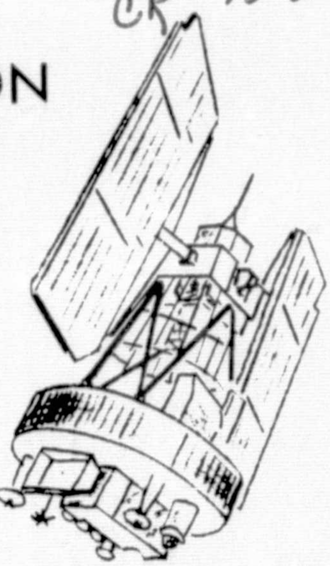
THE USE OF THE LANDSAT DATA COLLECTION SYSTEM AND IMAGERY IN RESERVOIR MANAGEMENT AND OPERATION



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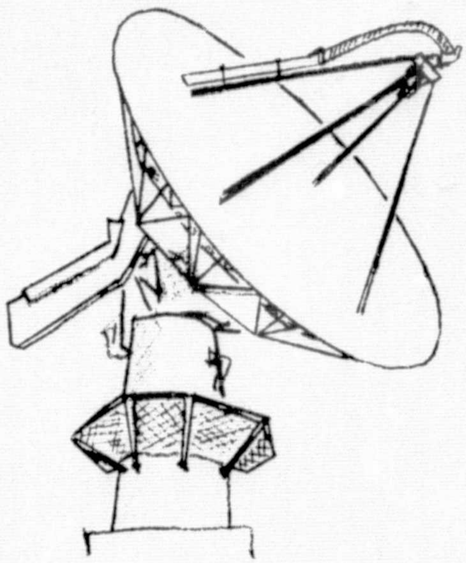

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASSACHUSETTS

LANDSAT FOLLOW-ON INVESTIGATION NO. 22510

THE USE OF THE LANDSAT DATA COLLECTION SYSTEM AND IMAGERY IN RESERVOIR MANAGEMENT AND OPERATION

Saul Cooper, Principal Investigator
Department of the Army
New England Division, Corps of Engineers
424 Trapelo Road
Waltham, Massachusetts 02154

Timothy D. Buckelew
New England Division, Corps of Engineers

Harlan L. McKim
Department of the Army
Cold Regions Research and Engineering Laboratory
P.O. Box 282
Hanover, New Hampshire 03755

Carolyn J. Merry
Cold Regions Research and Engineering Laboratory

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16. Abstract
The New England Division, Corps of Engineers demonstrated the use of the data collection and imagery systems in watershed management. A surplus antenna pedestal was refurbished and interfaced with a computer to provide an automatic ground receive station which operated nearly continuously for over 18 months. Adequate reliability for operational use was proven, and daily procedures were compressed to one half hour of operator time per day. Comparisons of costs and operation constraints were drawn among Landsat DCS, GOES DCS, and ground-based radio. Computer compatible tapes of Landsat imagery were analyzed to evaluate the mapping accuracy of the area of snow, to determine a relationship between the water equivalent of a snowpack and the radiance recorded in Landsat digital data, and to delineate wetlands and flood areas in New England. Sensor interfaces were developed and evaluated for the collection of real time environmental data via the Landsat DCS.

17. Key Words (Selected by Author(s))
Data collection, digital image processing, computer-compatible tapes, ground receive station, snow water content

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PREFACE

New England Division (NED) participated in Landsat Follow-on Investigation No. 22510 to demonstrate the construction and operation of a regional data downlink and to explore operational uses of Landsat imagery for hydrology. It was shown that a relatively simple, low cost, automatic ground receive station could be constructed and operated for data collection; and a study was made of matters related to the operation of the station, such as data reduction and management, personnel requirements, daily operating procedures, reliability, maintenance, and costs. A separate part of the investigation was carried out by the U.S. Cold Regions Research and Engineering Laboratory (CRREL) to explore computer analysis of digital images for extraction of hydrologic information and to develop techniques that will lead to the quantification of the water content of snow.

Participation in the Landsat Follow-on was stimulated by several factors. The original investigation, documented in NED's Landsat-1 Final Report (Cooper et al, 1975), suggested several avenues of further research for making imagery analysis and data acquisition operational for agencies such as the Corps of Engineers. Opportunities and resources were made available in the present investigation to gain experience in the technology of data collection by satellite and to make the comparisons and judgments necessary for developing fully operational systems. Alternative data collection systems have been examined, and based upon critical comparisons of cost and reliability, satellite methods are rated favorably. It has been possible to define precisely the range of downlink performance that users can expect with respect to maintenance, reliability, and personnel requirements. In the 1972-1974 Landsat investigation, the reliability of the overall data collection system (DCS) was proven, and the follow-on has demonstrated that an automatic ground receive station can also perform with high reliability.

The overall program was administered and directed by Saul Cooper, Principal Investigator. The portion of this report dealing with data collection and the ground receive station was prepared by Timothy D. Buckelew, Hydrologist, New England Division. Much credit and appreciation are due to many others who have assisted in various phases of the data collection activities, but especially to Mr. Paul Hetu (NED) who has been responsible for the management and field installation of equipment; to student assistants

Richard Colburn and John Burnham; to several offices of the U.S. Geological Survey for their cooperation and sharing of equipment in stream gaging stations; and to NASA for supporting such a progressive investigation. Special thanks go to Jacqueline Izzi for typing this manuscript.

The portion of the study dealing with imagery was under the direction of Dr. Harlan McKim (CRREL) and was prepared by Carolyn J. Merry, Research Geologist, Earth Sciences Branch, Research Division.

The authors also express their appreciation to the following personnel who assisted with CRREL's investigation: Blanchard Pratt and Richard S. Guyer for sensor interface development for the Landsat data collection platforms; to Gregor E. Fellers for development of the computer programs used to decode the data from the DCP's; to Eleanor Huke for her assistance in layout and arrangement of the computer displays and figures; to Dr. Stephen G. Ungar (NASA Goddard Institute for Space Studies) for development of the computer algorithms used in the analysis of the Landsat digital data; to Thomas L. Marlar and David A. Gaskin for field support; to Lawrence W. Gatto and Dr. Samuel Colbeck for technical review of sections of the snow cover analysis; to Ronald T. Atkins for technical review of the DCP sensor interface description; to Michael A. Bilello and Harold O'Brien for technical review of the snow cover analysis section.

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1.0 INTRODUCTION

This report documents progress made by New England Division, Corps of Engineers, in utilizing Landsat data and imagery products in watershed management, and it includes a description of sensors and interfaces developed for measuring water related parameters. The project was the result of the continuing need for reliable, timely, hydrologic data, and it evolved as a sequel to an earlier investigation into the feasibility of using satellite data for reservoir management (Cooper et al, 1975).

1.1 Organization of this Report

Sections 1 through 5 and Appendix A cover data collection activities, while sections 6 through 10 and Appendix B concern computer analysis of Landsat imagery and development of sensors. What follows in this introduction is a precis of the earlier report giving the major results and recommendations which led to the present follow-on.

1.2 Earlier Work with Landsat

Based on the 1972-1974 experience with a network of 26 data collection platforms, NED found real time data collection by orbiting satellite to be both reliable and feasible. For large scale systems of national scope, it is possible to design orbiting satellite systems that are more flexible, easily maintained and less expensive than conventional ground-based means. Even though the frequency of Landsat appearances (four to six times daily) is not suited to watershed management needs in all areas, it should be understood that the Landsat system is experimental; and one of the principal objectives is to test the feasibility of data collection by orbiting satellite.

In 1974 NED endorsed the institution of a satellite data collection system on a Corps-wide basis or a nation-wide system with sharing among other Federal and State agencies. A further recommendation was that any operational satellite configuration should include ground receive stations at major user locales for direct receipt of critical data, rather than the relay of data by land lines from a single station.

Experience with imagery in the former study indicated that Landsat photos may be enlarged about five times, or to a scale of 1:200,000 which is sufficient for defining gross feature patterns, such as the depiction of floods from the larger rivers in New England. This was judged to be only marginally useful for reservoir regulation purposes. Ice is readily detectable on the imagery as is the boundary between ice and open water. This was found useful for monitoring developing ice cover, especially over remote areas. Winter snow cover patterns are readily obtainable with excellent accuracy from Landsat imagery; however, photographic imagery provides only snow location, not water equivalent which is the important parameter from an operational viewpoint. Landsat imagery appears able to distinguish areas previously but no longer flooded, for periods of several months after flood recession.

NED concluded in the 1972-1974 report that the coordinated use of all data available to an operational reservoir control center should include the interaction between real time imagery and point data sources, such as ground truth obtained by the Landsat DCS. Before this interaction could become a reality it was considered necessary to provide some means of real time relay of Landsat imagery to an operational control center. In addition, the report recommended the continued development of an interactive system to better utilize computer compatible tapes to depict changes in hydrologic conditions.

2.0 HISTORICAL BACKGROUND

2.1 Corps' Mission

NED's involvement in space technology for imagery and data collection is tied to the mission of the Corps and more subtly to the manner in which New England has developed in the last century. Since the Industrial Revolution in the 1800's, the rivers of New England have been developed to supply water for power and transportation. As new means of transportation became more economical, both railroad and highway systems were built along the banks of the rivers to serve the expanding needs of the industrial, commercial and urban centers. Structures, such as buildings, roads, bridges and dams have restricted floodways to such an extent that considerable property and environmental damages have occurred even during only moderate floods. Notable floods of November 1927, March 1936, September 1938 and August 1955 have demonstrated the need for flood control to prevent these natural catastrophes.

At the direction of Congress, the U.S. Army Corps of Engineers developed a comprehensive plan of flood protection for each river basin. The protective works recommended generally consist of a combination of channel improvements, dikes or floodwalls at major damage centers augmented by upstream flood control reservoirs. Many of these reservoirs contain additional storage reserved for other uses such as water supply, conservation and recreation. The Corps has built 35 flood control reservoirs, 44 local protection projects and four hurricane barriers in New England at a total investment of $350 million.

2.2 Data Collection at NED

To gain maximum benefits from this comprehensive protection system, the New England Division requires hydrologic data such as river, reservoir and tidal levels; wind velocity; barometric pressure; and precipitation.

In the past this data was collected by field observations and relayed via telephone or voice radio. For a scan of New England it took several hours to compile and assess the data in this manner. As the flood control system expanded and the need for timely and reliable information increased, the Corps pioneered new methods of data collection.

In 1970 the Automatic Hydrologic Radio Reporting Network (AHRRN) was placed in operation. This ground-based radio relay system consists of 41 remote reporting stations, and a central control at Division Headquarters in Waltham, Massachusetts. This network, with the assistance of a computer, automatically collects and reduces the real time data that is essential for reservoir regulation. The remote reporting stations of this system are strategically located in five major river basins and at key coastal positions, with each contributing to a comprehensive hydrologic picture.

2.3 Entry into Satellite Data Collection

In June 1972 the Corps contracted with NASA for an experiment to study the feasibility of using the Earth Resources Technology Satellite for collection of environmental data from data collection platforms (DCP's). Of the 26 DCP's installed in locations throughout New England, many are situated at existing U.S. Geological Survey gaging stations. Between July 1972 and September 1975, Landsat relayed river stage, precipitation, and water quality data from DCP's to the Goddard Space Flight Center, whence it was sent to the New England Division within one or two hours via teletype.

As early as 1973 NED personnel envisioned a ground receive station, because it was apparent that real time data was needed without danger of disruption from regional power or telephone failures. Table 1 lists chronologically the major steps related to development of the ground receive station from 1973. Included in the table are significant events associated with the construction of the ground receive station, such as presentations, meetings, and a special briefing of the Chief of Engineers in January 1976 which led to a Corps-wide examination of the use of satellite data collection.

The present investigation began in 1975; and by late 1975 NED had constructed an inexpensive, semiautomatic, and easily maintained ground receive station as a follow-up to its original study. The Division is now able to receive hydrometeorological data from data collection platforms in the field directly at its headquarters in Waltham, Massachusetts with no time delays. The satellite tracking system operates unattended automatically at all times, with a computer controlling all processes.

2.4 Imagery Experience

From 1972 to the present, NED, in cooperation with the University of Connecticut and the Cold Regions Research and Engineering Laboratory, studied computer compatible tapes of Landsat scenes for potential hydrologic applications. In the Landsat-1 investigation it was concluded that gross outlines of waterbodies and snow or ice could be distinguished, but little advantage would be gained in watershed management without refined interactive computer techniques. Since that time Landsat photographs and taped scenes have been collected for selected areas of New England for hydrologic analysis. Work is continuing on development of computer techniques and regression analyses to relate multispectral "signatures" with systems involving snow water content, ground cover types, and varying slopes and elevations.

TABLE 1

CHRONOLOGY OF THE LANDSAT FOLLOW-ON INVESTIGATION AT NEW ENGLAND DIVISION

1973	
September - December	Preliminary discussions among personnel of NED, GSFC, NASA Wallops.
May	Satellite Workshop at Wallops Station, Virginia.
1974	
February	NASA/NED exploratory meeting at Waltham.
August	Funds transferred from OCE to NASA.
September	Final system specifications drafted by NASA for ground receive station.
October	Ground receive station site preparation
November	Inspection of DCS demodulator/decoder at Wallops.
	Conference at GSFC on satellite tracking software.
1975	
January	Technical proposal on ground receive station submitted by Scientific Atlanta.
February	Landsat Follow-on contract signed.
March	Coordination meeting among personnel of NED, CRREL and University of Connecticut.
April	Meeting at Waltham with NED, GSFC, Wallops and Scientific Atlanta personnel present.
April - May	Started acquiring 9-day imagery coverage of New England.
	Data sharing between NED and Saint John (New Brunswick) River Flood Forecast Center.

1975 (cont.)

May	Coordination meeting among personnel of NED, CRREL and University of Connecticut.
June	Type II Report No. 1.
	Satellite tracking programs debugged.
July	Acceptance trial of antenna and pedestal at Scientific-Atlanta in Atlanta, Georgia.
September	Type II Report No. 2.
	Arrival of antenna in Waltham.
October	Antenna installation.
	Presentations on data collection and imagery at Tenth International Symposium on Remote Sensing of the Environment, Ann Arbor, Michigan.
	Presentation before Atlantic Fisheries Biologists meeting, Newagen, Maine.
	Presentation before International Telemetering Conference (Silver Springs, Maryland) on ground receive station and imagery analysis.
November	Initial tracking of Landsat by ground receive station.
	Presentation before American Water Resources Conference at Baton Rouge, Louisiana.
	Tulsa, Oklahoma workshop on convertible data collection platforms.
December	Type II Report No. 3.

1976

January	Briefing of General Gribble, Chief of Engineers, on satellite data collection.
	Meeting at CRREL on cooperative remote sensing programs, among personnel of NASA GISS, and CRREL.

1976 (cont.)

February	Landsat DCS demonstration held at Boston USGS Regional office.
March	DCS data sharing with Saint John (New Brunswick) River Flood Forecast Center during spring runoff.
	Type II Report No. 4.
April	Coordination meeting at CRREL on CCT algorithm.
	Arrival of LaBarge convertible DCP's at NED.
	Consultation with NED/CRREL on use of Landsat imagery for detection of red tide by Mr. Jerry McCall of the Massachusetts Department of Environmental Quality Engineering.
May	Installation of time code generator in tracking system.
June	Type II Report No. 5.
	Meeting at Sugarloaf Mountain to plan emplacement of thermocouple cable.
July	Video taping of DCS equipment for public information.
September	Type II Report No. 6.
	Demonstration DCP assembled at ground receive station.
	Snow pillows installed at NED and northern Maine.
	Thermocouple chain interfaced with DCP and installed on Sugarloaf Mountain, Maine.
October	NASA briefing before discipline specialists.
	CRREL/GISS meeting to plan ongoing Landsat digital analysis.
November	Informal Earth Resources Program Review at GISS, New York, New York.

1977

February	Presentation on analysis of water equivalent of snow using Landsat imagery, before Eastern Snow Conference Belleville, Ontario.
April	Presentation at Meteorological Satellite Workshop on data collection systems, White Sands, New Mexico.
May	OCE briefing and survey conducted at NED jointly with NASA, NESS and ORI.
	Presentation on permafrost in New England at a seminar, University of Maine, Institute of Quaternary Studies, Department of Geological Sciences.

3.0 SCOPE AND OBJECTIVES OF THIS INVESTIGATION

3.1 Evaluation of the DCS

The first principal objective of this investigation was to evaluate the effectiveness of the DCS in aiding watershed management functions as compared to other conventional means. The study demonstrates the degree of utility of the Landsat data collection system with respect to reservoir regulation. A direct downlink was installed at Waltham as a cooperative effort between NASA and the Corps of Engineers. Areas that were explored in the management of the downlink were computer programming; data reduction, storage and retrievel; maintenance, downtime, service and costs; and daily operating procedures and personnel requirements. Comparisons of costs and operating procedures were to be drawn among alternative data collection systems such as GOES and ground-based radio.

3.2 Evaluation of Imagery

The second principal objective was to develop methods of using Landsat imagery information to assist in the planning, management and operation of NED water resource projects. To this end, several tasks were undertaken. Imagery was analyzed to evaluate mapping accuracy of the areal extent of snow. A preliminary relationship was determined between the water equivalent of a snowpack and radiance measured by Landsat. Imagery was also used to delineate wetlands and floodwaters in New England. Along with the two main objectives, it was possible to develop sensors and interfaces for obtaining environmental real time data by the Landsat DCS.

4.0 LANDSAT DATA NETWORK AT NED

4.1 Initial Steps

The present DCS study into operational uses of Landsat was an extension of the 1972-1974 feasibility investigation, and plans for the follow-on investigation were underway in 1973. It was recommended that surplus equipment, compatible with our needs, be used to construct a regional downlink at Waltham. NASA personnel provided technical support in planning and integrating components; and a contract was issued to Scientific-Atlanta in Atlanta, Georgia, for refurbishing the surplus equipment and furnishing several new components. NED prepared the site for the antenna, furnished the computer equipment for controlling the system, and was responsible for software development.

4.2 Installation

The system was installed and operating in late 1975; and after testing and shakedown, NED examined all facets related to operating and maintaining a downlink. The most significant topics examined include:

a. DCP development
b. personnel requirements
c. malfunctions, downtime and repair costs
d. comparisons of downlink to conventional methods
e. computer programs for orbit prediction and tracking
f. data reduction and storage
g. daily operating procedures

Each of these topics is covered in the sections which follow; and an in-depth view of all computer programs, data files, special devices, and operating procedures is given in Appendix A.

4.3 System Design and Operation

The Landsat tracking system at NED integrates a set of about 20 programs or subroutines (software), about ten disc data files, and several pieces of equipment (hardware). The hardware components are listed in table 2 and depicted in figures 1 and 2. Software and data files which were designed at NED are described in detail in Appendix A.

4.4 Network Description

The overall data collection system (DCS) comprises the satellite, one or more ground receive stations, and many remote, automatic data collection platforms, which are equipped by users to sample local environmental conditions (NASA, 1976a). Up to 26 platforms were deployed by NED at any time during the course of this investigation.

4.5 Deployment of DCP's

4.5.1 Site Selection

NED's data collection platforms were deployed to serve various functions while testing the feasibility of satellite data collection systems. Sites were established for:

- field test purposes
- expansion to areas outside the AHRRN coverage
- demonstrations

TABLE 2

COMPONENTS OF LANDSAT TRACKING STATION AT NED

Item	Number	Manufacturer
Antenna, Parabolic, 15'	custom made	Scientific-Atlanta
RF Feed and Waveguide Assembly	custom made	"
Tracking Pedestal	Model 3203	"
Manual Command Unit	Model 3732	"
Servo Control Unit	Model 3615A	"
DC Amplifier	Model 3641	"
SCR Power Amplifier	Model 3635	"
Digital Comparator	Model 1848	"
Punched Tape Programmer	Model 3823	"
Tape Reader	Model RRS6300	Remex
Parametric Amplifier	Model SCP-290	Scientific Communications, Inc.
Air Dryer	Model 550	Puregas
Digital Synchro Display	Model 1842	Scientific-Atlanta
Receiver, Basic Unit	Model 410A	"
UHF RF Tuner	Model 423	"
PM Demodulator, Wide Angle	Model 444A	"
IF Filter	Series 430	"
Spectrum Display Unit	Series 450	"
Signal Generator, S-band Test	Model 7100	Microdyne Corp.
Time Code Generator	Model 9100A	Datum, Inc.
Demodulator/Decoder, Data	custom made	NASA, Wallops Station
Terminal, Cathode Ray Tube	Model 4014-1	Tektronix
Hard Copy Unit	Model 4631	"
Graphics Tablet	Model 4953	"
Minicomputer	Model 1220	Data General Corp.
Disc Unit, Magnetic	Model 4057	"

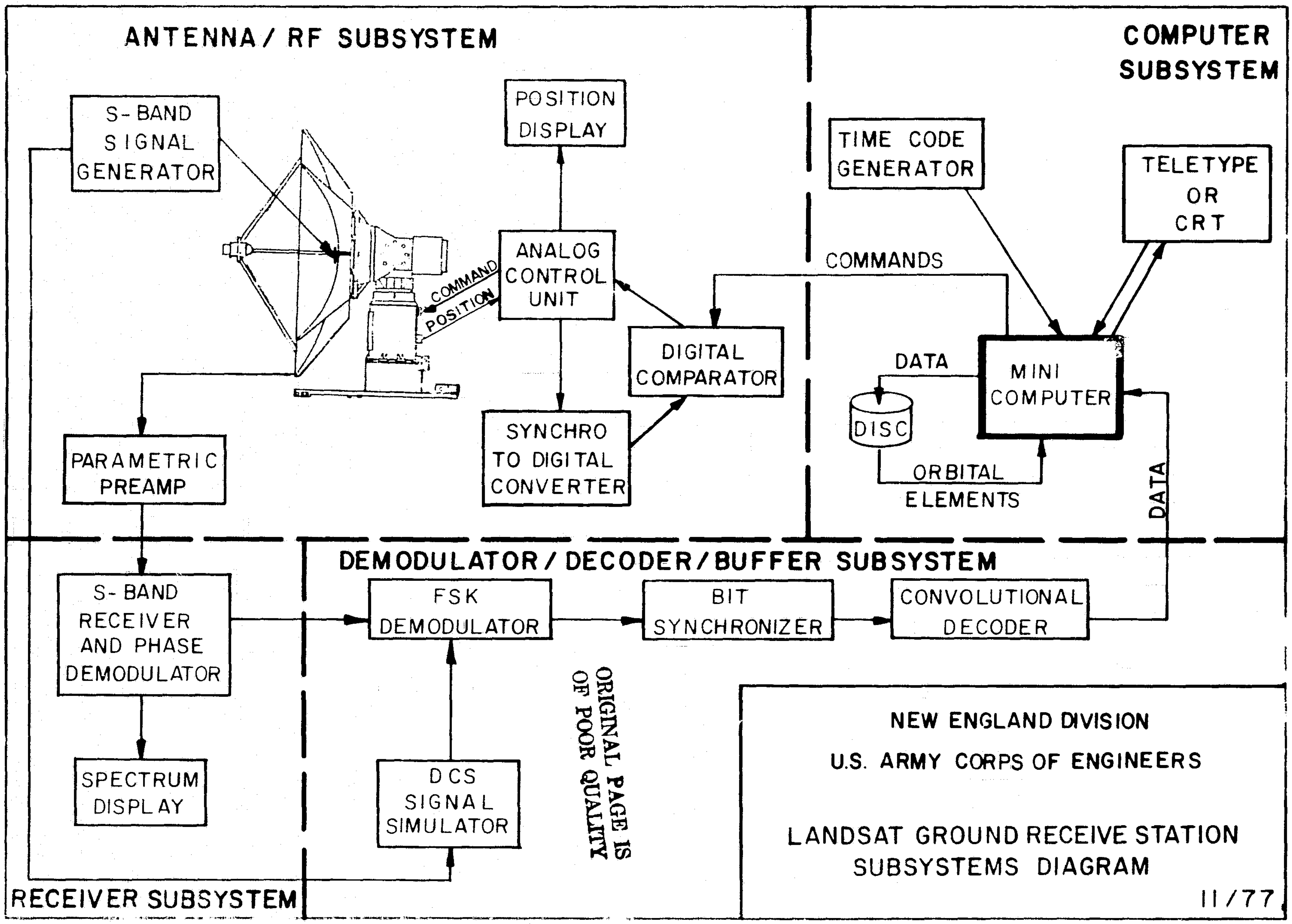
ANTENNA / RF SUBSYSTEM
S-BAND SIGNAL GENERATOR
POSITION DISPLAY
ANALOG CONTROL UNIT
COMMAND
POSITION
DIGITAL COMPARATOR
SYNCHRO TO DIGITAL CONVERTER
PARAMETRIC PREAMP
COMPUTER SUBSYSTEM
TIME CODE GENERATOR
TELETYPE OR CRT
COMMANDS
DATA
MINI COMPUTER
DISC
ORBITAL ELEMENTS
DATA
DEMODULATOR / DECODER / BUFFER SUBSYSTEM
FSK DEMODULATOR
BIT SYNCHRONIZER
CONVOLUTIONAL DECODER
DCS SIGNAL SIMULATOR
S-BAND RECEIVER AND PHASE DEMODULATOR
SPECTRUM DISPLAY
RECEIVER SUBSYSTEM
NEW ENGLAND DIVISION
U.S. ARMY CORPS OF ENGINEERS
LANDSAT GROUND RECEIVE STATION
SUBSYSTEMS DIAGRAM
11/77

FIGURE 1

COMPUTER ROOM

15 FT. RECEIVING ANTENNA

ORIGINAL PAGE IS
OF POOR QUALITY

FIG. 2

The primary criterion for DCP deployment was the need for continuous real time data collection in sites that supported NED's water control mission. These comprised the majority of our DCP's and were usually interfaced with stream or precipitation gages (see sitelist, figure 3). In some cases sites were chosen for their remoteness, climatic harshness, or on the other hand, for their accessibility. DCP's were co-located at existing AHRRN stations, such as Plymouth and Goffs Falls, New Hampshire and Hartford, Connecticut to compare the hydrologic data.

Several DCP's extended or enhanced our coverage of New England, such as Cornish, North Anson, West Enfield, Fort Kent, Ninemile Bridge, and Allagash Falls in Maine; and Cranston and Forestdale, Rhode Island. DCP's at these sites provided more comprehensive real time data from New England rivers than was practical with other methods at our disposal.

It should be noted here that DCP's were not placed with the strategic aim of integration with the Merrimack Hydrologic Model which has been under development by NED and the Hydrologic Engineering Center in Davis, California. In the early assessment stage of the investigation this integration was considered to be beyond our reach with regard to the time, manpower, and funds available. Implementation of the HEC model is being pursued using the AHRRN.

A final category of DCP site selection includes those set up as demonstrations and tests. These include:

a. DCP's interfaced with snow pillows in the winters of 1975-1976 and 1976-1977.

b. DCP's interfaced with meteorological stations in North Dakota by CRREL.

c. A DCP interfaced with a thermocouple chain in Maine by CRREL.

d. A demonstration DCP at NED to show sensors, interfaces, platforms, antennas, and typical cabling.

e. A DCP at Manchester, Connecticut, Nature Center maintained by the Hartford office of the U.S. Geological Survey, as a public demonstration.

LANDSAT-2 - DCP INFORMATION SHEET
U.S. ARMY CORPS OF ENGINEERS, NEW ENGLAND DIVISION 12 OCTOBER 1977

DCP NO.	STATION NAME	PARAMETER(S)*	LAT	LONG
7012	ST. JOHN RIVER AT NINEMILE BRIDGE, ME.	RS WES	46 42 00	69 42 59
7273	ST. JOHN RIVER AT FORT KENT, ME.	RS	47 15 27	68 35 35
7304	SHIELDS BROOK NEAR ST. POMPHILE, P.Q.	RS	46 56 30	69 38 58
7110	ALLAGASH FALLS, ME.	AT,GT,WES	46 57 05	69 11 43
7071	PENOBSCOT RIVER AT WEST ENFIELD, ME.	RS	45 14 12	68 38 56
7272	CARABASSETT RIVER NEAR NORTH ANSON, ME.	RS	44 52 09	69 57 20
7356	SACO RIVER AT CORNISH, ME.	RS	43 48 35	70 46 53
7127	SOUTH MOUNTAIN, N.H.	P	42 58 59	71 35 21
7201	PEMIGEWASSET RIVER AT PLYMOUTH, N.H.	RS	43 45 33	71 41 10
7021	MERRIMACK RIVER NEAR GOFFS FALLS, N.H.	RS	42 56 54	71 27 52
7246	WACHUSETT MOUNTAIN, MA.	P	42 29 24	71 53 15
6063	IPSWICH RIVER NEAR IPSWICH, MA. (1)	RS	42 39 35	70 53 39
7271	NORTH NASHUA RIVER AT FITCHBURG, MA.	RS	42 34 34	71 47 19
7107	NED, WALTHAM, MA. (LABARGE)	P	42 23 46	71 12 56
7325	NED, WALTHAM, MA.	WES	42 23 46	71 12 56
7345	PAWTUXET RIVER AT CRANSTON, R.I.	RS	41 45 03	71 26 44
7254	CONNECTICUT RIVER AT HARTFORD, CT.	RS	41 46 10	72 40 04
7355	CONNECTICUT RIVER NEAR MIDDLETOWN, CT.	RS	41 33 40	72 36 45
7206	PORTER BROOK NEAR MANCHESTER,CT.(2)	RS	41 45 55	72 30 12

6216,7042,7101 (3)RL,AT,GST,GT,WP
7103-7105,7107-7120.7125 ASSIGNED TO CRREL'S C/DCP'S
7147,7220,7142,7207,7171,7233,7242,7335,7010 SPARES

* P - PRECIPITATION
WES - WATER EQUIVALENT OF SNOWPACK
RS - RIVER STAGE
RL - RESERVOIR LEVEL
WQ - WATER QUALITY (TEMPERATURE, CONDUCTIVITY, PH AND DISSOLVED OXYGEN)
AT - AIR TEMPERATURE(S)
GST - GROUND SURFACE TEMPERATURE
GT - GROUND TEMPERATURE(S)
WP - WIND PASSAGE
PV - PARAMETERS VARIABLE
T - TEST SET

(1) DCP OWNED BY U.S. GEOLOGICAL SURVEY, BOSTON, MA.
(2) DCP ON LOAN TO U.S. GEOLOGICAL SURVEY, HARTFORD, CT.--ON DEMONSTRATION AT THE MANCHESTER NATURE CENTER
(3) DCP ON LOAN TO U.S. ARMY COLD REGIONS RESEARCH AND ENGINEERING LAB, HANOVER, N.H.

Figure 3. Data Collection Platform Sitelist

f. Water quality monitors interfaced with DCP's at Fitchburg, Chicopee, West Springfield and Webster, Massachusetts.

4.5.2 Interfacing Sensors and DCP's

The initial translation of river stage to a transmittable signal is often performed by a float well or manometer-type gage. In a float well configuration, the level of a float on the water surface is followed by a taut vertical tape which runs over a pulley on a shaft. The shaft is coupled to an analog to digital recorder (ADR) which translates the shaft rotation to a digitized signal. Either a "telekit" or a semiconductor memory unit latches and holds the latest value for the DCP to read.

A manometer-type gage functions by sensing the amount of (nitrogen) gas pressure needed to force bubbles down through a tube into the water body to the datum level. A moveable mercury well is moved by a motor to balance the pressure of the gas. The motor shaft motion provides the analog of water stage. From this point the transmission path is similar to the float well configuration.

Rainfall is usually measured with weighing or tipping bucket rain gages that are equipped with ADR's. A gage records accumulated rainfall in the range from 0 to 99.99 inches. The data pathway to a DCP is similar to that of river stage. Rainfall rates may be computed from successive values and elapsed time between readings.

Landsat DCP's allow sensor input of 64 parallel bits, 64 serial digital bits, eight analog inputs, or combinations of these formats. Various brands of DCP's offer differing amounts of versatility and control of external devices. Users must configure their sensor equipment and cabling to conform to the data formats accepted by the DCP. A scheme using binary coded decimal (BCD) bit assignments was adopted in most applications at NED. By this method a four-digit decimal number representing the measured parameter is encoded in 16 bits divided into four groups of four bits each. It is convenient to handle such a group in its octal (base-8) form. Sixteen bits of information can be represented and conveniently handled as two octal triplets. For example, the octal triplets 237 373 represent the 16-bit pattern 10 011 111 11 111 011.

Each position of this pattern can be assigned the following values, respectively:

1 2 4 8 10 20 40 80 .01 .02 .04 .08 .1 .2 .4 .8

During encoding at the DCP, the bit values are ones - complemented so that a 0 in the binary form stands for a "high" or presence of the decimal value, and 1 stands for "low" or absence of the decimal value. By these conventions the sample bit pattern above represents 2 + 4 + .2, or the decimal number 6.2.

Several of these schemes or bit assignments were used at NED at various times and with various types of sensors and DCP's. The problem of remembering which scheme is in use at each field location is handled by our computer using the program P3 and the disc file "INDX" (see Appendix A). Remembering over a period of months and years requires tables of station numbers, dates, and parameter types.

Whether a binary 1 stands for "high" or "low" depends on the user's sensor equipment and whether it performs simple switch closure or has another sort of input driver. The value or significance of each bit is determined by users and is incorporated into wiring and pin assignments. Any scheme adopted should be flexible enough to fit as many applications as possible. This will minimize the number of schemes and decrease the likelihood of misinterpretations of valid data.

4.6 NASA Support Data

Several forms of support data were supplied by NASA during this investigation. DCS data was provided by teletype within a few hours and by punched card and computer printout within a week of acquisition. Photographic prints and transparencies of Landsat scenes of New England were also furnished. The scenes were processed by EROS Data Center of the USGS in South Dakota and were delivered usually from 4 to 8 weeks after acquisition by NASA. Image quality was high in most cases. At first, scenes were collected from all of New England, but in mid-1975 coverage was reduced to a study area in northern Maine, thereby increasing the number of passes that could be handled with available funding. Cloud cover tolerance was also reduced to 30 percent or less.

4.7 Personnel Requirements for Ground Receive Station

Approximately one person-year was required for planning, site preparations, programming, and acquisition of equipment that was not furnished by NASA or the antenna contractor. Mr. Timothy Buckelew was the principal programmer in the DCS investigation. His background includes five years of high level language programming, mathematical training through calculus and analytical geometry and exposure to sciences. Assembly level programming was needed and was learned on the job. At most times during program development, one or two college engineering students provided valuable assistance.

Once the ground receive station components were fully integrated and operating according to specifications, the personnel requirements for it diminished to one half hour of attention per day to perform tasks such as:

a. printing out data collected over night
b. checking the time code generator against standard time
c. entering orbital elements each week
d. inserting or removing DCP directory entries
e. retrieving sets of data as needed

In addition, the service of a part-time technician was required for deployment and maintenance of a system of 30 DCP's. This job includes antenna installation, wiring, interfacing, DCP initialization and checkout, battery maintenance, trouble-shooting, DCP replacement, documentation, etc. DCP's that were faulty were shipped out for repair at a NASA-affiliated laboratory. One full-time technician could manage the entire system including downlink and DCP network provided there were access to support groups for service when malfunctions occur.

4.8 Reliability of Ground Receive Station

A study of DCP reception versus peak elevation angle to the satellite from Waltham was conducted over a 19-day period in April 1977. Reception is good for satellite passes having peak elevations down to 14°. For NED purposes a completely useful pass is one in which at least one message arrives per DCP. Usefulness diminishes quickly from 14° to 12° passes; and over half the network becomes silent for 10° to 5° passes. The last DCP's to report are the three experimental platforms in North Dakota.

The loss of messages as the satellite progresses to the west is caused by several factors: antenna gain patterns on DCP's and the satellite; increase in range; and possibly the fact that the downlink antenna at Waltham begins to be obscured by buildings when elevation angles are less than 13°. The significant finding of this examination is that the DCS is highly useful for passes having peak elevations as low as 12°.

The ideal configuration for a regional downlink is similar to the system tested during this experiment. The sizes of components used were ones available as surplus equipment. A 15-foot dish was installed at NED, but from discussions with other people in this field it was clear that a 12-foot dish would have been adequate. Most other subsystems in the downlink are nearly ideal because the hardware and software were tailored to fit needs of this specific purpose.

The weakest link in NED's system was the S-band receiver. We lost many days of service when this component failed. It is recommended that two be purchased, if possible, for system redundancy. Margins of estimates in the RF link analysis may have been excessive, but it is hard to say precisely which items were overly conservative. Hardware present but not needed includes an extra position indicator (which came as surplus equipment); a spectrum display unit in the receiver; and a programmable paper tape reader for input of azimuth and elevation angles. The tape reader would not be necessary if the pedestal were interfaced directly to the computer or the pedestal had auto tracking capability.

The performance of the ground receive system conformed to NASA's specifications and far exceeded NED's original expectations. Data reception quality (according to system specifications) had to be at least 90 percent error-free when the satellite is above elevation 25°. This degree of performance has been consistently demonstrated by the system. Moreover when examined in the context of collection of hydrologic data, the performance of the system including a set of DCP's transmitting at 3-minute intervals is much better than that which is indicated above. For hydrologic events, rates of parameter change are typically slow, so a high proportion of messages from one DCP in one satellite pass are identical. Receipt of several identical messages does not increase the amount of intelligence received; thus, if at least one message comes in during a pass, it still represents a high degree of success. (Upward and downward trends of a parameter can be calculated from comparison of individual DCP's messages from successive passes.)

DCS data furnished from NASA by teletype was used as a backup to our ground receive station and as a standard of comparison for the station's performance. NED's receipt of DCP messages ranged from 80 to 90 percent that of NASA. This performance is considered excellent. Four messages per DCP per pass is the practical maximum for NASA for high satellite passes. Receipt of five messages is rare. In the calculation of performance as a percent, there is a discrete downward jump as one message per DCP per pass is lost, causing a strong tendency toward 75 percent, or three out of four. Our 15-foot antenna may miss a DCP's message, transmitted when the satellite is low, which NASA's high gain 40 or 60-foot dishes will receive; but the performance of the 15-foot dish for higher segments of passes compares very well to larger dishes.

Putting the 80-90 percent performance in other words, slightly over one half the time we got the same number of messages as NASA and the rest of the time we missed one message. It was rare for NASA to receive a DCP that we failed to get at least once per pass, and vice versa.

The sources of errors experienced were not checked, because more sophisticated test equipment would have been needed. Reliance was placed on the decoder/demodulator/buffer subsystem to flag errors detected during convolutional decoding and not to flag valid messages as erroneous. After that, data were reduced and checked by the minicomputer for reasonableness (that is, to fall within limits). Finally data were scanned by the users for reasonableness or the presence of discontinuities; an example can be seen in figure 4. The abrupt increase shown in this figure was judged to be valid because of the likelihood of "ice runs" in April; and hourly values recorded by the USGS showed a smooth, rapid increase. Users should suspect nonvalid data if the discontinuity varies consistently by one bit value in the "binary coded decimal" coding scheme.

A longitudinal study of the performance history of all our General Electric DCP's placed in the field from 1972-1976 shows that they are very reliable. Available data compiled from technician's records include the duty cycles (sometimes intermittent) of 23 DCP's over a span of approximately four years for a total service history of 70.1 DCP-years. During this time several events could have forced a visit to the DCP site: initial installation, mechanical or electronic failure, preventive maintenance, battery change, or vandalism. For this study, final removal was not defined as a forced visit since removal was not urgent in most cases. Over the 70.1 DCP-years there were about 95 forced visits for an average of 1.4 forced visits per DCP-year. In other words, slightly under nine months elapsed between two forced visits to the same DCP. Our early experience (or inexperience) with DCP's is included in this analysis, so it may be assumed that for us or another experienced group to start now with the knowledge already gained would involve far fewer DCP failures and on the average assure nine months or more between forced visits.

4.9 Malfunctions, Downtime, and Repair Costs

After many months of operation of the ground receive station, it became possible to assess the amount of downtime experienced and the nature of malfunctions serious enough to cause the whole system to be useless. During most of the early part of this investigation, the Landsat was not rigorously tracked every day for

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7171 NINEMILE BR., ME.
 3/28/77 19:44  STG= 5.03FT   7153.CFS   5.5CSM
 3/28/77 21:26  STG= 5.03FT   7156.CFS   5.5CSM
 3/29/77  8:12  STG= 5.02FT   7124.CFS   5.5CSM
 3/29/77  9:55  STG= 5.03FT   7156.CFS   5.5CSM
 3/29/77 19:51  STG= 5.04FT   7188.CFS   5.6CSM
 3/29/77 21:32  STG= 5.04FT   7188.CFS   5.6CSM
 3/30/77  9:59  STG= 5.09FT   7310.CFS   5.7CSM
 3/30/77 19:57  STG= 5.17FT   7620.CFS   5.9CSM
 3/30/77 21:41  STG= 5.18FT   7655.CFS   5.9CSM
 3/31/77  8:26  STG= 5.39FT   8376.CFS   6.5CSM
 3/31/77 10: 4  STG= 5.32FT   8135.CFS   6.3CSM
 3/31/77 20: 0  STG= 5.18FT   7655.CFS   5.9CSM
 3/31/77 20: 3  STG= 5.11FT   7414.CFS   5.7CSM
 3/31/77 21:46  STG= 5.20FT   7723.CFS   6.0CSM
 4/ 1/77  8:30  STG= 5.81FT   9953.CFS   7.7CSM
 4/ 1/77 10:10  STG= 5.10FT   7380.CFS   5.7CSM
 4/ 1/77 20: 6  STG=11.33FT  35460.CFS  27.5CSM
 4/ 2/77  8:33  STG=12.21FT  37230.CFS  28.9CSM
 4/ 2/77 10:17  STG=12.40FT  37600.CFS  29.1CSM
 4/ 2/77 20:13  STG= 5.38FT   8341.CFS   6.5CSM
 4/ 2/77 21:54  STG= 5.39FT   8376.CFS   6.5CSM
 4/ 3/77  8:37  STG= 5.59FT   9076.CFS   7.0CSM
 4/ 3/77 10:21  STG= 5.55FT   8955.CFS   6.9CSM
 4/ 3/77 20:16  STG= 5.40FT   8410.CFS   6.5CSM
 4/ 3/77 22: 4  STG= 5.38FT   8341.CFS   6.5CSM
 4/ 4/77  8:45  STG= 5.30FT   8067.CFS   6.3CSM
 4/ 4/77 10:27  STG= 5.30FT   8067.CFS   6.3CSM
 4/ 4/77 20:20  STG= 5.40FT   8410.CFS   6.5CSM
 4/ 5/77  8:50  STG= 5.33FT   8170.CFS   6.3CSM
 4/ 5/77 10:33  STG= 5.29FT   8032.CFS   6.2CSM
INT
R
```

Figure 4. River Stage Data from Ninemile Bridge, Maine.

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reasons other than malfunctions, so there is no valid method of quantifying downtime for that period. However, during an all-out endurance test in May and June of 1977, near 100 percent dependability was attained in ground receive station performance for 60 days.

Downtime was experienced occasionally during the investigation, and it must be viewed in the context of the mission of the Water Control Branch: when operationally useful data was needed, effort had to be channelled into our operational system, the AHRRN. At those times less attention was paid to rapidly correcting malfunctions in the satellite ground receive station which was considered experimental. Some of the main causes of malfunctions are described below.

1. The radio receiver crystal oscillator failed repeatedly. Solution: entire receiver was returned to factory or field service organization for repair*; several days at a time were lost.

2. An RF cable broke or vibrated loose on several occasions in the tracking pedestal. Solution: field service technicians made on-site repairs.

3. Computer malfunctions were caused by power interruptions or surges. This type sometimes led to disc file loss, a time - consuming mishap. If the computer aborted early on a weekend, this led to loss of whole days of data. Solution: run the computer with the power failure protection option. However, if this is done on our system, only a small disc is on-line. For matters of convenience, it was usually decided to run without the power failure protection.

4. There were also computer malfunctions associated with a long-standing and obscure electrical problem. Occasionally this problem was acute enough to disrupt operations for days. It caused erroneous reads and writes of the disc files, and most often caused false azimuth and elevation commands to be sent to the tracking pedestal, thereby causing it to slew wildly and blow fuses. Solution: a field service technician found an intermittent open circuit in the main power line to the computer.

5. Our minicomputer is apparently sensitive to high temperatures. Solution: keep the computer room temperature at about 18° C.

*Between December 1976 and July 1977 malfunctions in the antenna and receiver subsystems occasioned repair costs of $2,445.

It should also be noted that most of the components of the system were completely free from malfunctions, including the following:

- antenna reflector
- feed
- waveguide
- air drying and pumping system
- paramp
- all standing cables
- data demodulator
- digital input/output interface
- time code generator
- S-band test signal generator and feed
- software (after initial debugging)

The weakest points in the system were the S-band receiver and power instability at ~~the computer~~. The latter problem can be solved by power protection devices, and the former can be solved by component redundancy.

4.10 Cost Comparisons of Data Collection Systems

Experience with data collection technology during and prior to the investigation enables us to estimate the costs of various data collection systems. Estimates given below were derived from conversations and correspondence with manufacturers and other Government agencies. For a fuller economic analysis forecasting market conditions and costs, a report by Ecosystems International, Incorporated (NASA, 1977), is recommended. Our observations are consistent with that report. Estimates have been made for only those media that are both available to us and reliable during storms that reach hurricane intensity. Those restrictions exclude meteor burst and telephone communication, leaving line-of-sight radio and satellites.

4.10.1 Line of Sight Radio (LOS)

NED's Automatic Hydrologic Radio Reporting Network has been in use for over seven years. It consists of an automated data collection system superimposed over an older voice radio network. Experience with the procurement and operation of the AHRRN suggests that a system can be installed for about $20,000 per reporting station. A 40-station network would therefore cost $800,000. Maintenance is currently $65,000 per year on just data collection hardware, exclusive of voice radio equipment; and the cost is increasing about 10 percent per year. Maintenance over 10 years (the standard life time adopted for Government-owned equipment) would amount to over $1,035,000. Total cost for installation of a system of 40 stations and maintenance for 10 years would be over $1,795,000.

4.10.2 Landsat Downlink

A ground receive station capable of tracking a polar orbiting, Landsat-type satellite requires less hardware than the radio network. A 12-foot parabolic dish would be sufficient, and either an autotracking or step-tracking pedestal could be cmployed. The former type pedestal would simplify the configuration and cut costs. Costs may be summarized as follows:

12-foot antenna with tracking pedestal	$100,000
computer and receiving equipment	100,000
40 DCP's with interfaces and procurement overhead	160,000
annual maintenance	
computer	8,000
pedestal	2,000
40 DCP's	4,000
Sub-total	14,000
10-year maintenance total, assuming 10% increase per year	210,000
Total, including procurement and 10-year maintenance	$570,000

The computer mentioned above consists of minicomputer with 32 to 64 K memory, simple disc storage, I/O, interfaces, etc.. About $40,000 would be spent for these items. Receiving equipment comprising preamplifier, receiver, decoder, cabling, etc., costs an additional $60,000.

DCP's currently can be obtained for about $3,000 each, but $4,000 is a realistic figure to allow for interfacing, procurement overhead, batteries, and cabling. A price reduction approaching 50 percent can be expected during the next five to 10 years, parallelling the price reductions in the semiconductor industry. The use of ordinary microprocessors will generalize DCP design and cut expense of research and development on tailored DCP's.

4.10.3 GOES Downlink

The equipment for a GOES downlink differs from that of Landsat in that a larger dish is needed (18 feet is desirable), but simpler aiming devices can be employed since GOES hovers around one point in the sky. If more than one channel is to be received, multiplexing and buffering equipment is needed to route simultaneous messages into one computer. Estimates for components and 10 years of maintenance may be summarized as follows:

18-foot antenna with pedestal	$ 50,000
computer and receiving equipment	100,000
40 DCP's	160,000
maintenance	210,000
Total, including procurement and 10-year maintenance	$520,000

Costs of DCP's and maintenance are assumed to be the same as those encountered with a Landsat station.

4.10.4 Significance of Cost Comparisons

In summary, GOES and Landsat downlinks are approximately equal in cost and both are cheaper than LOS radio for comparable networks. The cost advantage at this time depends on the existence of Government funded satellites (NASA, 1977). As long as such satellites exist, an agency gains a strong advantage by using them instead of procuring a whole system.

5.0 RESULTS AND DISCUSSION OF SATELLITE DATA COLLECTION

The following items are considered significant results of this investigation in the use of the Landsat DCS:

1. The reliability of data collection platforms, Landsat itself, and NED's downlink were judged to be high. This finding has led to our continued involvement with satellites as a data collection medium.

2. Component redundancy is an important consideration in any operational flood control data collection system. Our experience has shown that with many components in series (as they are in the DCS) a failure in one component causes an entire breakdown.

3. A significant outcome of installing the DCS downlink was a potential increase in ability to function in the flood control

mission with no additional manpower. This potential became apparent during the storms which struck New England during this investigation. For example, during April and May of 1975 our DCP's on the Saint John River in northern Maine provided hydrologic information for relay to flood forecasters at the New Brunswick Power Commission office in Fredericton, New Brunswick, Canada. Prior to Landsat, part of this area could not be monitored in real time because of the high costs involved. In August 1976, the remainder of hurricane "Belle" travelled through Vermont, New Hampshire, northern Maine, and Canada's Maritime Provinces dumping 3 inches of rain in many areas. In Canada and Maine local storms dropped up to 2 inches during the following week, causing the Saint John River to reach near flood stages at Fort Kent, Maine. During this event DCS data from the region was received from three of our DCP's and from one belonging to Canada's Department of the Environment. The resulting high runoff after these storms was studied in connection with the proposed Dickey-Lincoln School dams to be built in that area, and it was found that for this watershed creditable flood hydrographs could be generated from DCS data. Corps personnel who have seen the system in operation have deemed the potential sufficient to warrant further investment in the field of satellite data collection.

4. Service was required in the field for malfunctioning DCP's or battery replacement on the average of every nine months, and the method that evolved was to visit them as needed, rather than to make rounds on schedule. A set of strong arguments favoring our adopted method is found in recent research (NASA, 1977).

5. A single Landsat is suitable for data that is needed daily or twice daily. Slowly changing or integrated parameters such as wind passage and snow accumulation may be monitored with ease; but the system is not suitable for rapidly changing or variable data such as peak rainfall or insolation. In general it is not adequate for collecting hydrologic data in small or flashy watersheds.

6. Costs of satellite data collection systems are less than comparable line-of-sight radio systems as long as the investment in the satellite is borne by a single agency. It is recognized that commercial satellite may be economically favorable within a few years (NASA, 1977).

7. Experience with Landsat and exposure to GOES lead to the conclusion that for reservoir regulation an ideal data collection system would draw features from both satellites. Our needs

would be best suited by a geosynchronous satellite having random reporting, the timing of which could be governed by the DCP. Alternatively, a geosynchronous satellite operated to allow hourly reports or emergency reports would be acceptable.

8. In August 1977 we invited an electronics team from the National Space Technology Laboratory, Bay St. Louis, Mississippi, to perform tests on the 15-foot antenna at NED, to determine its adequacy to receive GOES data. As a result of these tests and our own favorable evaluation of GOES for use in reservoir control, we are adding GOES acquisition capability to the ground receive station. We intend to retain Landsat tracking capability as a backup in case the entire GOES system fails. Appropriate electronic switch-over devices are being built into the combined station. Receiving and computer equipment is on order, and installation is scheduled for May 1978.

9. NED is strongly considering further use of general purpose microprocessors for DCP control, data handling at the remote site, threshold detection, encoding and modulation, along the lines of the work already performed at the University of Tennessee (NASA, 1976b). The capabilities of microprocessors as control and monitoring devices have been adequately demonstrated recently, and cost savings and greater flexibility are anticipated with their use.

6.0 BACKGROUND ON IMAGERY STUDY

6.1 Project Sequence

The U.S. Army Engineer Division, New England and the Cold Regions Research and Engineering Laboratory have been involved in the Landsat DCS and 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 DCS studies by developing sensor interfaces for the Landsat data collection platforms (DCP's) and evaluating 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's.

6.2 Hydrologic Parameters

A coordinating committee comprising personnel from NED, CRREL and the University of Connecticut selected the following hydrologic parameters that would affect reservoir operation and management:

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.

7.0 DIGITAL PROCESSING OF THE LANDSAT CCT'S

7.1 Description of the Landsat CCT's

Landsat-1 and Landsat-2 circle the Earth in a 572-mi (920 km) near-polar orbit once every 103 minutes, each completing approximately 14 orbits per day. The multispectral scanner (MSS) on each satellite continuously scans perpendicularly to the spacecraft's direction with an oscillating mirror (NASA, 1976a). 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 μm (NASA 1976a). The spectral information is transmitted in digital form to ground stations. During image data processing at the NASA Goddard Space Flight Center a black and white photograph can be produced depicting an area approximately 115 mi (185 km) on a side for the following spectral regions: MSS band 4 (0.5-0.6 μm), MSS band 5 (0.6-0.7 μm), MSS band 6 (0.7-0.8 μm) and MSS band 7 (0.8-1.1 μm). This information is also available in digital form on a computer compatible tape, or CCT.

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 2,432 scan lines with each scan line covering 3,200 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).

7.2 Description of the Computer Analysis 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).

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

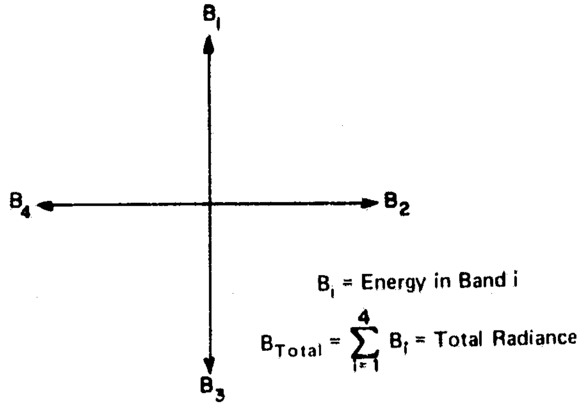
The geometric correction provides for a 1:24,000 scale computer printout which permits accurate location of test sites. The computer classification algorithms developed for analysis of the digital data allow for both components of the data (each of the four wavelength bands and associated energy value for each pixel) to be evaluated when classifying the Landsat data into various categories. In addition, atmospheric corrections were 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 represent the radiant energy received by the satellite in one of the four bands (figure 5a). 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 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 are provisions for evaluating brightness differences and for weighing these differences in with the color discrimination when constructing the classification categories.

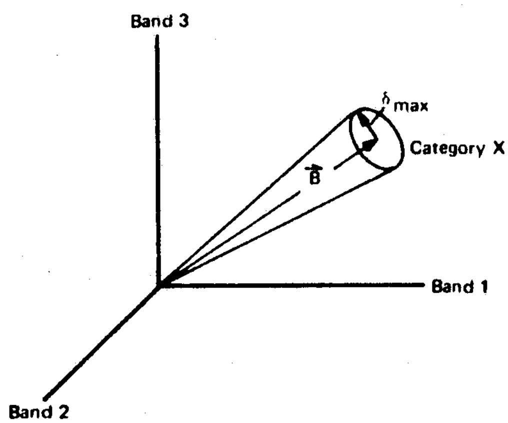
Discrimination based solely on color is obtained when the difference in direction between the color vectors (observations) is examined. If the angle between the observations is smaller than some user-defined *criterion*, the vectors are considered to be lying in the same direction and, therefore, the 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 four Landsat bands). If an observation lies within a solid angle smaller than the user-defined criterion, δ_{max}, it is said to belong to the category represented by the multispectral signature (figure 5b). Therefore, all vectors lying within a cone of angle, δ_{max}, about the signature representing category X belong to category X.

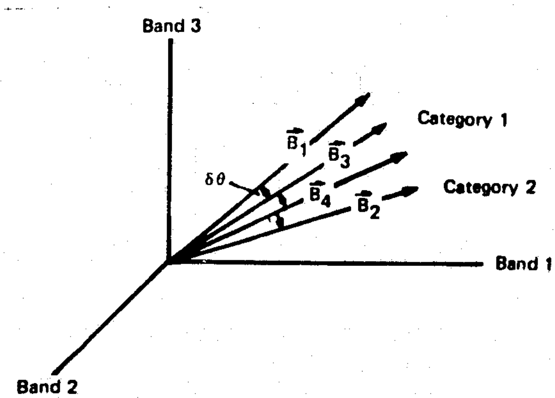
In the unsupervised mode the color vector corresponding to the first observation is compared with all subsequent observations. If color vector 1 is similar in direction to color vector 2 (i.e., $\delta\theta \leq \delta_{max}$), observation 2 is placed in the same category as the first observation (figure 5c). 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



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



b. <u>Supervised mode</u>. The user-defined criterion, δ_{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.



c. <u>Unsupervised mode</u>. $\vec{B}_3$ is similar in direction to $\vec{B}_1$ ($\delta\theta \leq \delta_{max}$) 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 5. The concept of the four-dimensional "color" space used in computer classification algorithm.

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 (δ_{max}). Thus, in the classification process, a relatively small weighting of brightness allows very 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.

7.3 Computer Data Handling and Analysis

A Harris COPE 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.

8.0 SNOW COVER ANALYSIS

8.1 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; Alfoldi, 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 coalesces and coarsens 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 volume of spring runoff from a watershed more accurately than is now possible.

8.2 Approach

8.2.1 Selection of Site

The Dickey-Lincoln School Lakes Project, Maine (figure 6), 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 there is not an adequate data collection system for evaluating the water equivalent of the snowpack each year.

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 36 inches (91 cm) and occurs uniformly throughout the year with about 30 percent in the form of snow. The average annual snowfall is about 100 inches (254 cm) which occurs during 8 months of the year (NED, 1967). Average winter snow depth ranges between 20 and 40 inches (51 and 102 cm) with the upper limit exceeding 50 inches (127 cm). Water equivalent of the snowpack reaches a maximum in late March and usually exceeds 10 inches (25 cm). 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 selected snow courses obtained in the upper Saint John River basin by the U.S. Geological Survey and the Allagash Wilderness Waterway Agency for the winter season of 1972-1973 (U.S. Department of Commerce, 1973) (figure 7). The Allagash B snow course is located within a mixed forest near the confluence of the Allagash and Saint John Rivers at an elevation of about 640 feet (195 m) msl and is characterized by a southeast exposure with gently sloping terrain (figure 8). The Beech Ridge snow course is located within a mixed forest near the Frontier-Churchill Road near Umsaskis Lake at an elevation of about 1,300 feet (396 m) msl and is characterized by a western exposure on gently sloping terrain (figure 8). The

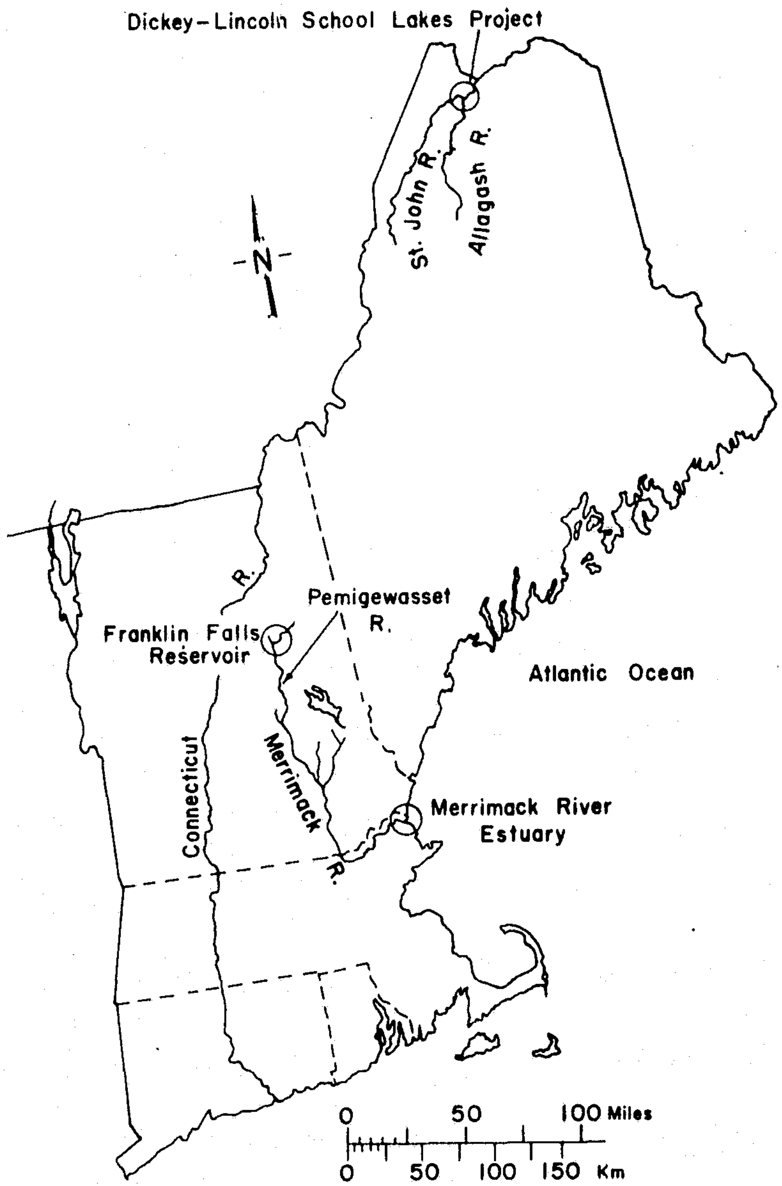


Figure 6. Site location map for the imagery analysis.

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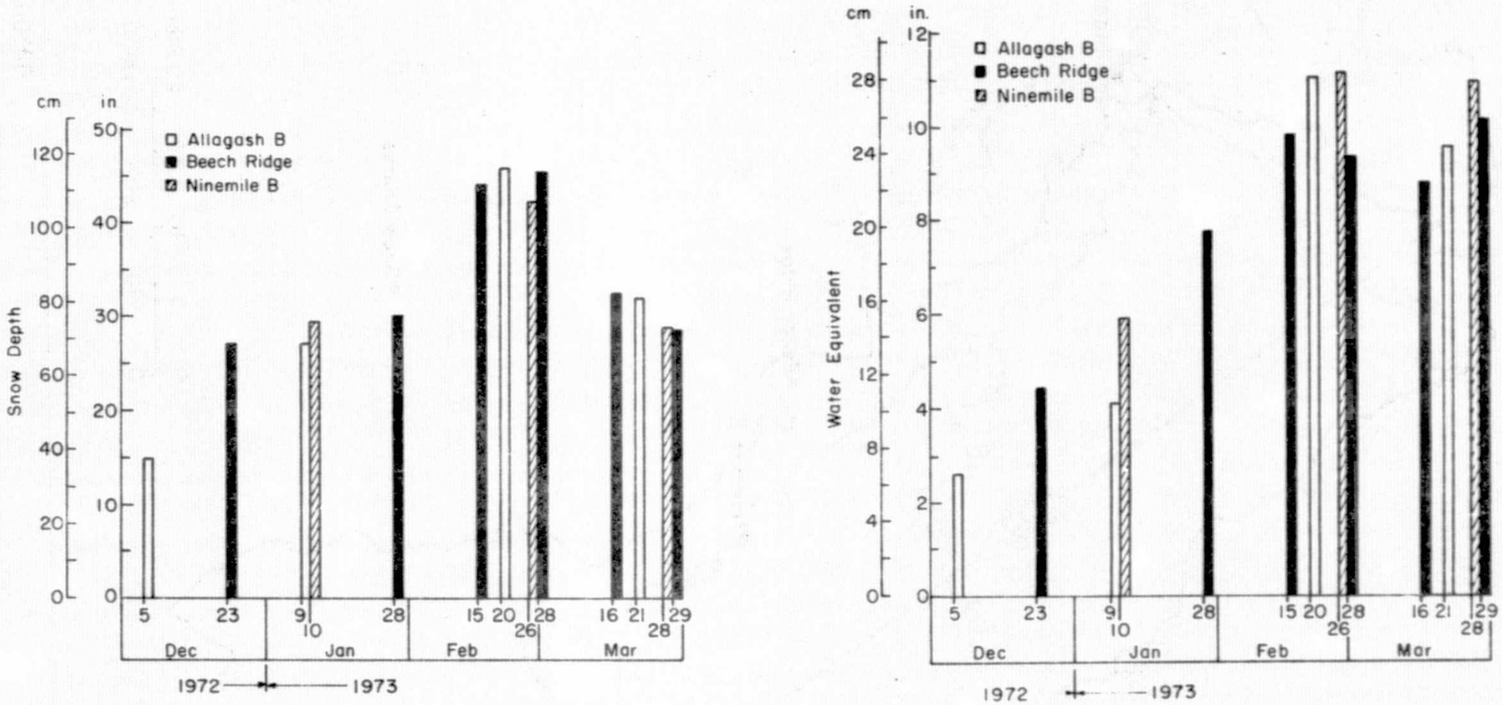
OF POOR QUALITY

35



a. Snow depth

b. Water equivalent

Figure 7 Snow depth and water equivalent data for selected snow courses in the Dickey-Lincoln School Lakes Project, Maine, during the 1972-73 winter season.

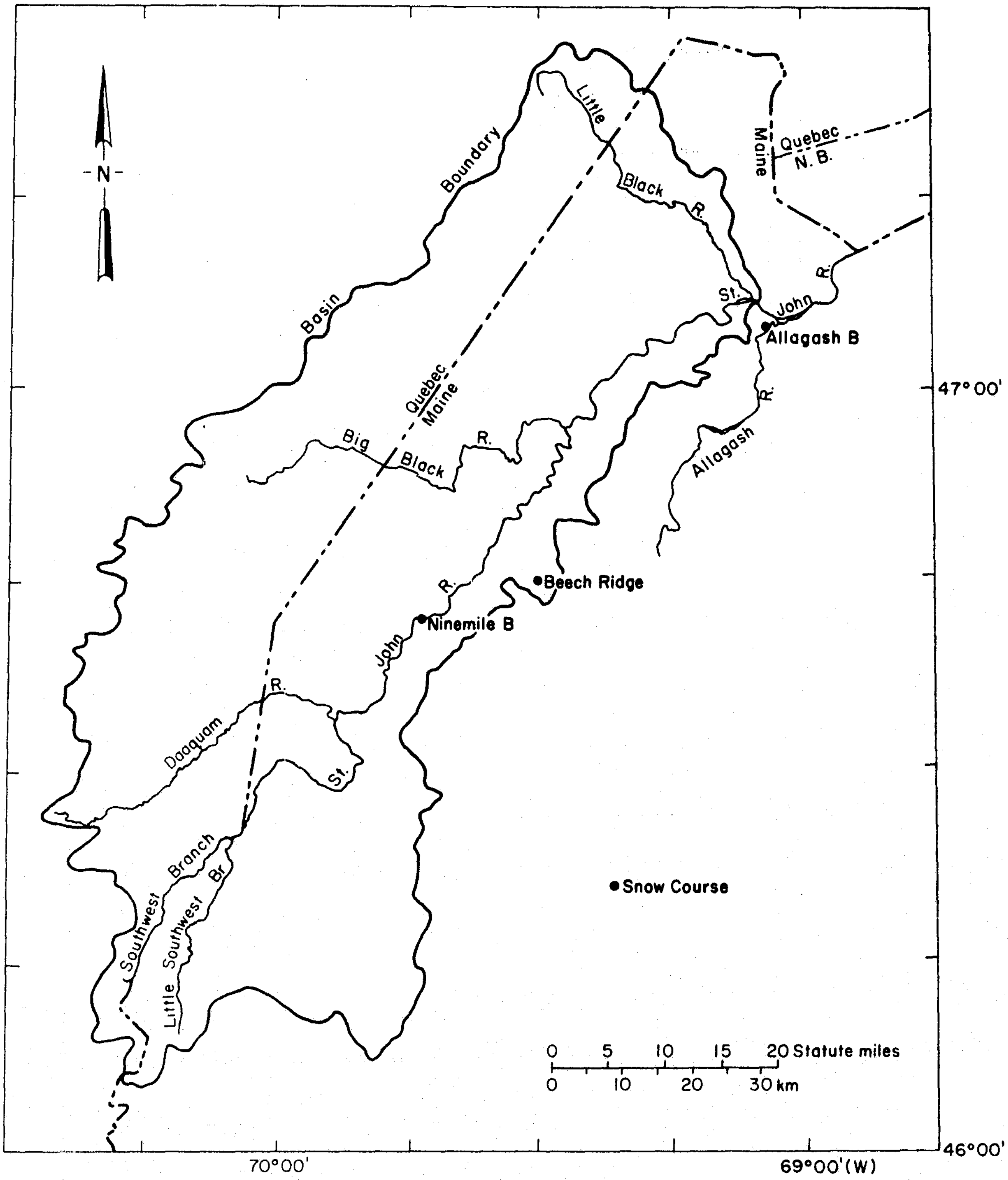


Figure 8. Location map of the Allagash B, Beech Ridge and Ninemile B snow courses.

Ninemile B snow course is located within a coniferous forest on the floodplain near the USGS gaging station on the Saint John River at an elevation of about 950 feet (290 m) msl and is characterized by a northwest exposure (figure 8).

8.2.2 Snow Course Data

The available cloud-free Landsat CCT's of the upper Saint 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 7 for the three snow courses (table 3) for 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 50 airline miles (80.5 km) 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 9.2 inches (23.4 cm) of snow associated with a water equivalent of 0.65 inches (1.6 cm) was recorded at Caribou, Maine. In addition, on 8 February 1973 there was a minor snowfall of 1.6 inches (4.1 cm) with a water equivalent of 0.12 inch (0.3 cm). Based on these data, the estimated 9.5 inches (24.1 cm) was assumed to be reasonable.

TABLE 3

SNOW COURSE DATA
(11 February 1973)

Snow Course	Latitude/ Longitude	Snow Course Length (ft)	Sampling Points	Snow Depth (in)*	Water Equivalent (in)*
Allagash B	47°05'N/69°04'W	1,000	10	42	9.6
Beech Ridge	46°36'N/69°28'W	-	-	41	9.4
Ninemile B	46°42'N/69°43'W	1,000	10	38	9.5

*1 inch = 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 (146.9 mi^2 or 380.6 km^2) at a scale of 1:24000. 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 2.3 $miles^2$ (6.0 km^2). 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.

8.3 Results and Discussion

Unsupervised classifications were performed on the three snow course sites for the 11 February 1973 CCT for a range of δ_{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.

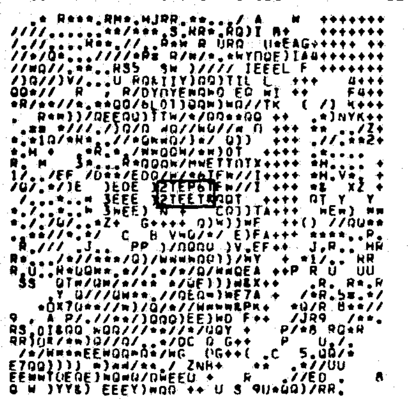
The three snow course computer classification printouts for 11 February 1973 are shown in figures 9, 10, and 11 (Merry, et al, 1977). The location of the snow course is shown outlined on the computer test site. The radiance values associated with each pixel within the snow course are indicated by the arrows within the *categorization summary* shown in figures 9, 10 and 11. 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 between the signatures within a category, with the smaller numbers indicating little variation. The *normalized radiances* in each band (*B1', B2', B3' and B4'*) always add up to unity 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* (mW/cm^2 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.

*Milliwatts per square centimeter per steradian.

ALLAGASH B SNOW COURSE
640' ELEVATION   ASPECT: SOUTHEAST

WATER EQUIV. 9.6"
SNOW DEPTH 42"

DIGITIZED OUTPUT OF SUBSEGMENT(S) 726.
SHOWING 45 CATEGORIES



CATEGORIZATION SUMMARY

NORMALIZED RADIANCES / TRUE RADIANCES

		NUM.	TOL.	B1'	B2'	B3'	B4'	B1	B2	B3	B4	TOTAL RADIANCE
	/	157	2.	0.26	0.16	0.16	0.42	1.38	0.87	0.89	2.24	5.38
	*	126	2.	0.27	0.16	0.16	0.41	1.33	0.81	0.82	2.06	5.01
	.	126	2.	0.27	0.16	0.16	0.41	1.25	0.74	0.75	1.87	4.62
	+	118	1.	0.25	0.21	0.17	0.37	5.12	4.15	3.39	7.57	20.23
	Q	101	2.	0.25	0.16	0.17	0.42	1.47	0.95	0.96	2.43	5.81
	W	75	2.	0.25	0.16	0.17	0.43	1.51	1.00	1.02	2.62	6.15
	)	57	2.	0.25	0.16	0.16	0.43	1.62	1.08	1.09	2.80	6.59
▶	E	49	2.	0.24	0.16	0.17	0.43	1.70	1.15	1.16	2.99	7.00
	R	47	2.	0.28	0.16	0.17	0.40	1.17	0.68	0.71	1.68	4.24
▶	T	19	1.	0.24	0.16	0.17	0.43	1.75	1.20	1.23	3.18	7.36
	Y	13	1.	0.24	0.17	0.17	0.42	1.95	1.37	1.37	3.36	8.06
	U	12	1.	0.30	0.16	0.16	0.37	1.20	0.65	0.66	1.50	4.00
	I	10	1.	0.23	0.16	0.17	0.44	1.99	1.41	1.43	3.74	8.57
	O	9	1.	0.23	0.17	0.17	0.43	1.95	1.41	1.41	3.55	8.32
▶	&	8	1.	0.25	0.17	0.16	0.41	1.95	1.35	1.27	3.18	7.74
▶	P	8	1.	0.26	0.18	0.16	0.40	1.96	1.34	1.24	2.99	7.53
	A	8	1.	0.23	0.18	0.17	0.41	2.57	2.02	1.90	4.53	11.02
	S	7	1.	0.28	0.17	0.16	0.39	1.09	0.64	0.63	1.50	3.87
	D	6	1.	0.26	0.17	0.17	0.40	1.71	1.11	1.12	2.62	6.56
	F	5	1.	0.24	0.19	0.17	0.40	2.80	2.13	1.94	4.60	11.47
	G	5	1.	0.25	0.19	0.17	0.39	3.94	3.10	2.67	6.28	15.99
	H	5	0.	0.25	0.15	0.18	0.42	1.09	0.69	0.78	1.87	4.82
	J	4	0.	0.25	0.17	0.19	0.39	1.20	0.79	0.89	1.67	4.74

CATEGORIZATION SUMMARY

NORMALIZED RADIANCES / TRUE RADIANCES

		NUM.	TOL.	B1'	B2'	B3'	B4'	B1	B2	B3	B4	TOTAL RADIANCE
	K	4	1.	0.23	0.19	0.16	0.42	3.30	2.69	2.31	5.93	14.24
	L	4	1.	0.23	0.17	0.17	0.44	1.77	1.30	1.28	3.36	7.71
	Z	4	1.	0.24	0.19	0.17	0.41	2.41	1.87	1.68	4.11	10.08
	X	4	1.	0.24	0.18	0.17	0.41	2.51	1.89	1.78	4.30	10.49
	C	4	1.	0.28	0.18	0.16	0.38	2.21	1.45	1.26	2.99	7.91
	*	4	1.	0.27	0.15	0.15	0.43	1.06	0.60	0.59	1.65	3.98
	V	4	1.	0.27	0.17	0.18	0.38	1.74	1.09	1.12	2.43	6.37
	B	3	1.	0.23	0.19	0.17	0.40	3.56	2.97	2.53	6.17	15.23
	(	3	1.	0.30	0.21	0.16	0.33	3.23	2.34	1.79	3.55	10.91
	N	3	1.	0.25	0.18	0.16	0.41	2.40	1.77	1.56	3.92	9.66
	M	3	1.	0.24	0.16	0.18	0.42	1.20	0.79	0.90	2.06	4.95
	,	3	0.	0.27	0.17	0.19	0.37	1.10	0.69	0.74	1.49	4.02
	1	3	1.	0.25	0.15	0.17	0.43	1.17	0.73	0.79	2.06	4.74
▶	2	3	0.	0.24	0.17	0.18	0.41	1.72	1.26	1.29	2.99	7.26
	3	3	0.	0.28	0.19	0.16	0.38	1.80	1.21	1.04	2.43	6.46
	4	3	1.	0.24	0.19	0.17	0.40	3.40	2.65	2.38	5.61	14.03
	5	3	0.	0.30	0.17	0.17	0.36	1.10	0.60	0.60	1.31	3.62
▶	6	3	0.	0.22	0.16	0.16	0.46	1.55	1.13	1.08	3.18	6.93
	7	3	1.	0.25	0.17	0.17	0.41	2.12	1.45	1.37	3.36	8.30
	8	3	1.	0.31	0.18	0.16	0.35	1.00	0.56	0.52	1.12	3.21
	9	3	0.	0.31	0.17	0.18	0.34	1.05	0.56	0.60	1.12	3.34
	0	3	0.	0.23	0.16	0.16	0.45	1.75	1.17	1.22	3.36	7.50

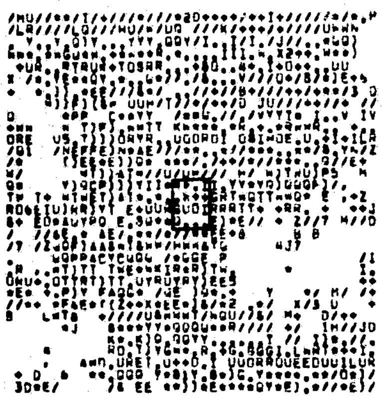
NO. POINTS CLASSIFIED = 1048 NO. POINTS UNCLASSIFIED = 232

DELMAX = 0.0200   BRIGHTNESS WEIGHING = 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 9 Computer classification printout of the Allagash B snow course (11 February 1973).

DIGITIZED OUTPUT OF SUBSEGMENT(S) 60U, SHOWING 43 CATEGORIES



BEECH RIDGE SNOW COURSE
1300' ELEVATION ASPECT: WEST

WATER EQUIV. 9.4" SNOW DEPTH 41"

CATEGORIZATION SUMMARY

		NUM.	TOL.	NORMALIZED RADIANCES / TRUE RADIANCES B1' / B1	B2' / B2	B3' / B3	B4' / B4	TOTAL RADIANCE
	/	160	1.3	0.13 / 0.76	0.14 / 0.63	0.06 / 0.37	0.68 / 4.11	6.06
▶	•	120	0.5	0.12 / 0.70	0.14 / 0.78	0.06 / 0.34	0.68 / 3.92	5.74
▶	.	117	0.9	0.13 / 0.75	0.14 / 0.80	0.06 / 0.37	0.67 / 3.92	5.84
▶	•	78	1.2	0.12 / 0.80	0.13 / 0.85	0.06 / 0.39	0.69 / 4.49	6.54
▶	9	54	0.9	0.13 / 0.70	0.14 / 0.75	0.06 / 0.34	0.66 / 3.55	5.34
▶	4	50	0.6	0.13 / 0.70	0.14 / 0.75	0.06 / 0.39	0.67 / 3.74	5.54
	)	49	0.9	0.13 / 0.65	0.13 / 0.69	0.06 / 0.30	0.69 / 3.55	5.16
	E	43	0.6	0.12 / 0.65	0.13 / 0.72	0.05 / 0.31	0.70 / 3.42	5.60
	R	40	0.7	0.13 / 0.75	0.13 / 0.75	0.06 / 0.36	0.67 / 3.74	5.40
	T	38	0.8	0.12 / 0.65	0.13 / 0.70	0.06 / 0.32	0.69 / 3.74	5.41
	Y	37	0.9	0.14 / 0.75	0.14 / 0.78	0.06 / 0.35	0.65 / 3.55	5.44
▶	U	34	0.6	0.14 / 0.80	0.14 / 0.78	0.07 / 0.37	0.66 / 3.74	5.69
▶	I	31	0.7	0.14 / 0.65	0.14 / 0.65	0.07 / 0.40	0.65 / 3.92	6.02
▶	O	23	0.5	0.14 / 0.80	0.13 / 0.78	0.06 / 0.37	0.67 / 3.92	5.87
	&	12	0.5	0.11 / 0.65	0.13 / 0.75	0.06 / 0.32	0.70 / 4.11	5.83
	P	10	0.6	0.13 / 0.65	0.14 / 0.67	0.06 / 0.25	0.68 / 3.36	4.96
	A	10	0.4	0.12 / 0.60	0.13 / 0.68	0.06 / 0.29	0.69 / 3.55	5.11
	S	9	0.4	0.13 / 0.80	0.15 / 0.91	0.06 / 0.39	0.65 / 3.92	6.02
	D	9	0.7	0.15 / 0.96	0.16 / 1.04	0.07 / 0.47	0.62 / 4.11	6.58
	F	8	0.5	0.12 / 0.60	0.12 / 0.59	0.05 / 0.25	0.71 / 3.55	4.99
▶	G	8	0.3	0.13 / 0.75	0.15 / 0.89	0.07 / 0.40	0.65 / 3.74	5.76

	NUM.	TOL.	NORMALIZED RADIANCES / TRUE RADIANCES B1' / B1	B2' / B2	B3' / B3	B4' / B4	TOTAL RADIANCE
H	7	0.4	0.14 / 0.80	0.15 / 0.90	0.07 / 0.41	0.64 / 3.74	5.86
J	6	0.5	0.13 / 0.87	0.13 / 0.93	0.06 / 0.43	0.68 / 4.27	6.89
K	6	0.5	0.14 / 0.85	0.15 / 0.91	0.07 / 0.41	0.63 / 3.74	5.91
L	6	0.3	0.15 / 0.85	0.14 / 0.80	0.07 / 0.38	0.65 / 3.74	5.76
Z	5	0.6	0.11 / 0.70	0.11 / 0.71	0.05 / 0.32	0.72 / 4.48	6.21
X	4	0.5	0.14 / 0.96	0.15 / 1.00	0.06 / 0.43	0.65 / 4.48	6.87
C	4	0.4	0.14 / 0.70	0.14 / 0.74	0.06 / 0.30	0.66 / 3.36	5.10
•	4	0.4	0.15 / 0.85	0.15 / 0.84	0.07 / 0.41	0.63 / 3.55	5.64
V	4	0.2	0.15 / 0.90	0.15 / 0.93	0.07 / 0.43	0.63 / 3.92	6.19
B	4	[illegible]	0.12 / 0.84	0.12 / 0.83	0.05 / 0.34	0.71 / 4.86	6.86
(	4	0.2	0.11 / 0.65	0.12 / 0.69	0.05 / 0.27	0.72 / 4.11	5.72
N	4	0.4	0.15 / 0.80	0.14 / 0.79	0.06 / 0.35	0.65 / 3.55	5.46
M	4	0.4	0.15 / 1.02	0.15 / 1.02	0.07 / 0.48	0.64 / 4.48	7.01
,	4	0.4	0.15 / 1.04	0.14 / 0.99	0.06 / 0.44	0.65 / 4.67	7.14
1	3	0.3	0.14 / 0.80	0.16 / 0.89	0.07 / 0.38	0.63 / 3.55	5.62
2	3	0.4	0.15 / 0.95	0.16 / 1.01	0.07 / 0.43	0.62 / 3.92	6.31
3	3	0.3	0.12 / 0.89	0.14 / 1.03	0.06 / 0.44	0.68 / 4.86	7.18
4	3	0.2	0.13 / 0.85	0.12 / 0.81	0.06 / 0.40	0.69 / 4.67	6.73
5	3	0.2	0.13 / 0.80	0.11 / 0.70	0.05 / 0.32	0.71 / 4.48	6.30
6	3	0.3	0.16 / 1.37	0.15 / 1.26	0.07 / 0.57	0.62 / 5.23	8.43
7	3	0.3	0.12 / 0.90	0.12 / 0.90	0.05 / 0.37	0.72 / 5.61	7.77
8	3	0.3	0.11 / 0.70	0.11 / 0.75	0.05 / 0.34	0.73 / 4.66	6.65

NO. POINTS CLASSIFIED = 1030 NO. POINTS UNCLASSIFIED = 350

DELMAX = 0.0110 BRIGHTNESS WEIGHING = 0.200

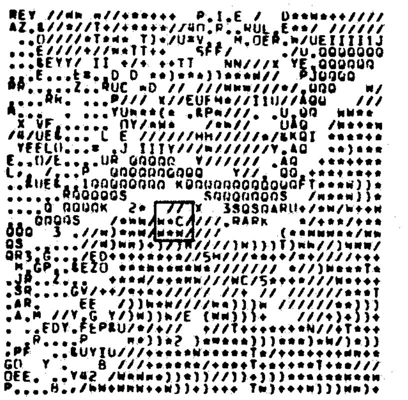
100.00 PERCENT OF BAND 1 USED IN ALBEDO CALC.
100.00 PERCENT OF BAND 2 USED IN ALBEDO CALC.
100.00 PERCENT OF BAND 3 USED IN ALBEDO CALC.
100.00 PERCENT OF BAND 4 USED IN ALBEDO CALC.

Figure 10 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"

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



4

CATEGORIZATION SUMMARY

NORMALIZED RADIANCES / TRUE RADIANCES

		NUM.	TOL.	B1' / B1	B2' / B2	B3' / B3	B4' / B4	TOTAL RADIANCE
►	/	225	3.	0.17 1.17	0.06 0.44	0.15 1.02	0.62 4.24	6.87
►	*	163	2.	0.19 1.04	0.07 0.39	0.15 0.84	0.58 3.18	5.45
	.	151	3.	0.17 2.81	0.06 0.99	0.13 2.19	0.64 10.71	16.70
	+	93	2.	0.20 0.98	0.08 0.38	0.16 0.79	0.57 2.80	4.95
	Q	93	3.	0.15 4.46	0.05 1.52	0.13 3.71	0.67 19.54	29.22
►	W	89	2.	0.18 1.05	0.07 0.39	0.16 0.88	0.59 3.36	5.69
	)	65	2.	0.19 0.98	0.07 0.37	0.16 0.83	0.58 2.99	5.16
	E	28	2.	0.14 1.75	0.05 0.63	0.14 1.79	0.67 6.52	12.68
	R	19	2.	0.15 3.20	0.05 1.12	0.13 2.80	0.67 14.31	21.42
	T	17	2.	0.20 0.95	0.08 0.36	0.16 0.74	0.56 2.62	4.67
	Y	17	1.	0.10 1.44	0.04 0.54	0.15 2.06	0.71 9.81	13.85
	U	16	1.	0.14 1.51	0.05 0.54	0.15 1.59	0.66 7.00	10.63
	I	13	1.	0.08 1.28	0.03 0.47	0.15 2.47	0.74 12.11	16.34
	O	10	1.	0.18 1.98	0.06 0.70	0.14 1.51	0.62 6.93	11.11
	&	10	1.	0.19 2.37	0.06 0.81	0.13 1.65	0.62 7.76	12.59
	P	10	1.	0.21 2.20	0.07 0.78	0.13 1.36	0.59 6.32	10.65
	A	9	1.	0.15 3.59	0.05 1.30	0.13 3.00	0.67 15.71	23.60
	S	8	1.	0.21 4.84	0.07 1.62	0.12 2.68	0.60 13.71	22.84
	D	6	1.	0.11 1.02	0.04 0.38	0.16 1.54	0.70 6.69	9.63
	F	6	1.	0.23 2.72	0.08 0.99	0.12 1.48	0.57 6.79	11.99

CATEGORIZATION SUMMARY

NORMALIZED RADIANCES / TRUE RADIANCES

		NUM.	TOL.	B1' / B1	B2' / B2	B3' / B3	B4' / B4	TOTAL RADIANCE
	G	5	1.	0.19 2.24	0.07 0.78	0.14 1.58	0.61 7.06	11.66
	H	4	1.	0.21 1.37	0.07 0.48	0.14 0.92	0.57 3.74	6.52
	J	4	1.	0.09 2.26	0.03 0.85	0.14 3.31	0.74 17.60	24.21
	K	4	0.	0.24 4.86	0.08 1.61	0.11 2.23	0.57 11.40	20.10
	L	4	0.	0.23 2.20	0.08 0.80	0.13 1.24	0.56 5.37	9.61
	Z	4	1.	0.12 2.35	0.04 0.82	0.14 2.68	0.70 13.64	19.48
	X	4	1.	0.29 2.70	0.11 1.00	0.12 1.10	0.49 4.67	9.47
►	C	3	1.	0.24 1.58	0.10 0.64	0.14 0.87	0.52 3.36	6.47
	=	3	1.	0.14 1.68	0.06 0.64	0.14 1.68	0.66 7.66	11.67
	V	3	0.	0.24 2.47	0.09 0.87	0.13 1.27	0.54 5.48	10.09
	B	3	1.	0.25 3.05	0.08 1.02	0.12 1.49	0.55 6.79	12.35
	(	3	1.	0.24 1.37	0.09 0.48	0.15 0.84	0.53 2.99	5.68
	N	3	1.	0.21 1.35	0.08 0.52	0.14 0.87	0.56 3.55	6.30
	M	3	1.	0.24 3.30	0.08 1.12	0.12 1.70	0.56 7.85	13.96
	,	3	1.	0.20 2.80	0.07 0.95	0.13 1.71	0.60 8.22	13.69
	1	3	1.	0.08 1.62	0.03 0.59	0.14 2.92	0.75 15.38	20.51
	2	3	1.	0.26 1.65	0.09 0.56	0.14 0.91	0.50 3.18	6.30
	3	3	1.	0.26 4.45	0.09 1.45	0.11 1.82	0.54 9.09	16.81
	4	3	1.	0.14 1.27	0.05 0.48	0.15 1.40	0.66 6.17	9.31
	5	3	1.	0.23 1.53	0.09 0.60	0.13 0.87	0.55 3.74	6.75

NO. POINTS CLASSIFIED = 1116 NO. POINTS UNCLASSIFIED = 164

DELMAX = 0.0225 BRIGHTNESS WEIGHING 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 11 Computer classification printout of the Ninemile B snow course (11 February 1973).

The Allagash B snow course computer classification printout is shown in figure 9. The total radiance of pixels contained in the snow course area varied from 6.93 to 7.74 mW/cm^2 sr (categories: E T & P 2 6), which corresponded to a water equivalent of 9.6 inches (24.4 cm) obtained from the snow course data. An important observation was that the radiance for MSS band 7 was consistently 2.99 or 3.18 mW/cm^2 sr, a difference of only one energy level.

The Beech Ridge snow course computer classification printout is shown in figure 10. The total radiance of pixels contained in this snow course varied from 5.34 to 6.54 mW/cm^2 sr (categories: * . + Q W U I O G) and corresponded to a water equivalent of 9.4 inches (23.9 cm) obtained from the snow course data. The Ninemile B snow course computer classification printout is shown in figure 11. The total radiance for the pixels contained in the site varied from 5.45 to 6.87 mW/cm^2 sr (categories: / * W C) and corresponded to a water equivalent of 9.5 inches (24.1 cm) obtained from the snow course data.

The radiance varied from 5.34 to 7.74 mW/cm^2 sr over the three sampled snow course areas, which corresponded to a water equivalent value of approximately 9.5 inches (24.1 cm) (Merry, et al, 1977). The range in radiance values from 5.34 to 7.74 mW/cm^2 sr may be attributed to variations in vegetative cover, slope and aspect which occurred 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 Saint John River (figure 9 and 11 showed the highest radiance, which ranged from 20.23 to as high as 29.22 mW/cm^2 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 vegetative cover, slope, aspect, geomorphic position and, to a lesser degree, elevation.

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

Average multispectral signatures were extracted for the three snow course sites from the four-band energy values for 11 February 1973 and 23 July 1973 to study seasonal variations in radiance. The multispectral signatures from these dates are shown in table 4.

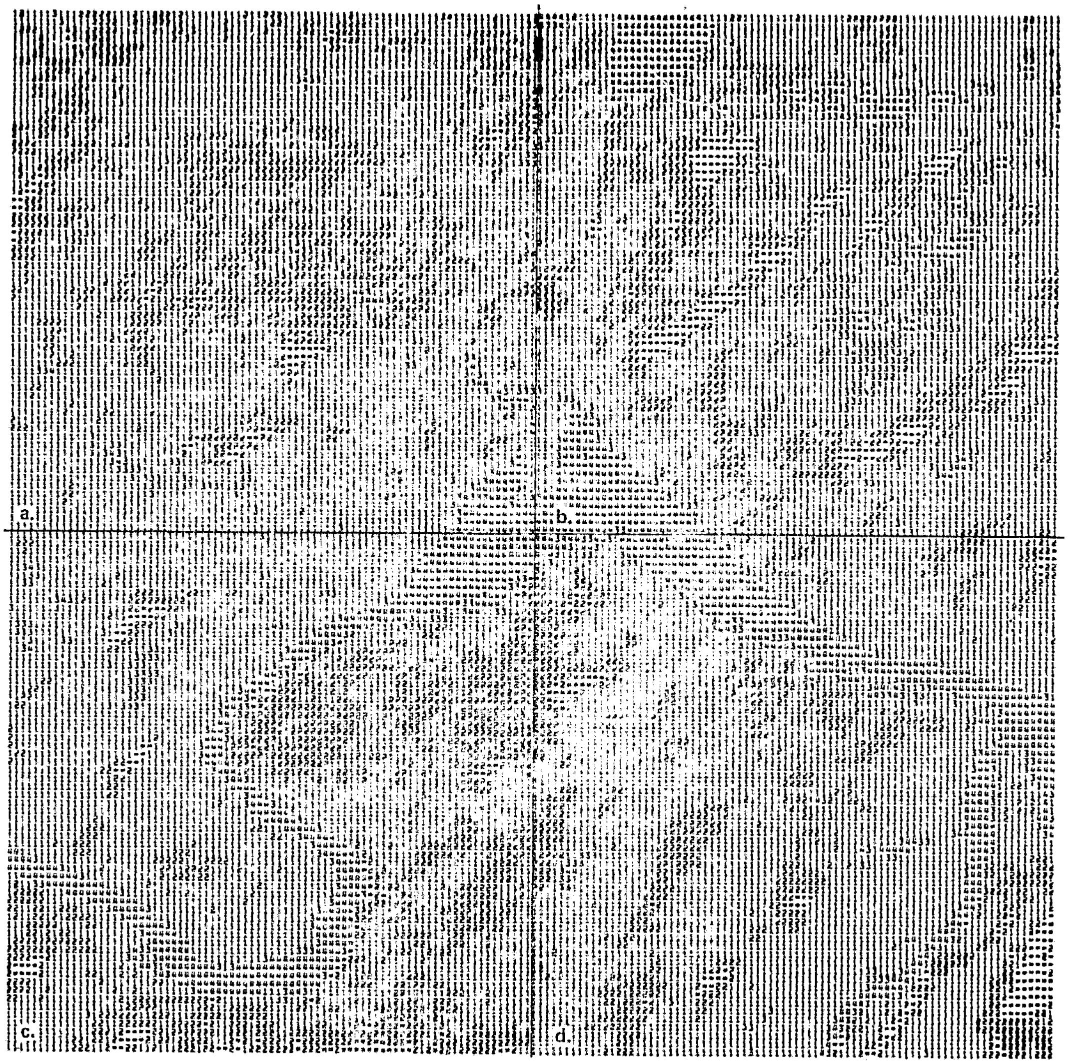
TABLE 4

AVERAGE MULTISPECTRAL SIGNATURES (mW/cm^2 sr) FOR THE THREE SNOW COURSES

Snow Course	Date	MSS 4	MSS 5	MSS 6	MSS 7	Total Radiance
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 areas where the three snow courses are located showed about the same radiance value (3 mW/cm^2 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 Ninemile B site is in a coniferous forest and the four-band multispectral signatures are slightly different from those of the other two sites.

Figure 12 shows the computer classification of snow cover/vegetation classes for the 11 February scene of a selected area (35.2 mi^2 or 90 km^2) near the confluence of the Saint John and Allagash Rivers with the correlative USGS topographic map. The multispectral signatures (table 5) for a supervised classification were derived from table 4 for the three snow course sites during February and another multispectral signature was derived from the four-band energy values for the Allagash and Saint John River channels. The four snow cover/vegetation classes are shown in table 6.



a. Actual signature table

Sym	Num	B1	B2	B3	B4	Albedo
1	3797	1.60	1.06	1.05	2.62	6.33
2	1000	1.17	0.68	0.69	1.66	4.20
3	155	3.16	2.41	2.11	4.95	12.65
4	97	4.94	3.94	3.24	7.19	19.31

No. points classified = 5059
No. points unclassified = 61

b. Actual signature table

Sym	Num	B1	B2	B3	B4	Albedo
1	3[illegible]28	1.72	1.14	1.11	2.76	6.71
2	835	1.18	0.68	0.67	1.61	4.14
3	441	3.16	2.45	2.14	5.07	12.82
4	[illegible]	5.02	4.07	3.26	7.32	14.65

No. points classified = 4044
No. points unclassified = 176

c. Actual signature table

Sym	Num	B1	B2	B3	B4	Albedo
1	3235	1.60	1.06	1.05	2.64	6.35
2	1107	1.10	0.67	0.67	1.63	4.12
3	160	3.14	2.41	2.08	4.86	12.48
4	505	5.13	4.12	3.35	7.41	20.00

No. points classified = [illegible]
No. points unclassified = 105

d. Actual signature table

Sym	Num	B1	B2	B3	B4	Albedo
1	3479	1.54	1.01	1.01	2.57	6.14
2	849	1.16	0.68	0.66	1.61	4.09
3	148	3.22	2.47	2.11	4.90	12.69
4	515	5.02	4.04	3.28	7.29	15.63

No. points classified = 4391
No. points unclassified = 120

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OF POOR QUALITY

Figure 12 Computer Classification Printout showing four Snow Cover/Vegetation Classes (11 February 1973).

TABLE 5

INPUT MULTISPECTRAL SIGNATURES (mW/cm^2 sr) FOR THE FOUR SNOW COVER/VEGETATION CLASSES

Symbol on Map	Delmax	Multispectral Signatures MSS 4	MSS 5	MSS 6	MSS 7	Total Radiance	W2
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 6

SNOW COVER/VEGETATION CLASSES MAPPED FROM THE 11 FEBRUARY 1973 CCT

Symbol on Map	Snow Cover/Vegetation Characteristics	Water Equivalent (in)*
1	Mixed forest, 640 ft (195 m) msl elevation, southeast exposure, gently sloping.	9.6
2	Mixed forest, 1,300 ft (396 m) msl elevation, western exposure, gently sloping.	9.4
3	Coniferous forest, 950 ft (290 m) msl elevation, northwest exposure, level.	9.5
4	Open nonvegetated areas, lowest elevations, level.	-

*1 inch = 2.54 cm.

Patterns of snow radiance values can be observed on the computer classification printout (figure 12) which suggests the interrelationship of vegetation, slope and aspect. The symbols *1* and *2* are predominant, indicating mixed forest at various elevations. The symbol *3* occurs in isolated areas such as hilltops and along the river channels. The symbol *4* occurs as expected along the Allagash, Saint John and part of the Little Black Rivers. Also, there were a number of unclassified pixels (the dashes) which can be seen in figure 12. 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 9.5 inches (24.1 cm) or other types of site characteristics.

9.0 WETLANDS MAPPING

9.1 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 percent 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 1:250000 (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 1:500000 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 leaf 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 1:250000 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 1:250000 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 percent have been achieved using digital processing techniques.

Seven categories of marsh vegetation and marsh features were identified at an approximate scale of 1:20000 (Anderson, et al, 1973b). These categories included: water, sandy mud flat, organic mud flat, sparsely vegetated, 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), forest, agriculture, and exposed sand and concrete. The *Spartina alterniflora* was discriminated with an accuracy of 94 to 100 percent, the *Phragmites communis* showed a classification accuracy of 83 percent, but the discrimination of *Spartina patens* was only 52 percent.

9.2 Approach

The site selected for the wetlands mapping analysis was a 124-km^2 (48-mi^2) area of the Merrimack River estuary (figure 6). 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 was a primary test site for the NED-CRREL Skylab Earth Resources Experiment Package (EREP) project

(McKim, et al, 1975b). Ground truth data in the form of land use maps prepared from satellite and aircraft photographic data products were available for this site.

9.3 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 1:24000 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 (figure 13).

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 1:24000 photograph was placed over the grayscale computer printout (scale 1:24000) 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 7).

TABLE 7

AVERAGE MULTISPECTRAL SIGNATURES (mW/cm^2 sr)
FOR THE WETLANDS AND WATER CATEGORIES

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

The multispectral training signatures (table 7) were used in a supervised classification of the northern portion of the Merrimack River estuary. Various values of delmax were used until

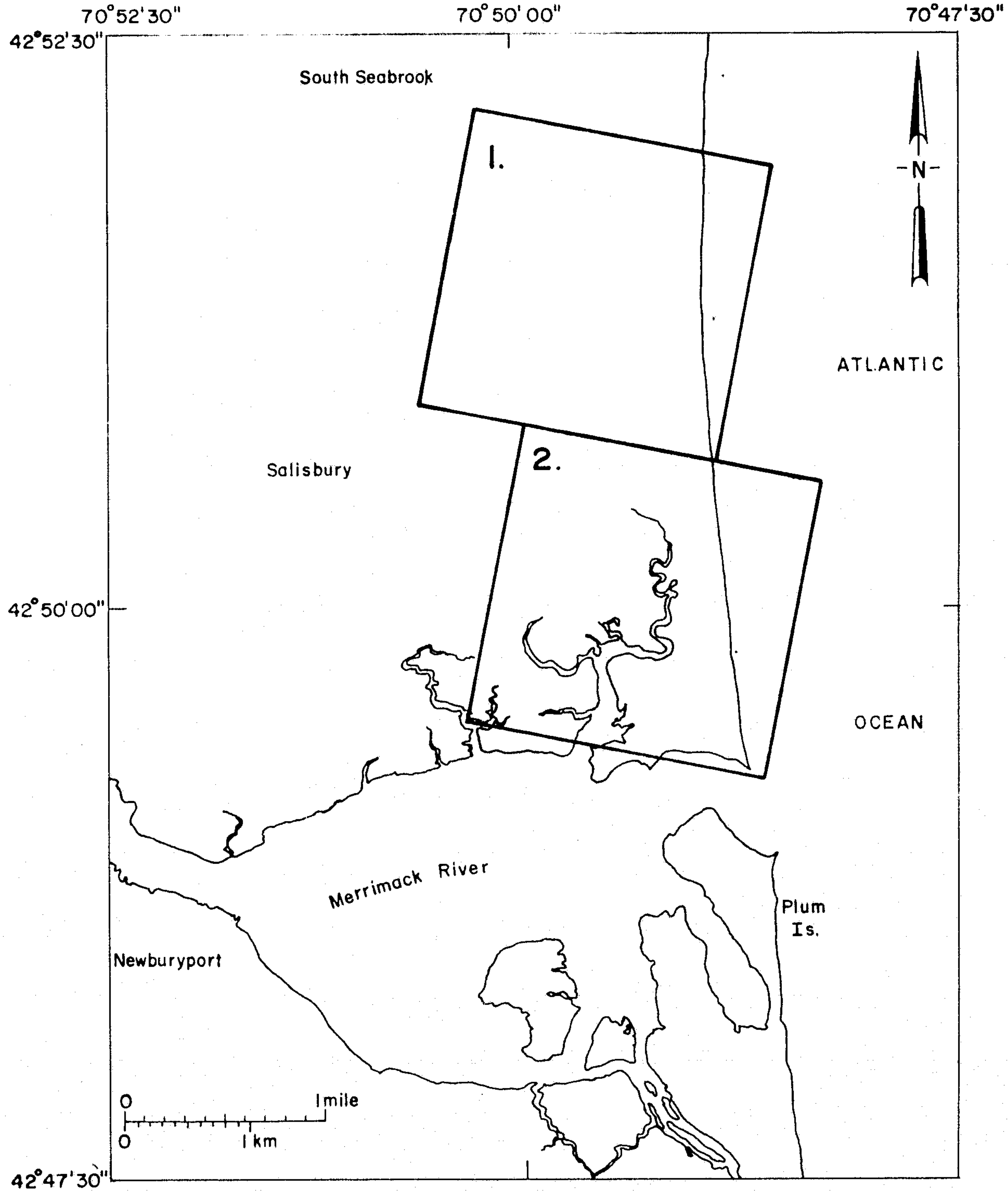


Figure 13 Location map of the two training sites used in the wetlands mapping analysis.

an optimum computer classification map of the wetland areas was obtained. The computer classification map is shown in figure 14. 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 percent was obtained for the wetlands unit, taking into account the misclassified and the unclassified wetlands pixels.

The reason for the 74 percent 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.

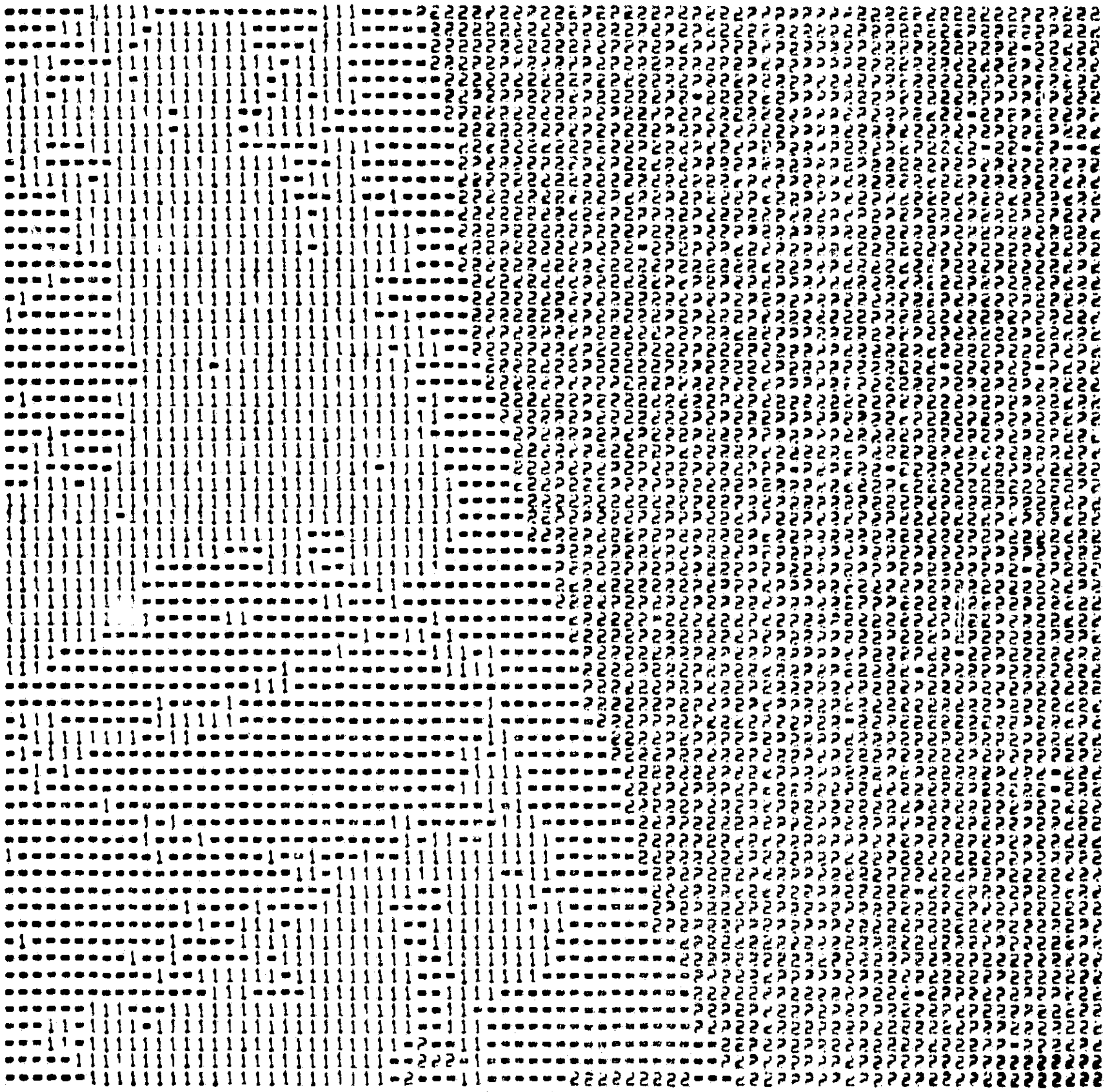
10.0 MAPPING OF FLOODED AREAS

10.1 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^2 (39 mi^2) or more have been made with less than 5 percent 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 (Range 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.



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	3.62
0.60	0.25	0.15	0.12	1.12

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

Figure 14 Computer classification printout of wetlands for the Merrimack River estuary (image ID 5444-14082).

Flood inundation mapping has been accomplished on MSS band 7 imagery enlarged to a scale of 1:250000 acquired one week to ten 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 (Hallbert, et al, 1973). These data compared favorably to 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 1:250000 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 1:250000 scale topographic maps and used as the data base for preparation of flood image maps. Specially filtered three-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 composites 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 1:62500; however, most mapping has been done on a regional basis at a scale of 1:250000.

10.2 Approach

Franklin Falls reservoir, New Hampshire (figure 6) was selected for the flooded areas mapping analysis based on a particular storm. 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 5.1 inches (13.0 cm) 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 most of the peak flood conditions in the Franklin Falls reservoir.

10.3 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 1:24000 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 15 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 320 to 360 feet (98 to 110 m))obtained from USGS topographic maps. Both outlines show very good agreement in total area of water depicted at the low-water reservoir stage.

Figure 16 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 369.5 feet (112.6 m) 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.

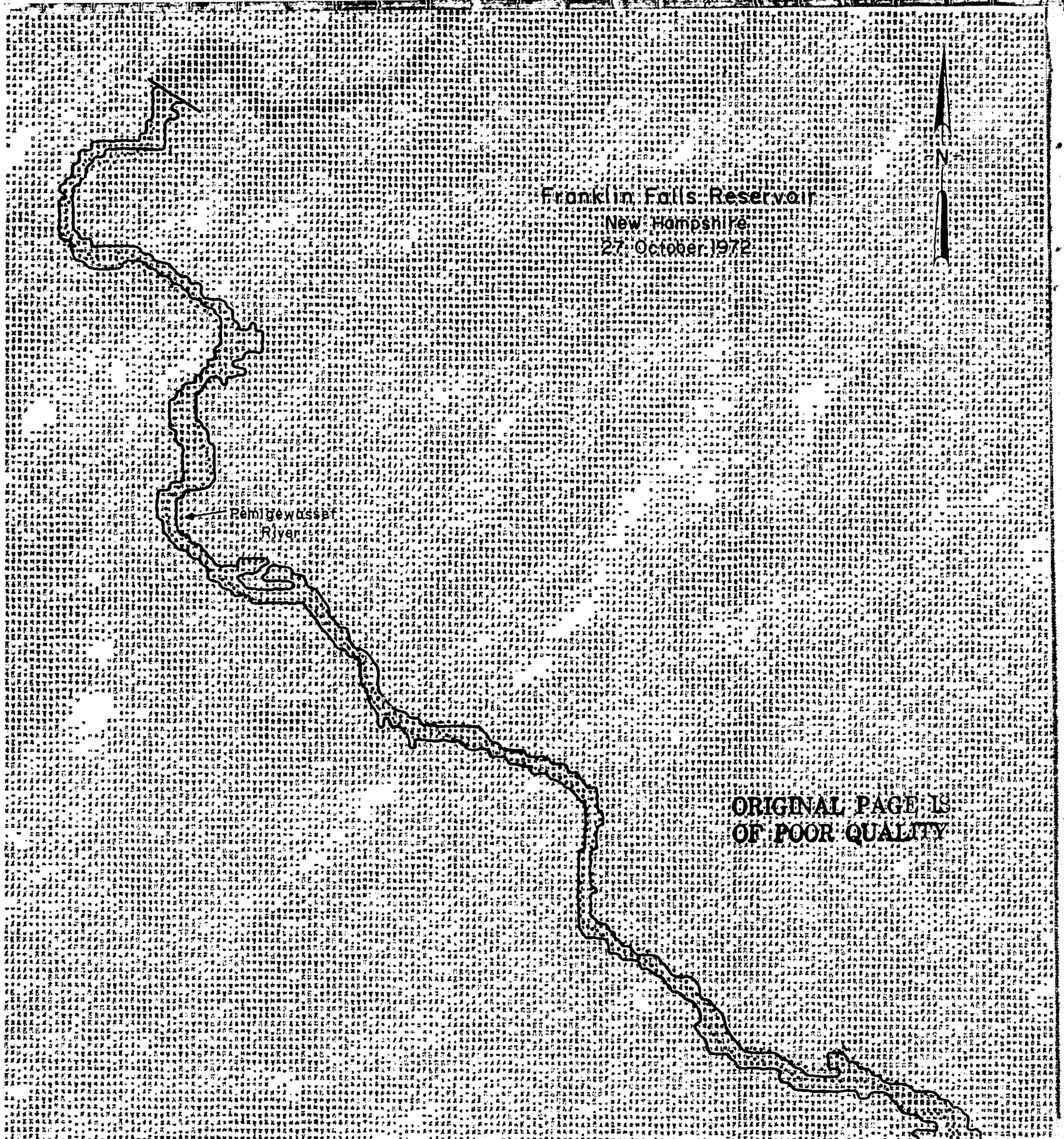


Figure 15. Grayscale printout of the Franklin Falls reservoir area, 27 October 1972

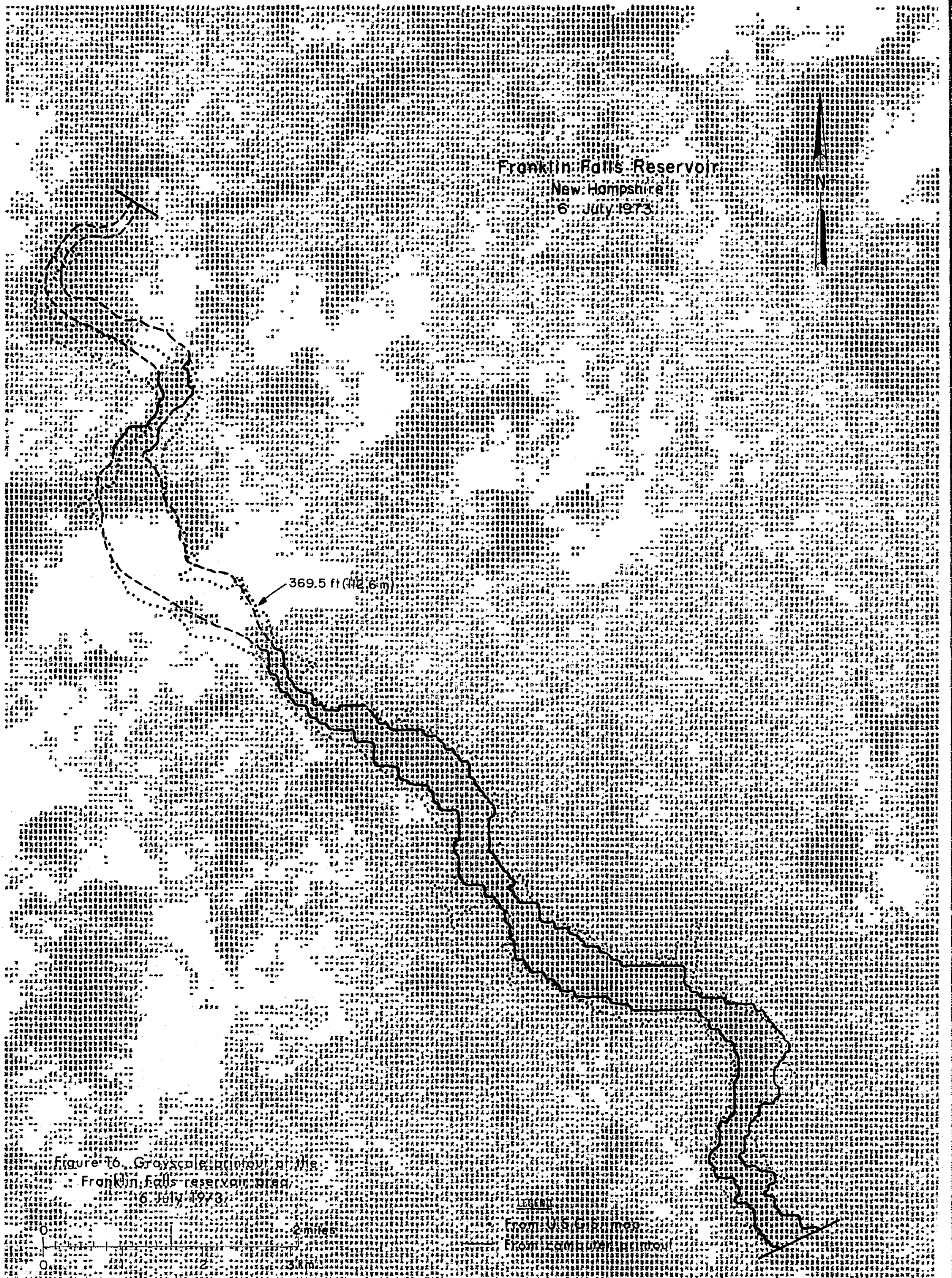


Figure 16. Grayscale printout of the Franklin Falls reservoir area 6 July 1973.

The acres of water were quantified for the 27 October and 6 July Landsat scenes. Table 8 shows the total number of pixels and acreage determined to be water within the reservoir area for both dates. It shows approximately 60 percent 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 8

AREAL EXTENT OF WATER WITHIN THE FRANKLIN FALLS RESERVOIR AREA ON 27 OCTOBER 1972 AND 6 JULY 1973

Date	Pixels (#)	Areal Extent (acres)**
27 Oct 1972	790	1,011.2
6 Jul 1973	1,333*	1,706.2

*Estimated
**1 acre = 4,046 m^2

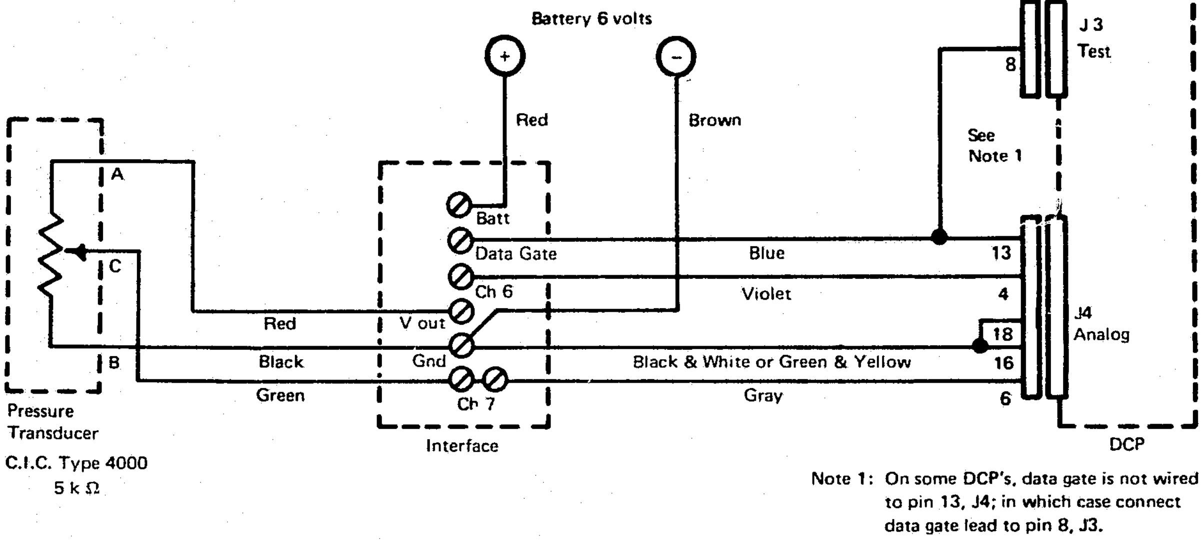
11.0 DCP SENSOR INTERFACE DEVELOPMENT

11.1 Snow Pillows

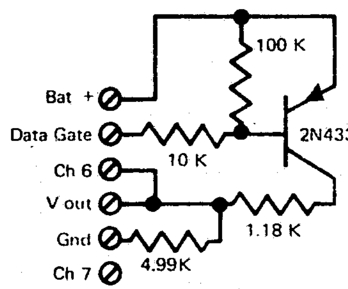
During the summer of 1975 two snow pillow transducer systems were interfaced to a General Electric DCP and installed at Ninemile Bridge on the Saint John River and at Michaud Farms on the Allagash River. A circuit diagram of the interface system is shown in figure 17.

The computer program used for decoding the data is shown in Appendix A. A graph of the water equivalent data from these two sites during the 1975-1976 winter season is shown in figure 18. The sudden increase in water equivalent around April for the Ninemile site cannot be explained and is probably spurious.

The Bournes 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 Bournes 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 an Endevco transducer was used to replace the Bournes transducer in the snow pillow interface.



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



b. CIRCUIT DIAGRAM – Interface

Figure 17 Circuit diagram of the snow pillow interface used in the 1975-76 winter season.

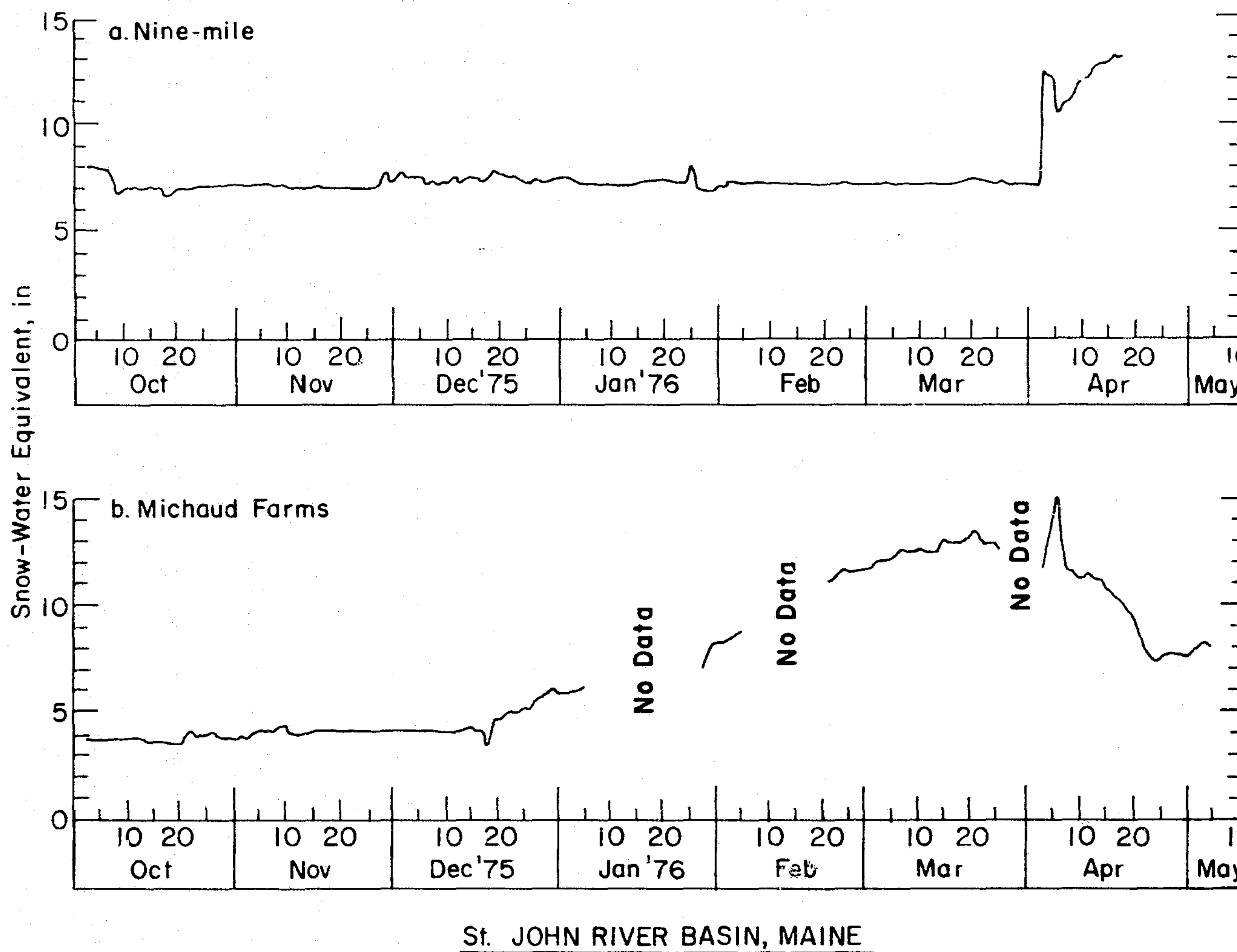


Figure 18 Water equivalent of snow data for the 1975-76 winter season.

58

The snow pillow transducer system using the Endevco model was used during the 1976-1977 winter season. A circuit diagram of this interface is shown in figure 19. 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 1976-1977 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.

11.2 Water Quality Monitor

A DCP was installed on the Saint John River in northern Maine at the Dickey Bridge, approximately one mile upstream of the confluence of the Saint John and Allagash Rivers. A Martek water quality monitor interfaced to the DCP transmitted the following water quality information: pH, dissolved oxygen, river stage, water temperature and conductivity. The sensor interface development and the computer program used to decode the data were accomplished during the Landsat-1 experiment (Cooper, et al, 1975; McKim, et al, 1975c).

The water quality data from this exercise are shown in figure 20. The dissolved oxygen probe operated intermittently and the river stage measured less than 2 feet (62 cm); therefore, these data were not included in figure 20. The pH between 10-12 August probably did not fluctuate as indicated on the graph. The water quality data compared favorably with onsite 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 Saint John River.

11.3 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 system could be used in reservoirs to monitor water temperature at various depths on a daily basis.

There is evidence of permafrost on the upper 1,000 feet (305 m) of Sugarloaf Mountain. The summit of the mountain is veneered with active, turf-banked terraces which have moved down-

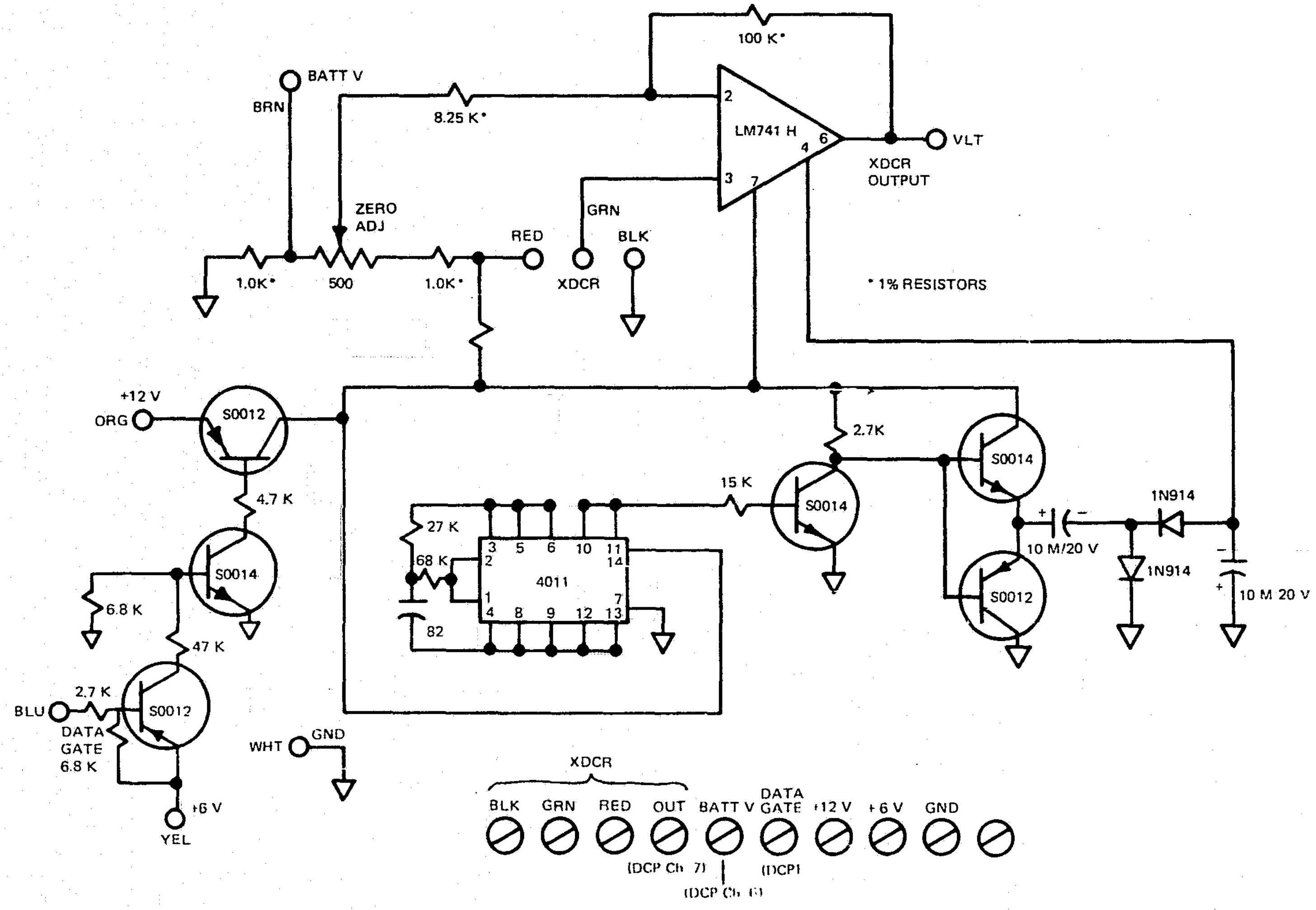
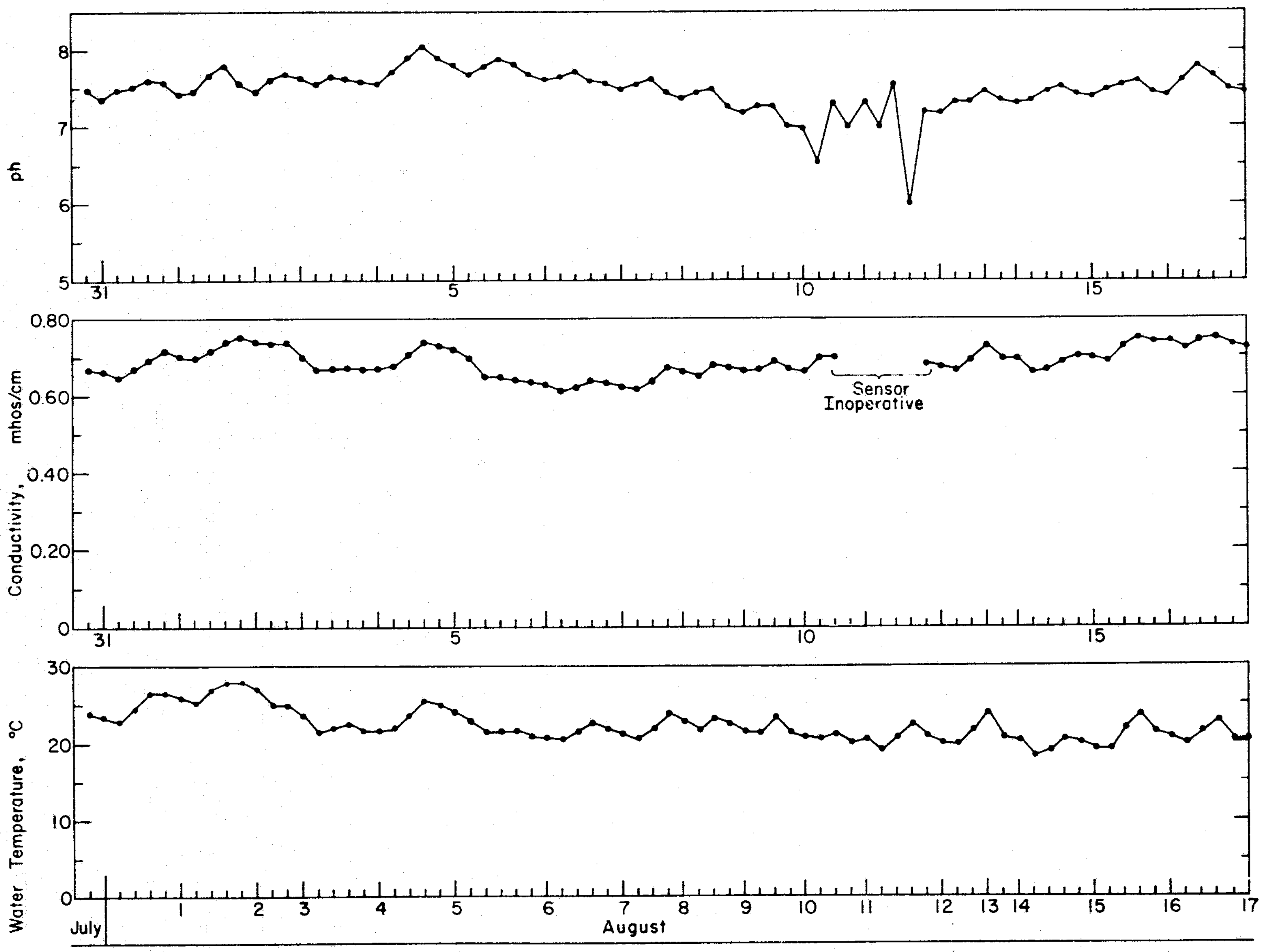


Figure 19 Circuit diagram of snow pillow interface used in the 1976-77 winter season.



St. JOHN RIVER BASIN, MAINE

Figure 20 Water quality data from the St. John River (summer 1976).

slope during the past five years at a rate of approximately 2 inches/year (5.1 cm/yr) (Borns, 1975). When the gondola ski lift was installed in 1967, the subsurface was 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 in the time period from 1967-1976 and had to be realigned. The deep pit at the summit that houses the counter-weight used in tensing the gondola cable contains water that is frozen year-round. The objectives of this study were to evaluate the reliability of the thermocouple interface under field conditions, to monitor the ground temperature measurement to a depth of 100 feet (30 m), and determine if permafrost conditions occur year-round at this latitude and elevation.

A complete circuit description of the thermocouple interface is illustrated in Appendix B. The thermocouple interface accepts inputs from 112 copper-constantan thermocouples. The inputs are arranged in 16 "banks" of seven inputs each. 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 9).

TABLE 9

ARRANGEMENT OF THE 28 THERMOCOUPLES IN FOUR BANKS

Bank	Thermocouple No.	Depth (ft)*
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 = .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 ± 0.25°C (±0.5°F) or 10μv 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 ± 0.5°C (0.9°F). The results from this experiment will be reported at a later date.

11.4 Tensiometer/Transducer System Interface

A soil moisture 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 inches) 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^3 with a specific gravity of 2.63 and a volume of voids of 47.9 percent are shown in table 10. 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 also supply the information in near-real time.

The precision and accuracy of the data are being evaluated. The results will be reported at a later time after the first field operations have been completed.

12.0 CONCLUSIONS ON IMAGERY AND SENSORS

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^2 sr in non-vegetated areas to less than 4 mW/cm^2 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^2 sr with the average radiance value being 6.4 ± 0.6 mW/cm^2 sr. The water equivalent of the snowpack for this range of radiance values was approximately 9.5 (24.1 cm) 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 drawn. 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 estimating water equivalent. This method, after tests for accuracy, would find use in estimating the volume of spring runoff.

TABLE 10

TYPICAL DATA FROM THE
TENSIOMETER/TRANSDUCER INTERFACE SYSTEM

USA CRREL Test Set
Hanover, New Hampshire
DCP 7110

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

The different changes in radiance for the 23 July 1973 (3 mW/cm^2 sr) and 11 February 1973 (5.34 - 7.74 mW/cm^2 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.

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 percent more water was observed on the 6 July 1973 scene than on 27 October 1972, which was as expected.

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

Snow pillow transducer systems for measuring the water equivalent of the snowpack in northern Maine were interfaced and field tested. Little valid data was transmitted from the field, because problems with the transducers were encountered during both winter test periods.

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

A soil moisture 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.

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

13.0 RECOMMENDATIONS

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

1. Further research work should be aimed at relating a wide range of ground truth sets to multispectral signature sets. It is clear that a method of quantifying the water equivalent of snow cannot be perfected with a small number of samples. Landsat CCT's should be furnished on a continuing basis for research in evaluating the snow cover of a watershed, especially during critical spring runoff periods (March through May). Nine day coverage provided by the Landsat satellites is not adequate for the operational needs of the NED Reservoir Control Center.

3. When a mapping accuracy of 75 percent is required, it is recommended that the Landsat digital data be used in regional evaluation of wetlands.

4. It is clear from this investigation that the Landsat Data Collection System is suitable for monitoring events for which dependable sensors are available. With more evenly timed coverage over each day, a system of polar-orbiting satellites would be operationally useful for collection of hydrologic data such as river stage and precipitation.

14.0 FUTURE PLANS

The snow cover analysis work will be continued by CRREL with the FY 78 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. If available, cloud-free Landsat CCT's will be acquired for the 1977-1978 winter season and analyzed.

Cloud-free Landsat CCT's will also be obtained over the Sleepers River watershed in Danville, Vermont for the 1972-1977 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.

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16.0 GLOSSARY

ADR - Analog to digital recorder. Typically a Fisher-Porter or Leupold-Stevens recorder, often equipped with a telekit for interfacing to DCP's.

AHRRN - Automatic Hydrologic Radio Reporting Network, NED's ground-based radio system.

Albedo - Refers to the fraction of incident radiation which is reflected by a material, summed over all wavelengths for a sunlit surface.

ASCII - Abbreviation for USA Standard Code for Information Interchange. An eight-bit character code.

Azimuth - Horizontal angle measured clockwise from north.

BCD - Binary Coded Decimal.

CCT - Computer compatible tape.

DCP - Data Collection Platform. Field installation used for sensing parameters, encoding data, and transmitting data to satellite.

DCS - Data Collection System. Refers to configuration including field stations, medium of transmission, and central station.

Epoch - A particular instant.

Julian Date - A count of days and fraction of days since a particular reference instant.

Micrometer - 10^{-6} meters; used in wavelength measure. Symbol: μm.

Multitasking - In a computer, several program tasks competing for devices and the central processor on a priority or queued basis.

NORADC - North American Air Defense Command.

Octal - Refers to a number system having 8 as a base.

Pixel - Picture element, the unit area of Landsat scenes.

Real Time Clock - Device in the Data General NOVA computer that consists of a crystal controlled clock and associated DG system software that are used (1) to keep track of date and time of day and (2) to provide for low resolution timing.

Sidereal Time - The relationship between an observer's meridian and some inertial coordinate system, for example, one based on the constellation Aries.

Stage - Water level.

Time Code Generator - A device which keeps standard time and outputs it in a form suitable for input to another device.

Tracking - Keeping the antenna pointed at the satellite, and in conjunction with that, logging any incoming data.

APPENDIX A

APPENDIX A

PROGRAMS AND OPERATING PROCEDURES USED IN GROUND RECEIVE STATION

Preparation for the ground receive station began over two years before the pedestal installation in October 1975. After firm commitments to construct the downlink were made in 1973, site preparation, hardware fabrication, and computer programming began late in 1974. A program was written by NED to predict satellite passes and a rudimentary version of a program to aim the antenna and simultaneously log incoming data was readied by June 1975. All programs (figure A-1) were written in-house, because previous experience had shown that complex programs written by outside consultants require extensive modification when installed and that in-house personnel may not know the groundwork and assumptions that go into them.

PREDICT

The program that predicts satellite passes over NED, "PREDICT" was the first one undertaken. While it was known that the problem of predicting the time of a satellite's rise over one's horizon and its path across the sky had been solved before, its solution was not available in a form that was compatible with NED's mini-computer, a Data General Nova 1220 with 32 thousand 16-bit words of core storage. (The Nova had been selected several years before for use with the Automatic Hydrologic Radio Reporting Network.) A prediction program was written in Fortran, because it is readily understood by in-house programmers and lends itself to later modifications. At that early stage of programming, assistance was provided by individuals at NASA Goddard Space Flight Center to quickly assemble the most useful algorithms and background material for writing PREDICT.

The task of debugging the combined routines that comprised PREDICT in the early stages was facilitated by the process of "units analysis", i.e., the terms in the right side of each line of Fortran were assigned appropriate engineering units, and simplified by cancellation wherever possible. The simplified expression of units was then associated with the single variable on the left side of the Fortran statement, and those units were employed in later statements when the same variable occurred. By checking the units on paper for the entire program (which ran to about 300 lines) down to the final result, the likelihood of immediately getting correct numerical answers was increased greatly.

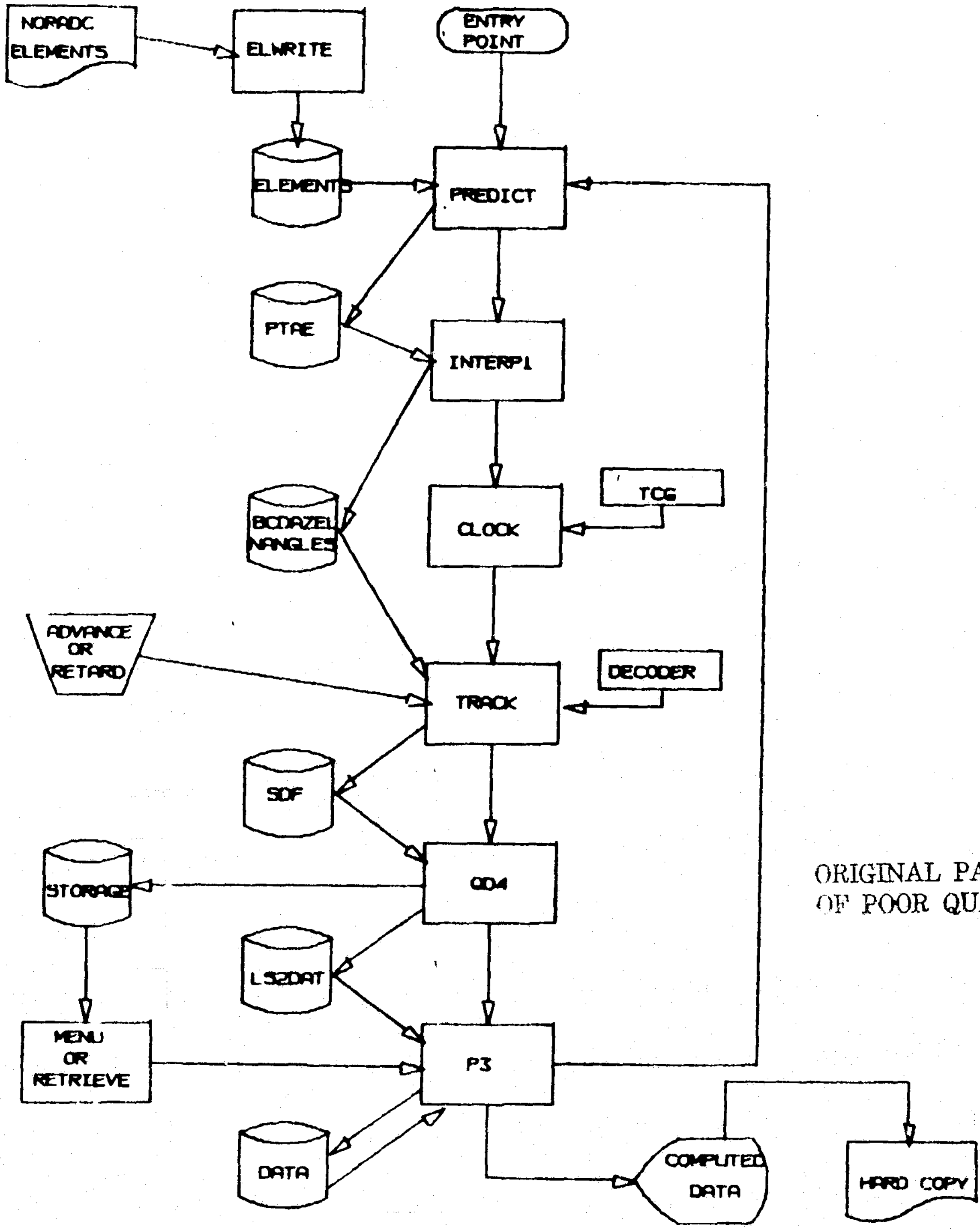

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Figure A-1. Landsat Tracking Flowchart.

PREDICT starts with inertial orbital elements and calculates station range vectors (azimuth and elevation) at selected time increments. Further program steps select only those vectors that are above the horizon. The program is generalized for any station and for any satellite in a nonequatorial orbit. For an aid to understanding the discussion of PREDICT see the flowchart in figure A-2 and the program listing.

After the current date and time are read by PREDICT, they are converted to sidereal time by the subroutine, TCALC. Sidereal time is an angular relationship between the Greenwich prime meridian and an inertial X-axis which points toward the first point of the constellation Aries (Escobal, 1965). This angle is denoted by THETA (θ), local sidereal time. Knowing the east longitude (λe) of an observer's station and θg (Greenwich Sidereal time), θ can be easily determined by the relationship $\theta = \theta g - \lambda e$, where $\emptyset < \theta < 2\pi$ (Escobal).

To find the sidereal time, the Julian Date must also be calculated. The Julian Date is continuing count of each day elapsed since some arbitrarily selected epoch. (The epoch selected for Landsat orbital predictions in TCALC is January 1, 4713 B.C.) Each Julian day is measured from noon to noon; hence, it is an integer 12 hours after every midnight (Escobal, 1965). After the Julian Date and sidereal time are found, TSINCE, the number of days since the most recent NORADC EPOCH is calculated. TSINCE is then used to determine the unit vector pointing toward the satellite (see SGP of this text). This unit vector is converted to azimuth and elevation angles at the observer's station (degrees clockwise from north and degrees above the horizon, respectively - see SRV of this text). These two values are then written on the disc along with the time at which they occur in the file named PTAE. The Time of interest is then incremented seconds or minutes by the routine INCT, and the next values of azimuth and elevation are determined, etc. In this incremental fashion, the computer is able to predict the path of the satellite across the sky at the observer's site.

The file name PTAE stands for Paper Tape Azimuth Elevation. On rare occasions, for diagnostic purposes, it may be necessary to transfer the file PTAE to the paper tape punch to generate a paper tape that is suitable for input to the paper tape reader on the pedestal control equipment. PTAE is a disc file which comprises a time, a time increment, many pairs of azimuth and elevation angles, and a special file terminator. A sample of PTAE is shown in figure A-3.

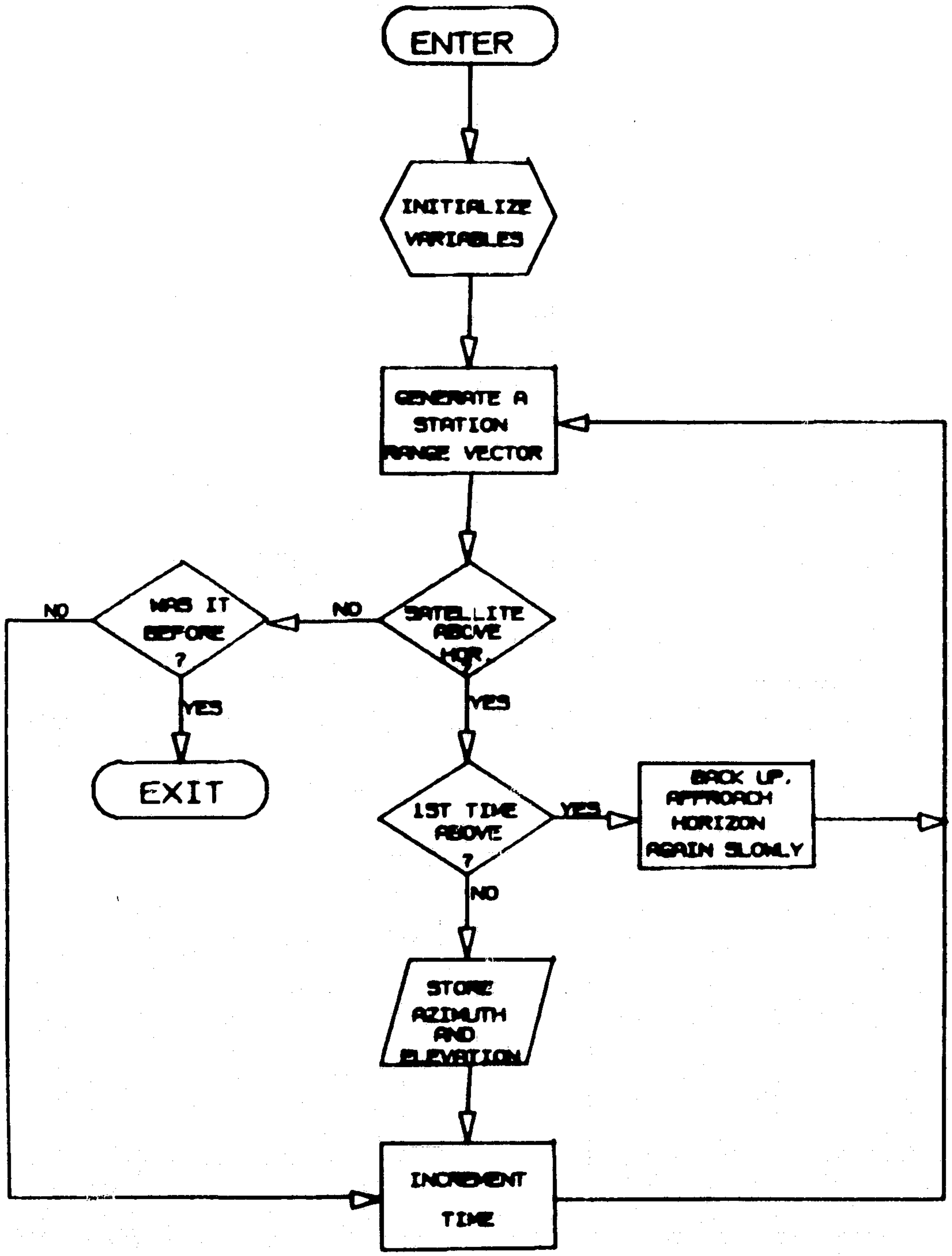

Figure A-2. PREDICT Flowchart.

```
                                   JULIAN DATE OF SATELLITE
                                   RISE TIME MEASURED FROM
TYPE PTAE
 281.979629630        <----        BEGINNING OF CALENDAR YEAR
  10.0                <----        DT. TIME INCREMENT (SECS)
A 95.89E   0.22:                   BETWEEN THE FOLLOWING
A 94.98E   0.61:                   ANGLE PAIRS
A 94.05E   1.00:
A 93.09E   1.39:
A 92.10E   1.77:
A 91.09E   2.16:
A 90.06E   2.54:
A 89.00E   2.92:
A 87.91E   3.29:
A 86.80E   3.66:
A 85.66E   4.02:      <----        PAIRS OF AZIMUTH AND
A 84.49E   4.38:                   ELEVATION ANGLES
A 83.29E   4.73:
A 82.06E   5.08:
A 80.81E   5.41:
A 79.53E   5.74:


A 57.43E   8.98:
A 55.82E   9.05:
A 54.21E   9.10:
A 52.59E   9.12:
A 50.93E   9.13:      <----        PEAK ELEVATION
                                   FOR THIS PASS


A 16.83E   3.81:
A 15.72E   3.45:
A 14.64E   3.08:
A 13.59E   2.70:
A 12.56E   2.32:
A 11.56E   1.94:
A 10.58E   1.56:
A  9.63E   1.17:
A  8.71E   0.78:                   PAIR OF STOW ANGLES:
A  7.80E   0.39:                   SENDS ANTENNA TO
A  6.93E   0.00:
A  0.00E  90.00:      <----        STOW POSITION
```

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Figure A-3. Format of File 'PTAE'.

```
OEDIT BCDAZEL

A
0 /28
1 /1.
2 /97
3 /96
4 /29
5 /63
6 /0
7 /
10 /1.
11 /0<015>
0
12 /000211
13 /000225
14 /000042
15 /000000
16 /000171
17 /000225
20 /000045
21 /000000
22 /000160
23 /000225
24 /000051
25 /000000
26 /000141
27 /000225
30 /000063
31 /000000
32 /000122
33 /000225
34 /000067
35 /000000
36 /000103
37 /000225
40 /000101
HOME
```

LOW ORDER AZIMUTH:

$$211_8 = 010\ \overset{.8}{0}01\ \overset{.08}{0}0\overset{.01}{1}_2 = .89_{10}$$

HIGH ORDER AZIMUTH:

$$255_8 = \overset{80}{010}\ \overset{10}{010}\ \overset{4\ \ 1}{101}_2 = 95_{10}$$

95.89

LOW ORDER ELEVATION:

$$042_8 = 000\overset{.2}{1}000\overset{.02}{1}0_2 = .22_{10}$$

HIGH ORDER ELEVATION

$$000_8 = 0_{10}$$

0.22

Figure A-4. Format of File "BCDAZEL".

In practice, PREDICT calculates azimuths and elevations at 10-second increments, so the angle pairs in PTAE are pointing angles for instants ten seconds apart. If these angles were fed to the pedestal, the antenna would jump quickly to the next position every ten seconds. The progress of the satellite is uniform, and it has been found that one-second incrementing of dish position is sufficiently small for continuous radio lock. Therefore, the program INTERP1 is executed right after PREDICT to interpolate ten angle pairs for every one pair in PTAE. Furthermore, INTERP1 recodes the angles from ASCII characters to a binary coded decimal (BCD) format suitable for the electronic interface enroute to the pedestal command equipment. The new angles are stored in a binary file called BCDAZEL (figure A-4) and the number of pairs of angles in BCDAZEL is stored in the file NANGLES.

The recoding in the program INTERP1 is done by bit-mapping. A set of special interfaces is used to route the BCD angle information from the Nova to the Scientific Atlanta 1848 Digital Comparator (see figure 1). Input to the comparator is in the form of two 18-bit BCD words representing azimuth and elevation. However, the Nova can output only 16-bit words, by way of the 4065 Digital Interface. For this reason, it was necessary to concatenate two <u>pairs</u> of 16-bit words into two 18-bit words in the sequence shown in figures A-5 and A-6.

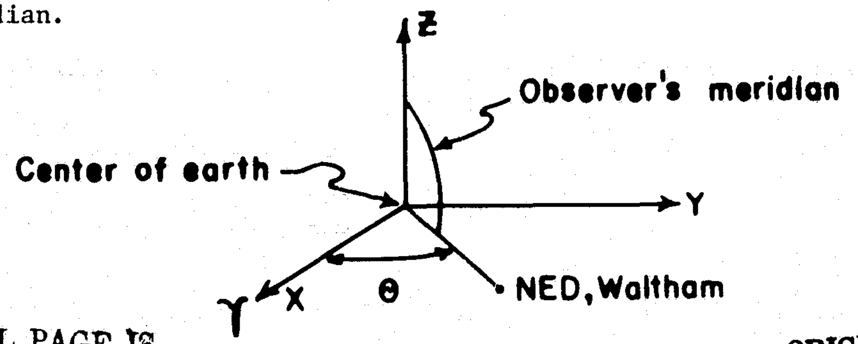
TCALC

TCALC is a time handling subroutine called by PREDICT which calculates the following three variables:

1. XJD - Number of Julian days - it is used to find TSINCE and THETA.

2. TSINCE - Number of days since most recent NORADC EPOCH. This is used by SGP to find the unit vector pointing toward the satellite (RDOT).

3. THETA, $\underline{\theta}$ - Sidereal time (measured in radians). The angle between a line from the center of the earth to the first point of the constellation Aries (T), and the plane of observer's meridian.



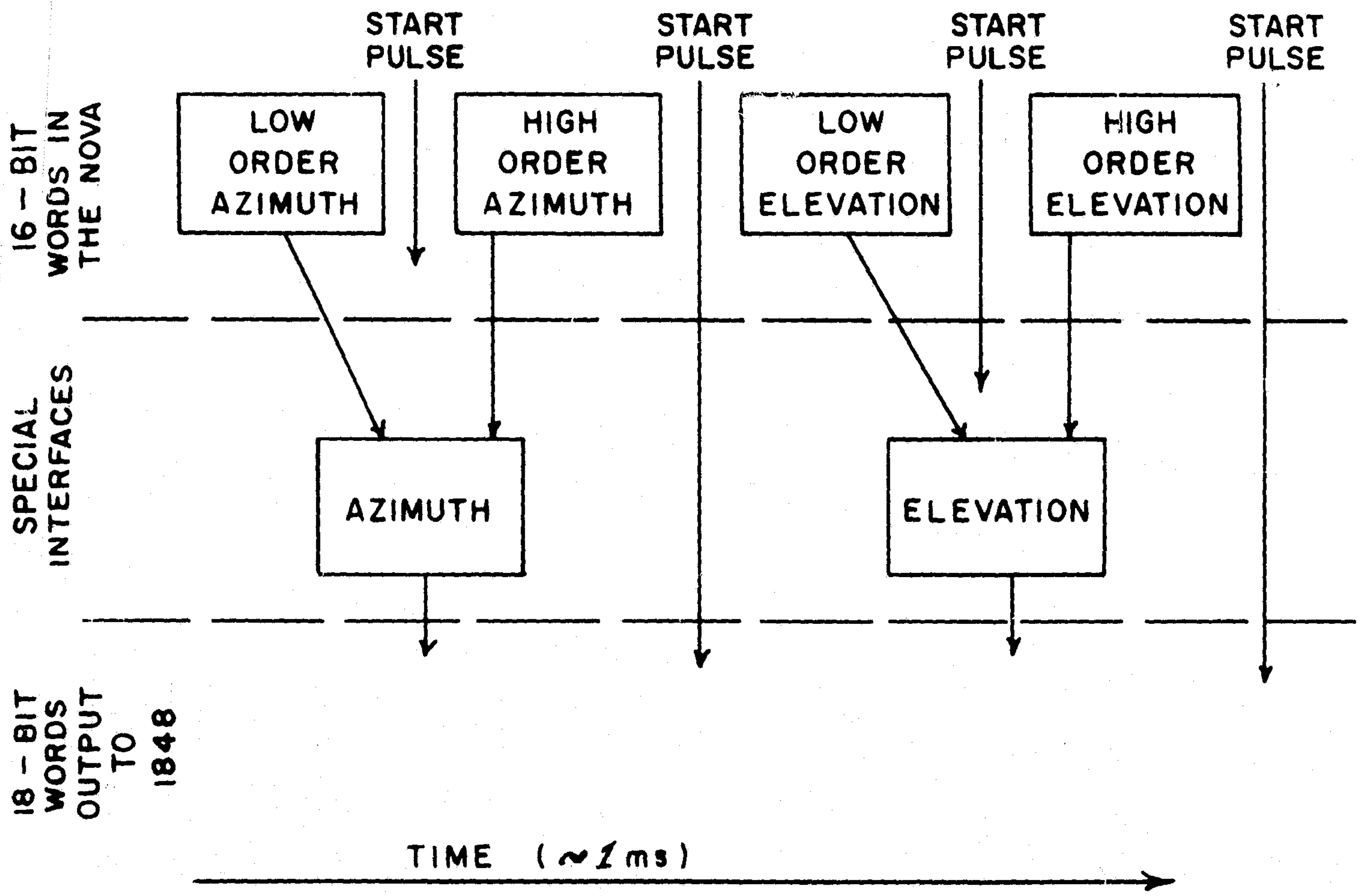


Figure A-5. Order of Transmission of Angular Information from Minicomputer.

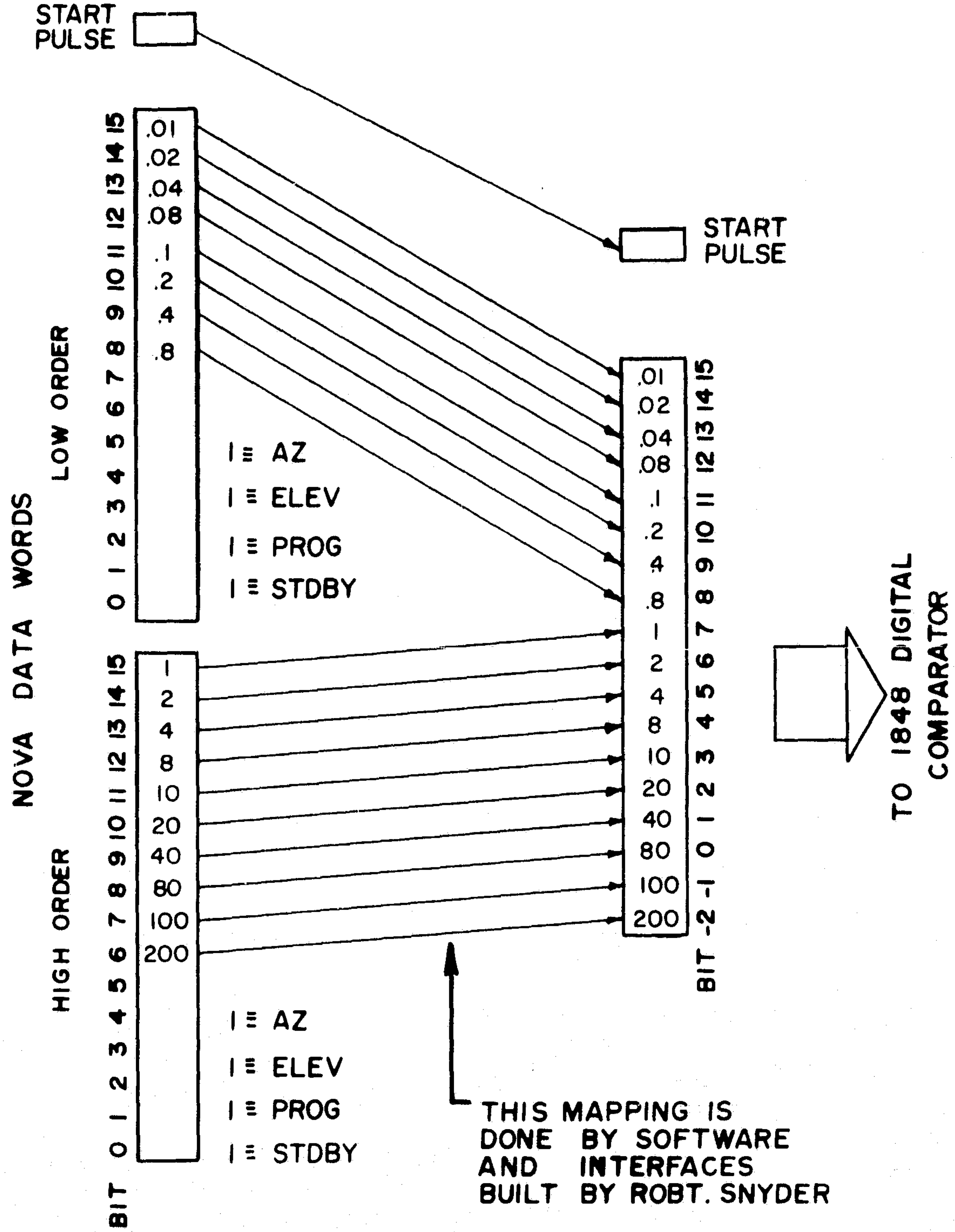


Figure A-6. Bit Mapping between NOVA Software and 4065 Interface Controlling 1848 Digital Comparator.

THETA is used by SRV in determining Azimuth (A) and elevation (H).

The following calculation (based on Escobal, 1965) derives sidereal time (THETA) from the following instant expressed as a date and Greenwich mean time:

August 23, 1975, at 10 hours, 15 minutes, Ø seconds. Number of hours, minutes, seconds expressed in minutes: DT = 615 minutes.

XJD = 2442648.5　　　DTHDT = .25068447

TU = (XJD-2415Ø2Ø)/36525= .7564271Ø47227926

THETA GØ = 99.6909833 + (36ØØØ.7689) (TU) + (.ØØØ387Ø8) $(TU)^2$ = 331.6485916Ø1549Ø

THETA G = THETAGØ + (DT) (DTHDT) = 125.81954Ø6515490°

THETA = (THETA G + LAMBDAE) (2π/360) = .9530184529430946 radians.

SGP AND SRV

SGP is a Fortran subroutine called by PREDICT embodying a truncated simplified general perturbation theory for use in the determination of Landsat pointing elements. SGP computes osculating position, velocity and mean classical elements. SGP is a first order analytical integration of the equations of motion including perturbations caused by the first two zonal harmonics of the geopotential. The zonal harmonic constants account for the effects of the noncircularity of the meridian cross sections of the earth. The perturbations caused by these harmonics are independent of the longitude of the satellite. SGP is based on the orbital elements a, A_{xn}, A_{yn}, i, Ω, and L which are well defined for all elliptic orbits except those that are nearly equatorial. For equatorial satellites, the elements A_{xn} and A_{yn} are ill-defined because of the indeterminacy of the node angle Ω to which they are referred. The SGP mathematical model is adequate to handle a majority of routine cataloguing. Accuracy is said to be better than one part in 10^9.

SRV ("Slant Range Vector") is a Fortran subroutine of PREDICT which transforms the orthogonal vectors and the time angle, THETA, from subroutine SGP into an azimuth/elevation coordinate system with the observer's station as the origin. Files of azimuth and elevation angles in this coordinate system describe the path of Landsat over a particular station during some interval.

TRACKING THE SATELLITE: PROGRAM "TRACK"

After PREDICT calculates the satellite's sky path and INTERP1 prepares a file of pointing angles, control goes automatically to the program TRACK which will perform six main functions. It is a complex multitasking program in which internal control shifts according to time as counted down by the Real Time Disc Operating System (RDOS) and according to the random arrival of DCP messages.

TRACK carries out the following main tasks:

1. Schedules itself by looking at the starting time of the upcoming pass. This time is the first number stored in the disc file BCDAZEL.

2. Orients the antenna 1-1/4 minutes before the satellite rises.

3. Starts repositioning the antenna second by second beginning at the instant the satellite rises.

4. Logs any data that arrive by way of the antenna/receiver/decoder pathway (see figure 1).

5. Accepts corrections from the terminal and console switches to advance or retard the tracking antenna by a certain number of seconds to improve antenna position.

6. Restores the antenna to the stow (upright) position when the last angle pair in file BCDAZEL has been sent.

7. Transfers the DCP data that have come in from a core buffer to a temporary disc file called "SDF" (Satellite Data File).

8. Finally chains to a program called QD4 which will decode field data from binary to an octal format similar to one used by NASA at Goddard.

Once PREDICT and INTERP1 have been executed for an upcoming pass, TRACK can be run at any time up to one minute 30 seconds before satellite rise time. Execution of TRACK after that causes problems which are signalled by the message "TOO LATE" being printed at the terminal. One then must quickly reset the system clock to an instant one minute and 30 seconds prior to the satellite rise time*; execute TRACK; and six seconds after the computer types "!", enter positive corrections that stand for numbers of seconds to enable TRACK to catch up with real time. (If this method has to be used, note that incoming data will be incorrectly time-tagged.)

*A typical command would be STOD 14:30:10; TRACK

C.8

Corrections (in seconds) are entered by means of the NOVA's console switches numbered Ø - 15, and the Tektronix terminal. The switches have binary significance in descending order from left to right, and bit Ø indicates the sign, + or -.

BIT:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	ON↑
	−																
	+									←	32	16	8	4	2	1	OFF↓

Thus, a correction of +20 would require that only switches 11 and 13 be up, whereas the correction -20 would have bits Ø, 11 and 13 up.

To effect the correction set in the switches, strike SPACE BAR on the terminal. Positive corrections will cause the antenna to jump ahead, and negative corrections will cause it to pause.

For DCS data to be usable, it must be timely and reduced. For this investigation timeliness was guaranteed by use of the direct downlink with no delays except insignificant propagation time between a DCP's report and our reception of that report. The matter of data reduction required further analysis and programming. It was necessary to screen out erroneous messages and any unwanted ones which were transmitted by DCP's which belong to other agencies. (In some cases other users' messages were gathered by our system for cooperative use.) Whenever two or more successive messages were identical they were compressed into one disc entry with the time of only the first transmission and the number of identical messages included. At this point the messages were stored in ASCII code in a main file on our largest storage medium, a twenty surface disc pack. Their format is a mixed decimal and octal representation that is a compromise between maximum density and understandability. For final reduction to readily comprehensible symbols, two or three programs are executed to retrieve data and either decode it into legible lines having engineering units or rapidly plot it as in the case of hydrographs. The overall handling scheme is shown in figure A-7.

Data gathered during a satellite pass are reduced and automatically displayed within two minutes after the pass. Old data are retrieved, decoded, and tabulated or plotted in less than two minutes also. A sample of plotted and tabulated data for a flood hydrograph of an actual flood which occurred at Fort Kent, Maine, in April of 1977 is shown in figure A-8.

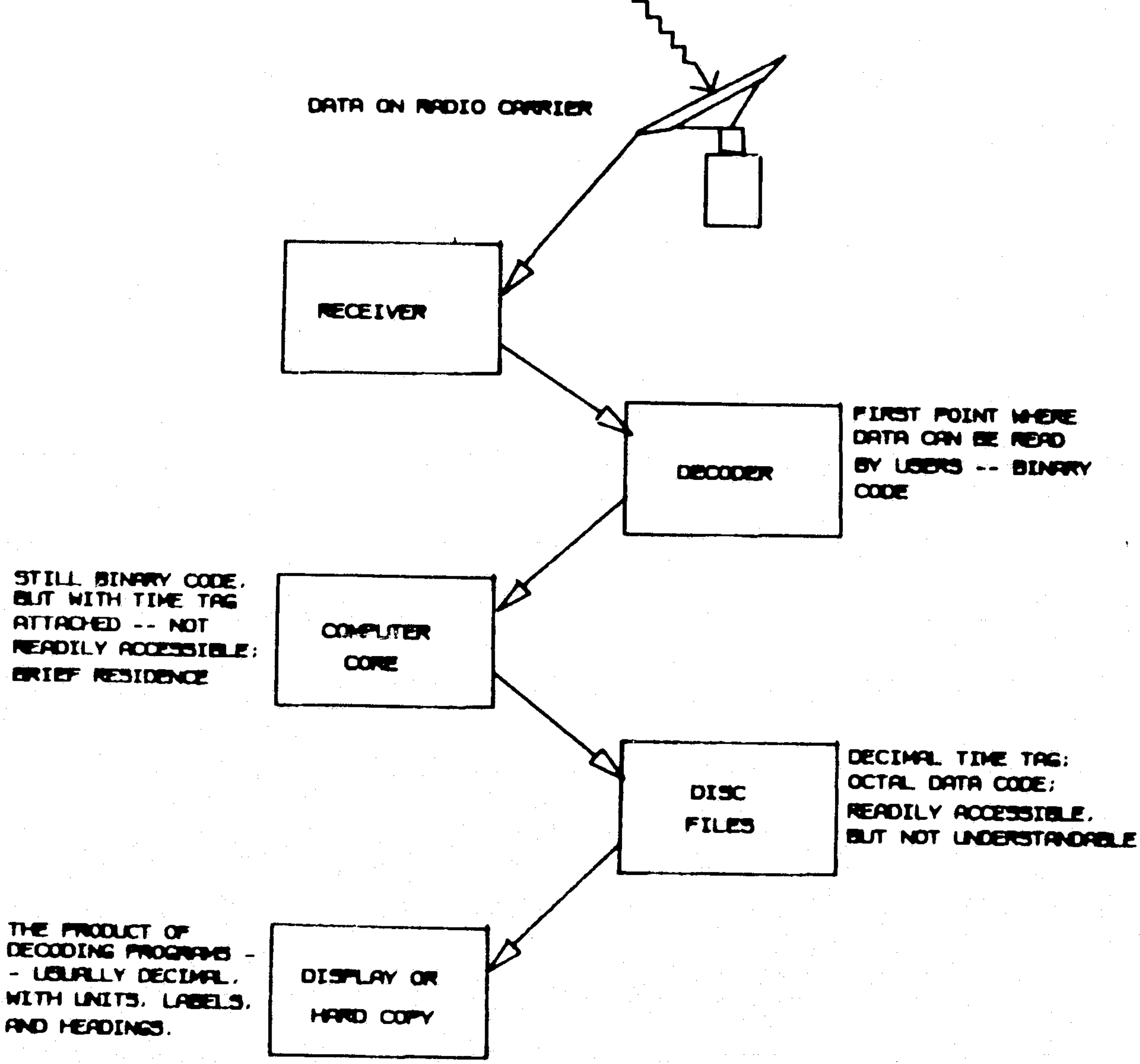


Figure A-7. Data Flow from Antenna to User.

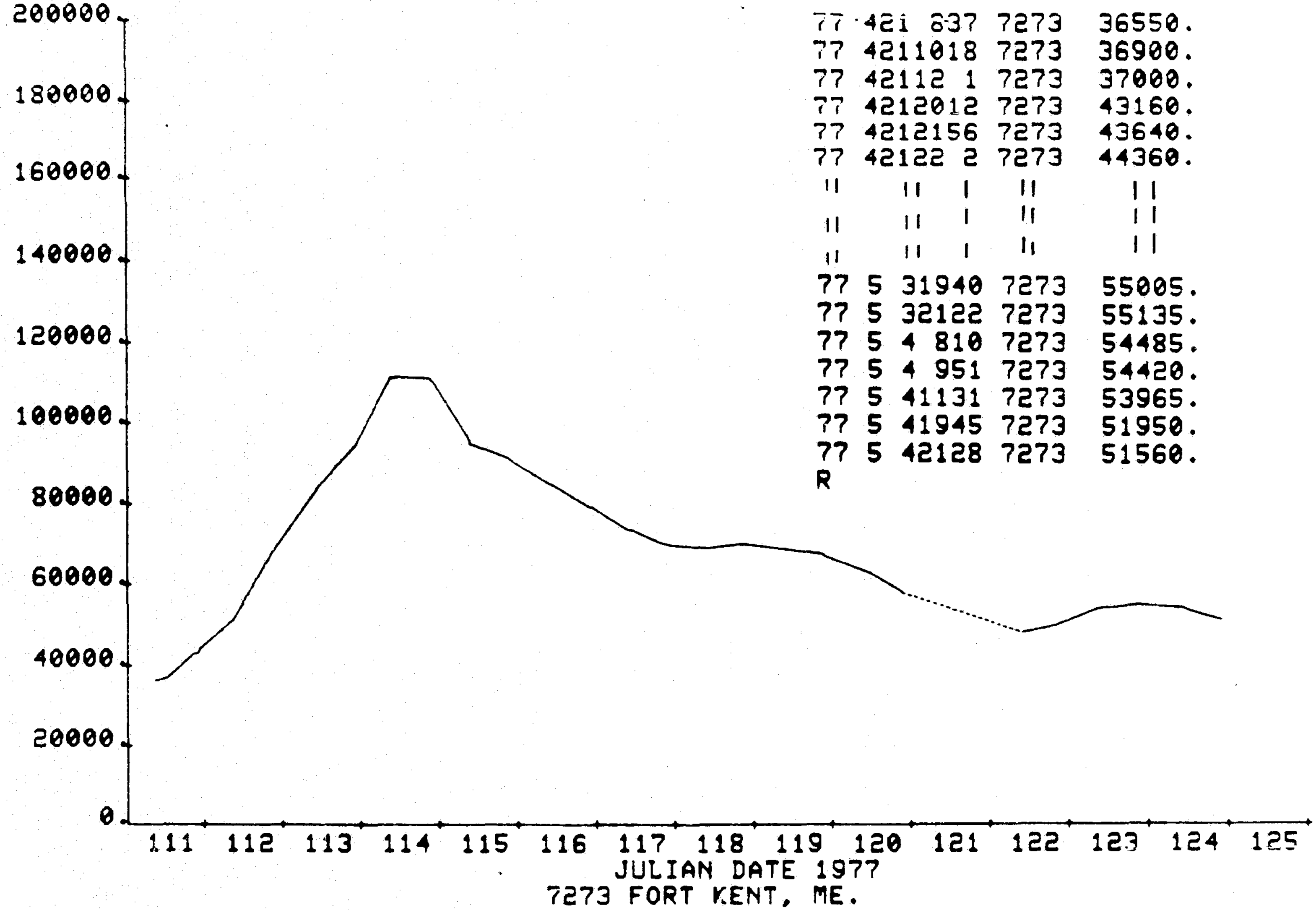


Figure A-8. Samples of Data Reduction by Plotting and Tabulation of a Flood Hydrograph.

OUTPUTTING DATA: QD4 AND P3

QD4 and P3 are programs that condition the raw field data received by the ground receive antenna for disc storage or for easy reading.

QD4

The temporary disc file "SDF" produced by TRACK immediately after a satellite pass becomes the input to QD4. Output from QD4 goes to a temporary file "LS2DAT" and a permanent file "STORAGE". Formats of these files are shown in figures A-9 and A-10.

The arrival time of each DCP message is recorded by LS1 by storing a seconds counter with each message. This number of seconds is accumulated from the beginning of each pass, and QD4 calculates a message arrival time by adding the number of elapsed seconds to the starting time. Coordinated Universal Time is employed to avoid problems that arise with standard versus daylight savings time.

P3

Legible output of DCS data is obtained by executing P3. Input to P3 is from the temporary disc file "LS2DAT". The program examines each message for the platform ID number, and looks up the ID in a table (INDX", figure A-10) which contains indices concerning the parameters being measured. These indices then direct program control to appropriate subroutines for calculating floating point decimal numbers and attaching labels. The kinds of parameters handled by P3 are shown in the site list, figure 3.

STORAGE NEEDS

The amount of disc storage needed for long term retention of Landsat DCP data is small and inexpensive. For parameters that are slow to change, such as river stage or precipitation, data may be compressed merely by counting successive identical messages as one message. Concatenations of message components would permit further compression of data on the order of 7:1. This has not been done at NED. We have found that a compression of 3:1 is attainable with no sacrifice of legibility of storage files and no highly sophisticated techniques. Hence, for a system consisting of one DCP reporting hydrologic data randomly at three minute intervals and one satellite having an orbit like Landsat's, the following calculation is typical:

```
               TYPE STORAGE
               610 1132230 7273 37 65377377377377377377
               610 1132321 7021377377267323377376 57126
YEAR           610 1132353 7246377163377377377377377377
MONTH          610 1132442E7254 67366345313232 64153227
               610 1132544 7356 77237377377377377377377
DAY            610 1132746 7142377377   0   0   0 20   0200
               610 11328 3E7201277141377377 33226215 31
               610 1132847 7273 37 65377377377377377377
HOUR           610 1132853 7356 77237377377377377377377
               610 115 2 2 7142377377   0   0   0 20   0200
               610 115 232 7207337375377377377377377377
MINUTE         610 115 245 6063277121377377377377377377
               610 115 253 6504 14341 23 14   0   0 14   6
               610 115 330 7127377 76377377377377377377
SECOND         610 115 350 7345 77341377377377377377377
               610 115 4 1 7124377377377377377377377377
               610 115 412 7021377377267323377376 57126
               610 115 415 7010160 40   0   0   0   0   0   0
ERROR CODE     610 115 428 7254327137377377377377377377
               610 115 5 7 7246377163377377377377377377
               610 115 526 7220277223377377377377377377
               610 115 528 7142377377   0   0   0 20   0200
               610 115 539 7272 77265377377377377377377
               610 115 546 6504 14341 23 14   0   0 14   6
               610 115 555 7775337375377377377377377377
PLATFORM I.D.  610 115 634 7127377 76377377377377377377
               610 115 648 7010160 40   0   0   0   0   0   0
               610 115 7 6 7273 37155377377377377377377
               610 115 7 8 7201277341377377377377377377
               610 115 744 7124   0   0   0   0   0   0   0   0
               610 115 745 7254377377377377377377377377
               610 115 752 7356 77277377377377377377377
               610 115 757 7171 77173377377377377377377
               610 115 810 7246377163377377377377377377
               610 115 822 6063277121377377377377377377
               610 115 833 7220277223377377377377377377
DATA           610 115 854 7142377377   0   0   0 20   0200
```

Figure A-9. Formats of File "STORAGE" or "LS2DAT".

NUMBER OF LINES IN THIS FILE

INDEX USED IN 'P 3' TO DIRECT PROGRAM CONTROL

PLATFORM LOCATION

PLATFORM I.D. NUMBER

```
22
7171 2 NINEMILE BR.., ME.
7273 2 FORT KENT, ME.
7071 2 WEST ENFIELD, ME.
7272 2 NORTH ANSON, ME.
7356 2 CORNISH, ME.
7127 3 SOUTH MT., N.H.
7201 2 PLYMOUTH, N.H.
7207 2 GOFFS FALLS, N.H.
7331 6 CRREL, HANOVER, N.H.
7214 1 CRREL, HANOVER, N.H.
7246 3 WACHUSETT MT., MA.
6063 2 IPSWICH, MA.
7106 2 FITCHBURG, MA.
7142 4 CHICOPEE, MA.
7021 4 WESTFIELD, MA.
701010 NED,WALTHAM, MA.
7220 2 FORESTDALE, R.I.
7345 2 CRANSTON, R.I.
7254 2 HARTFORD, CT.
7242 2 MIDDLETOWN, CT.
7206 2 MANCHESTER, CT.
6504 2 ST.FRANCIS R., N.B.
R
```

Figure A-10. Format of File "INDX".

$$\left[1\ \text{DCP}\right] \times \left[\frac{3\ \text{messages}}{\text{pass* DCP}}\right] \times \left[\frac{1\ \text{msg}}{3\ \text{msg}}\right] \times \left[\frac{(41)\text{8-bit bytes}}{\text{message}}\right] \times \left[\frac{4\ \text{pass}}{\text{day}}\right] \times \left[\frac{365\ \text{day}}{\text{year}}\right]$$

$$\approx 60\ \text{K}\ \frac{\text{8-bit bytes}}{\text{year}} = .25\%\ \text{of one twenty-surface disc pack}$$

Since these disc packs sell for as little as $60, the cost of the storage medium for an entire year of data from one DCP is no more than 15¢.

OPERATING PROCEDURES

The automatic tracking system for receiving Landsat data at New England Division consists of a 15-foot dish antenna, a tracking pedestal, pedestal control equipment, and a Data General Nova minicomputer with various accessories and interfaces. The relationship of all these parts is shown in the subsystems diagram, figure 1. Little knowledge is required to place the system in operation, because the programs have been written to guide the operator through the various options using either the Tektronix or Teletype terminal (figure A-13). Full control of the system to handle unusual situations requires some knowledge of the programs and various information files that are kept on disc. The operator may have to power up the Data General Nova minicomputer and execute programs to track the Landsat and store incoming data. Having the correct time of day and executing the tracking programs, the Nova should continue until interrupted by the operator. The programs are cyclical, and if one of them is interupted, it may be restarted later; that is, the operator may re-enter the cycle at several points.

The simplest procedure for tracking is as follows (refer to figure A-1):

1. Power up all equipment.

2. Execute the program PREDICT at least five minutes before an expected satellite rise time. This is accomplished by typing "PREDICT" followed by a carriage return.

REAL TIME CLOCK

To track Landsat accurately the Nova's real time clock must be set to Coordinated Universal Time (UTC). Accuracy of one-fourth second is sufficient. Two methods may be used - either manual or automatic.

Automatic Method. Execute the program CLOCK. Within two minutes the computer will signal completion by a message, and it will progress to the next program. If problems arise, use the manual method.

In the automatic method the computer uses an interface which samples (at 550 Hz) the serial code output of a time code generator. The time code generator (made by DATUM, Inc.) outputs a code which contains day, hour, minute, and second information within the frame of one minute.

Theory of Operation. The pulses in this code consist of Ø to 5 volt shifts for varying lengths of time. A positive shift lasting .2 seconds signifies a logical "Ø", a shift for .5 seconds signifies a "1", and a shift for .8 seconds signifies a special mark pulse. The computer samples this shifting voltage a 550 Hz; thus for a logical "Ø" the voltage would be "high" for .2 x 550 or about 110 times; for a "1" voltage would be high for .5 x 550 or about 175 times, and for a mark pulse the voltage is high for .8 x 550 or about 440 times. The string of Ø's, 1's and mark pulses are interpreted in a tabular fashion, made possible because their positions within one minute determine their values.

Manual Method. The Nova provides for its clock to be set by the teletype command STOD hh mm ss ↓ , where hh, mm, and ss stand for hour, minute and second.

Dial up the FTS number 8-323-4245 to get the National Bureau of Standards audio time signal. When you have found out what time mark will be coming up soon (e.g., the next minute), use the STOD command to prepare to enter that upcoming time, and hit RETURN exactly when the time marker is heard.

Setting the Time Code Generator. The NBS voice time signal may be used for the external reference (as suggested above for setting the Nova's real time clock manually). After becoming familiar with the controls and adjustments on the time code generator, the following procedure may be used to set it into operation:

Step 1. Set the POWER switch to the ON position.

Step 2. Press the STOP pushbutton. The visual time display should not be updating.

Step 3. Set the time of day by the following procedure:

Set the number desired in the unit seconds position on the PRESET thumbwheel switch; then press the SET button located directly under the unit seconds display; then proceed to preset the time desired in the tens of seconds position, pressing the tens of seconds SET button. Once again set the time desired for unit minutes in the PRESET switch, pressing the SET button under unit minutes. Follow this procedure proceeding from the least significant digit of the days display. Note that it is generally good procedure to preset a time as much as a minute ahead of the actual time. This is to give the operator time to set up the controls and be ready to start the generator on time.

Step 4. Observe the external time reference, and at the instant it coincides with the preset time in the time code generator display, press the START button. The time code generator should now start updating at one pulse per second.

ENTERING ORBITAL ELEMENTS

To track Landsat, the computer must predict when the satellite will rise over the horizon and compute the correct azimuth and elevation angles for the tracking pedestal. To predict those times and angles, a numerical description of the Landsat's orbit is entered into the computer through either the teletype or CRT terminal. This orbital information is contained in the element set provided by the North American Air Defense Command, Ent AFB, Colorado*. Eight of the elements (shown in figure A-11) are important to the NED system and their meanings, formats, and units are as follows:

1. EPOCH - An arbitrarily chosen recent instant expressed as a Julian date, at which the rest of the element set was determined. XXX.XXXXXXXX (DAYS)

2. NDOTØ** - First derivative of mean motion, + or - .XXXXXXXX

3. IØ - Inclination. XX.XXXX (DEGREES)

*Questions about NORADC elements can be addressed to:

SPACE DEFENSE CENTER
(Cheyenne Mountain Office)
ENT Air Force Base, Colorado

**"Ø" stands for zero; "O" is the 15th character of the alphabet.

ARMY ENGRS WAL

GRIFFISS ROME
S-9
710-324-6949 VIA 315-337-6275 MSG NBR 050857
R 050857Z DEC 75
FM SPACE DEFENSE CENTER ENT AFB COLO
TO USA ENDE WALTHAM MA
BT
UNCLAS SDC-O FO50851 0819 DEC 75
NEDED-W/ATTN COOPER

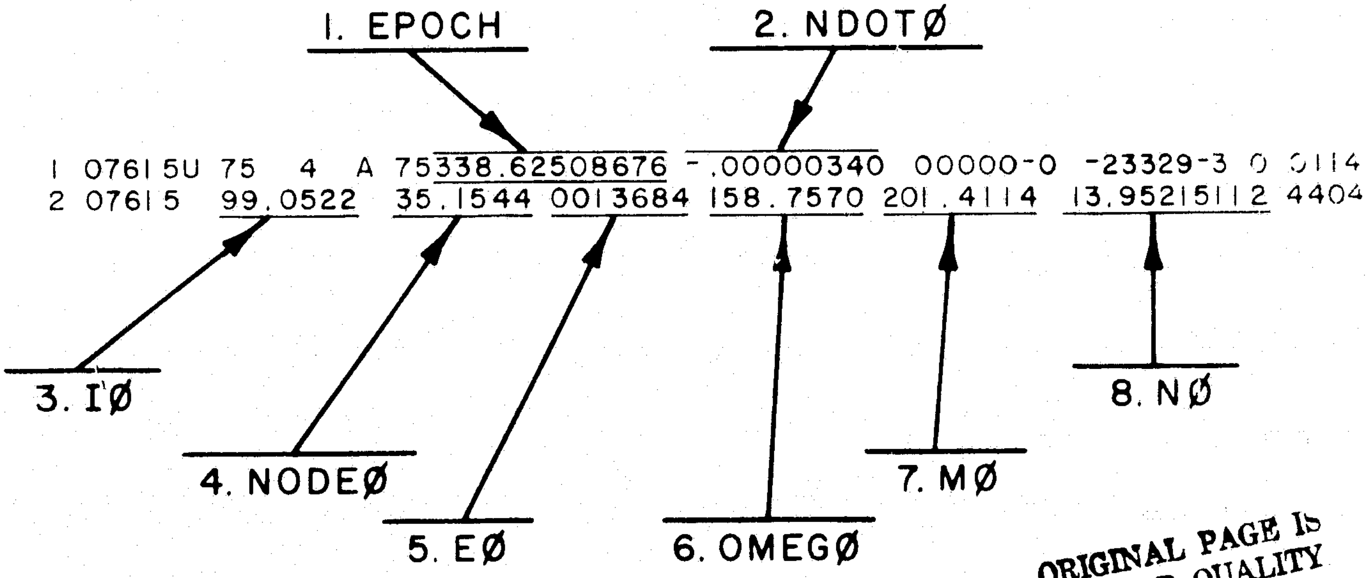


Figure A-11. Format of Orbital Elements provided by NORADC.

4. NODEØ - Right Ascension of the Ascending Node. XX.XXXX (DEGREES)

5. EØ - Eccentricity. .XXXXXXX (NO UNITS)

Notice that the decimal point is not printed on NORADC message, but must be supplied to Nova system.

6. OMEGØ - Argument of Perigee. XXX.XXXX (DEGREES)

7. MØ - Mean Anomaly. XXX.XXXX (DEGREES)

8. NØ - Mean Motion. XX.XXXXXXXX (REVS/DAY)

The orbital element set is entered into the system by executing a program called "ELWRITE", which stands for "Element Writer". ELWRITE is an interactive program which guides the operator in entering the numbers correctly. Because the numbers have many digits, it is easy to mistype them on the teletype keyboard; therefore, ELWRITE echoes each number as it is entered and allows revision of that one number. If no correction is needed, the operator types Y after "OK?" and enters the next number. If a correction is needed, the operator types N and retypes the same number. An example of the operator/computer dialogue for the element set of figure A-11 is given in figure A-12.

DCS RECEIVE SITE DECODING EQUIPMENT

Background. DCS Receive Site Decoding Equipment (or "decoder") consists of one rack-mounted cabinet containing RF and logic modules that demodulate, decode, and buffer incoming messages for presentation to a Data General 1220 minicomputer. The decoder was built by Robert Snyder of NASA, Wallops Island, Virginia. His documentation is available upon request. The functions performed by the decoder are shown in figure A-14, and the relationship of the decoder to the rest of the system is shown in figure 1.

In the field, data collection platforms collect, encode, and transmit sensor data to Landsat in a manner shown in the following block diagram.

```
ELWRITE
ENTER EPOCH,NDOT0,I0,NODE0,E0,OMEG0,M0,N0
DO YOU NEED FURTHER EXPLANATION? YES OR NO N
ANSWER YES(Y) OR NO(N) TO OK?
192.64706325
      192.647063250  OK?Y
0.0
        0.000000000  OK?Y
98.9660
       98.966000000  OK?Y
246.7513
      246.751300000  OK?Y
.0013733
        0.001373300  OK?Y
8.7956
        8.795600000  OK?Y
351.3396
      351.339600000  OK?Y
13.95255730
       13.952557300  OK?Y
R
TYPE ELEMENTS
          0.19264706325000000E  3
          0.00000000000000000E  0
          0.98966000000000000E  2
          0.24675130000000000E  3
          0.13733000000000000E -2
          0.87956000000000000E  1
          0.35133960000000000E  3
          0.13952557300000000E  2
      77
       7
      12
R
```

Figure A-12. Dialogue between Operator and Computer during Execution of 'ELWRITE'.

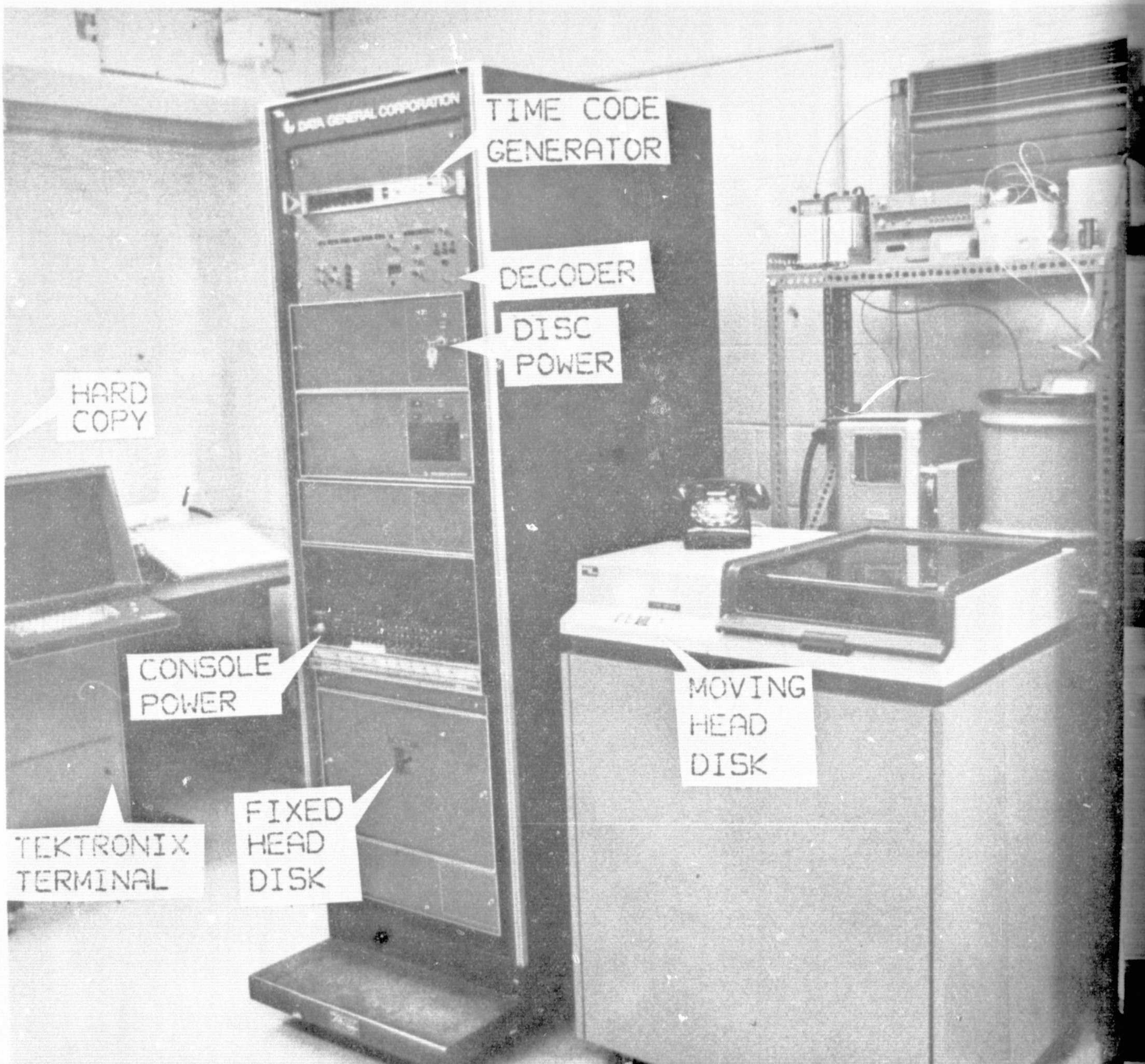
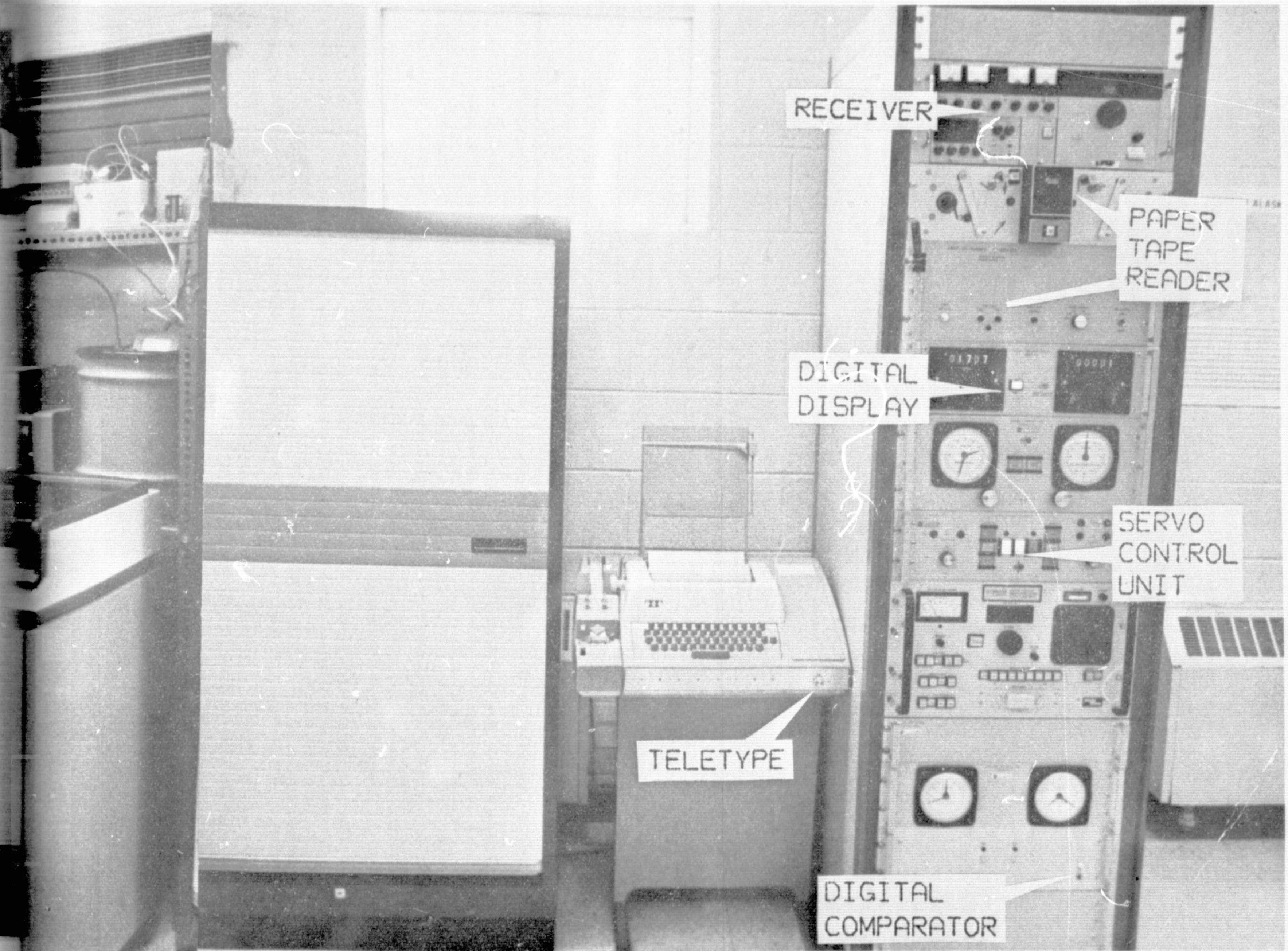


FIGURE A-13. Computer



RE A-13. Computer and Tracking Equipment

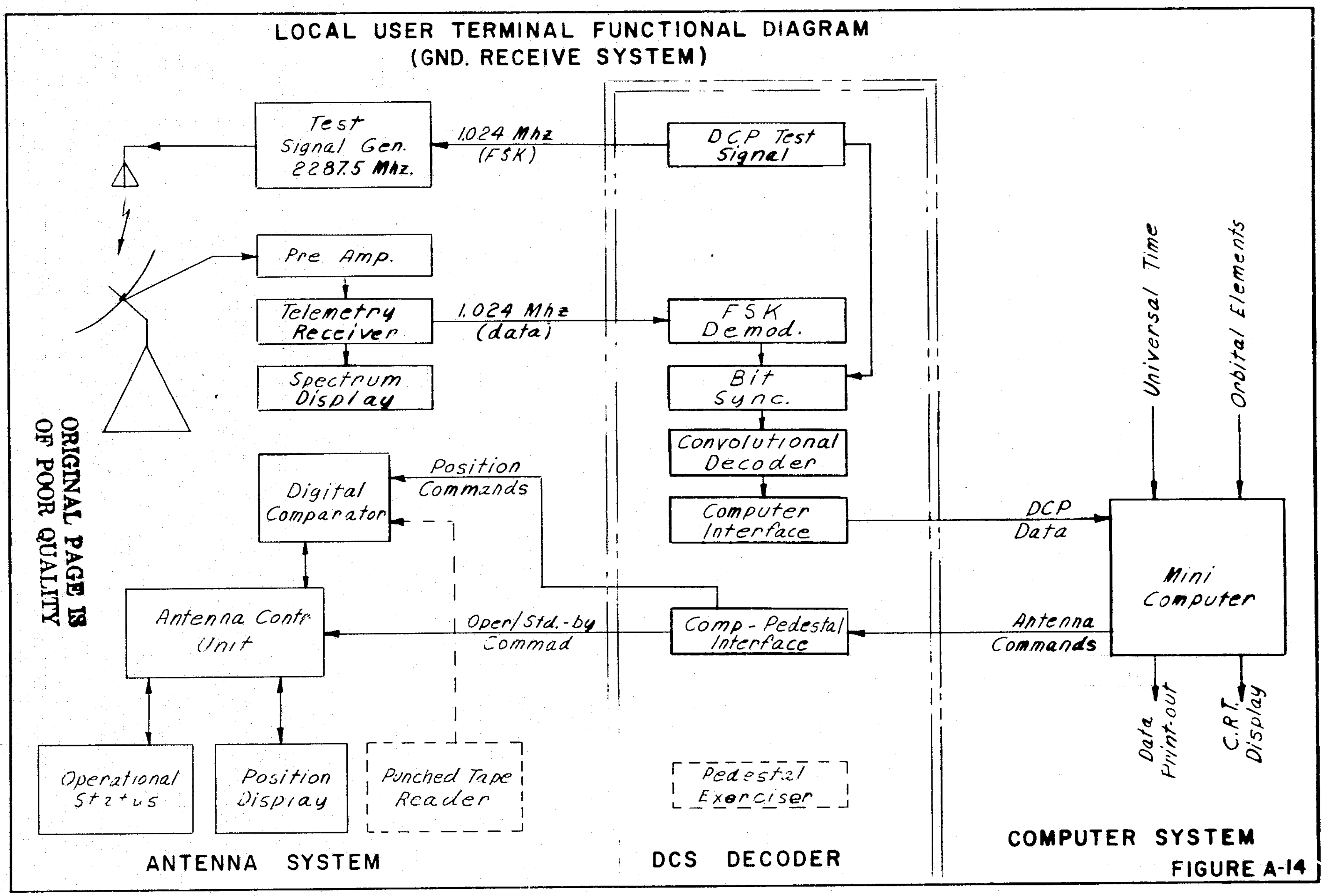
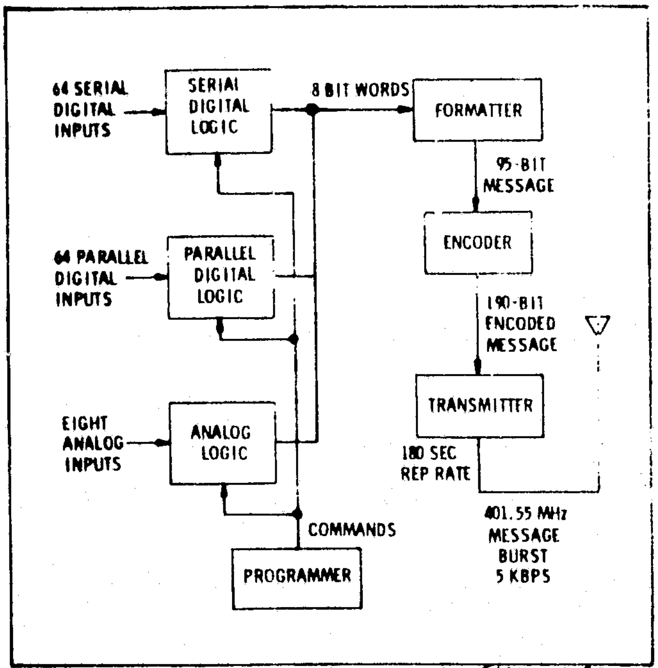


FIGURE A-14

ORIGINAL PAGE IS OF POOR QUALITY



(NASA, 1976a)

Before each transmission, each DCP message is encoded using a rate one half, length five, convolutional code, to produce a 190-bit message output (NASA, 1976a). The message is double the format shown in the following table.

Bits		
1-15	Preamble	
16-17	Synchronization	
18-27	Platform ID	
28-35	Data Word Number 1	Sensor 1 through 8 occupy 64 bits
36-43	Data Word Number 2	
44-51	Data Word Number 3	
52-59	Data Word Number 4	
60-67	Data Word Number 5	
68-75	Data Word Number 6	
76-83	Data Word Number 7	
84-91	Data Word Number 8	
92-95	Encoder run-out bits	

The Landsat spacecraft acts as a simple relay receiving, frequency translating, and retransmitting the message butsts. No onboard recording, processing, or decoding of the data is performed.

The output of the DCS receiver is applied to the premodulation processor where the DCS data are put on a subcarrier of the S-band equipment. This equipment retransmits the DCP messages to receive sites on the ground.

At the NED Ground Receive Site, the composite S-band signal is received, and the DCS subcarrier is extracted and inputted to the decoder which is the subject of this section. The decoder receives a 1.024 MHz subcarrier from the S-band receiver and applies the necessary operations to recover and decode the specific DCP data. The extracted data are formatted and inputted to the computer system by means of digital I/O interface and the computer's interrupt system.

In addition to the data decoding equipment described above, there is one other device in the decoder cabinet which performs a separate function. It is a special computer/tracking pedestal interface which reformats azimuth and elevation command words from the computer for presentation to the satellite tracking command equipment.

The relationship of the decoder to the rest of the system is shown on figure A-14. Also shown on this figure is the data stream along the pathway from the receiver to the functions "FSK demod", "Bit sync", "Convolutional Decoder", and "Computer Interface". Greater detail of this pathway and the interactions to carry out these functions is shown in figure A-15. Schematic diagrams showing individual components are available from NED.

DCS DECODER FUNCTIONAL DIAGRAM

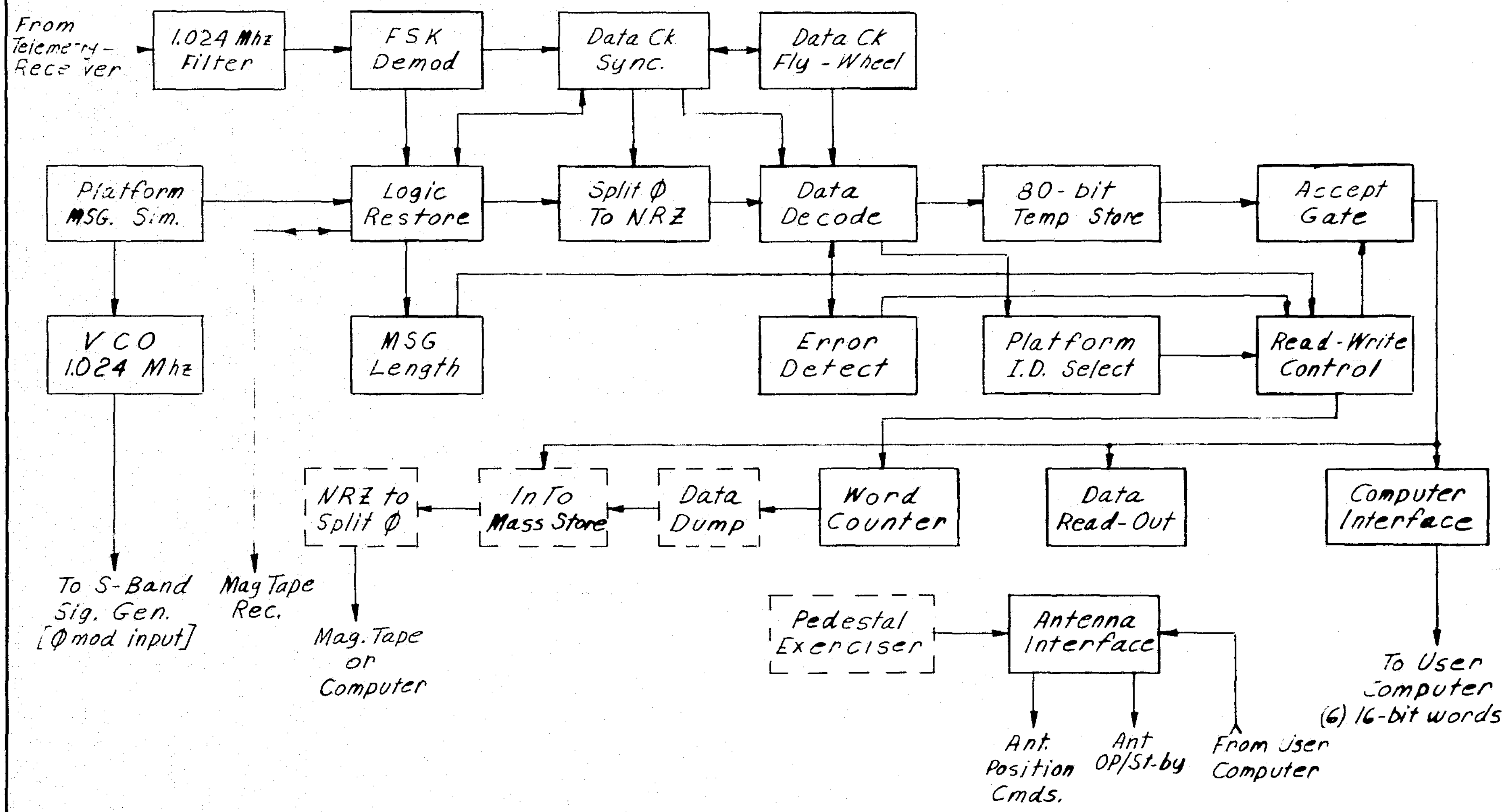


FIGURE A-15

COMPUTER PROGRAMS AND FILES

USED AT NEW ENGLAND DIVISION

```
C       SRCHS
C       RMC    19 JULY 1977
C
C  ROUTINE TO RETRIEVE DCS DATA FROM OCTAL
C    STORAGE FILE BY STATION OR DCP NUMBER
C
C  INPUT:        OCTAL DATA FILE
C                STATION OR DCP NUMBER
C                STARTING DATE
C                ENDING DATE
C
C  OUTPUT:       OCTAL DATA FILE CONTAINING
C                RECORDS FOR STATION BETWEEN
C                SPECIFIED DATES
C
C  SUBROUTINES:  OPNFLS,WDII,WICHDCP
C
C  FILES:        'STADCP'
C
        DIMENSION IA(16),IP(4),IE(4),IFILE(5)
        CALL NEWPAG
        CALL OPNFLS(2,41,3,-1)
10      WRITE(10,11)
11      FORMAT(1X,'STARTING DATE: ',Z)
        READ(11,12)IP(2),IP(3),IP(1)
        IPY=IP(1)                       ;2 DIGIT YEAR
        IP(1)=MOD(IP(1),10)             ;1 DIGIT YEAR
        IP(4)=0                         ;DUMMY HOUR
12      FORMAT(I2,1X,I2,1X,I2)
        WRITE(10,13)
13      FORMAT(1X,'ENDING DATE: ',Z)
        READ(11,12)IE(2),IE(3),IE(1)
        IE(4)=0
        IE(3)=IE(3)+1                   ;MAKE INCLUSIVE
        IE(1)=MOD(IE(1),10)             ;SAME AS ABOVE
        ACCEPT 'STATION(0 FOR DCP):',NSTA
        IF(NSTA.EQ.0)GO TO 20
        CALL WDII(IP(2),IP(3),IPY,NDAY) ;DAYS SINCE 1 JAN 72
        CALL WICHDCP(NSTA,NDAY,IPD,JPRM)
        GO TO 25
20      ACCEPT 'PID:',IPD
25      KK=0
        KS=0
        DO 80 I=1,3
        KC=1                            ;SEEK COUNTER
30      K=KC*(10**(3-I))+KS             ;SEEK BLOCKS
C       TYPE 'K=',K
        CALL FSEEK(2,K)
35      READ(2,40,END=70)IA
40      FORMAT(I1,5I2,A1,I4,8I3)
        DO 45 J=1,3
        IF(IA(J).EQ.0)GO TO 35
45      CONTINUE
        DO 50 L=1,4
C       TYPE 'IA,IP: ',IA(L),IP(L)
C  PAST STARTING DATE ?
        IF(IA(L).EQ.IP(L))GO TO 50      ;ON THE NOSE
        IF(IA(L).LT.IP(L))GO TO 60      ;NO
        GO TO 70                        ;YES
50      CONTINUE
        GO TO 90                        ;GO TO OUTPUT
60      KC=KC+1                         ;ANOTHER BLOCK
        GO TO 30
70      KK=(KC-1)*(10**(3-I))           ;BACK UP A BLOCK
        KS=KS+KK                        ;DECREASE BLOCK SIZE
80      CONTINUE
C  OUTPUT DATA
90      IF(IA(8).EQ.IPD)WRITE(10,100)IA
        IF(IA(8).EQ.IPD)WRITE(3,100)IA
100     FORMAT(1X,I1,5I2,A1,I4,8I3)
        READ(2,40,END=200)IA
C  CHECK FOR ENDING DATE
        ICT=0
        DO 110 LL=1,3
        IF(IA(LL).GE.IE(LL))ICT=ICT+1
        IF(ICT.EQ.3)GO TO 200
110     CONTINUE
        GO TO 90
C  EXIT OR CONTINUE
200     WRITE(10,202)
202     FORMAT(1X,'MORE? ',Z)
        CALL NOECH(1,IANS)
        IF(IANS.EQ.89)TYPE 'YES'
        IF(IANS.EQ.89)GO TO 10
        TYPE 'NO'
        CALL EXIT
        END
R
TYPE OPNFLS
C       SUBROUTINE TO OPEN INPUT AND OUTPUT FILES
C       ICH=0........NO INPUT FILE
C       IBK>0........FOPEN INPUT FILE
C       JCH=0........NO OUTPUT FILE
C       JBK>0........FOPEN OUTPUT FILE
C       JBK<0........APPEND OUTPUT FILE
C
        SUBROUTINE OPNFLS(ICH,IBK,JCH,JBK)
        DIMENSION IFILE(5),JFILE(5)
        IF(ICH.EQ.0)GO TO 25
        WRITE(10,10)
10      FORMAT(1X,'INPUT FILENAME: ',Z)
        READ(11,20)IFILE
20      FORMAT(5A2)
        IF(IBK.EQ.0)CALL OPEN(ICH,IFILE,1,IER)
        IF(IBK.GT.0)CALL FOPEN(ICH,IFILE,IBK)
25      IF(JCH.EQ.0)GO TO 40
        WRITE(10,30)
30      FORMAT(1X,'OUTPUT FILENAME: ',Z)
        READ(11,20)JFILE
        IF(JBK.EQ.0)CALL OPEN(JCH,JFILE,3,IER)
        IF(JBK.GT.0)CALL FOPEN(JCH,JFILE,JBK)
        IF(JBK.LT.0)CALL APPEND(JCH,JFILE,3,IER)
40      RETURN
        END
R
```

```
TYPE TRACKLOAD
RLDR 4/K 16/C TRACK T1 T2 T3 WG CHK ANT $TTO/L ^
TASKCALL FMT.LB FORT.LB
R
TYPE TRACK
C    TRACK   CALLED BY WHOSNEXT OR EXEC'D BY ITSELF
C    WAITS FOR SATELLITE RISE TIME - ZMIN,
C    ORIENTS ANTENNA, TRACKS SATELLITE, LOGS DATA
C    ACCEPTS CORRECTIONS, DUMPS DATA AT END OF
C    PASS, STOWS ANTENNA IN UPRIGHT POSITION
C    TURNS ON AND OFF CIRCUITRY IN COMMAND
C    EQUIPMENT, CHAINS TO QD3
C  TDB 14 NOV 75
      COMPILER DOUBLE PRECISION
      DIMENSION ID(3),IT(3),IT2(11),IT3(11),IT5(11)
      COMMON/KBLK/IT1(11)
      EXTERNAL T1,T2,T3
      COMMON/KEY/KEY1,KEY2,KEY3,KEY4

C    KEY-'S ARE USED TO PASS MESSAGES AS FOLLOWS:
C       KEY1    T1 TO LS1
C       KEY2    T1 TO WG
C               WG BACK TO T1
C       KEY3    T5 TO T1
C       KEY4    T1 TO WG        TIME COUNTER

      COMMON/IBLK/DAYSINMO(12)
      DATA DAYSINMO/31.,28.,31.,30.,31.,30.,31.,31.,30.,31.,
     $30.,31./
C     TYPE 'HIT   CTRL F'
      ZMIN=1.25/1440.
C     CALL DFILW('SDF',IER)
C     CALL CFILW('SDF',2,IER)
      CALL OPEN(5,'DCDAZEL',1,IER)
      CALL APPEND(15,'TLOG',3,IER)
      CALL OPEN(12,'STARTANGLE',1,IER)
      CALL OPEN(7,'NANGLES',1,IER)
      CURDTE=0.
      CURTIME=0.
      KEY2=0
      KEY3=0
      KEY4=0
      CALL TIME(IT,IER)
      IF(IER.NE.1)TYPE 'TIMERR',IER
      CURTIME=DFLOAT(IT(1))+(DFLOAT(IT(2))/60.)+(DFLOAT(IT(3))/
     $3600.)
      CALL DATE(ID,IER)
      IF(IER.NE.1)TYPE 'DE',IER
      II=ID(1)-1
      DO 6 J=1,II
6     CURDTE=CURDTE+DAYSINMO(J)
      CURDTE=CURDTE+DFLOAT(ID(2))
      IF((ID(3)/4*4.EQ.ID(3)).AND.(ID(1).GT.2))CURDTE=CURDTE+1.
      CURDTE=CURDTE+CURTIME/24.  ;CURRENT JUL TIME SINCE 1 JAN
      READ(5,10,END=100)TSINCE,DT
10    FORMAT(F13.9,F6.1)
      IF(CURDTE.GT.364.)TYPE'RESET EP,YR,&FEB IN CLOCK,UTII,&TCALC
     >). SEE P.18 IN ESCOBAL'
      IF(CURDTE.LE.(TSINCE-ZMIN))GO TO 50 ;TASK SCHEDULING
      TYPE '********* TOO LATE *********'  ;TOO LATE FOR CU
RRENT PASS
      CALL CHAIN('PREDICT.SV',IER)
      IF(IER.NE.1)TYPE 'PREDICTRD',IER
      CALL EXIT

C     TASKER  T1 SENDS ANGLES,T2 ORIENTS,T3 GATHERS DATA
C     T5 ACCEPTS CORRECTIONS

50    READ(7,51)IT1(2)  ;NO. TIMES TO EXECUTE

C     NOTE THAT IT1(2) IS THE LOC THAT IS MODIFIED BY T5

51    FORMAT(I6)
      XTIME=(TSINCE-IDINT(TSINCE))*24.
      IT1(4)=XTIME  ;STARTING HOUR
      IT1(5)=(XTIME-DFLOAT(IT1(4)))*3600.  ;SECOND WITHIN H
OUR
      IT1(6)=3
      IT1(7)=DT
      IT1(11)=100
      CALL FQTASK(DUM,T1,IT1,IER,-1)
      IF(IER.NE.1)TYPE 'FQ1',IER
      IMIN=IT1(5)/60
      ISEC=IT1(5)-IMIN*60+.1
      WRITE(10,80)IT1(4),IMIN,ISEC
      WRITE(15,80)IT1(4),IMIN,ISEC
80    FORMAT(' NEXT PASS AT ',I2,':',I2,':',I2)
      IT2(2)=1  ;ORIENT ANTENNA ONCE
      XTIME=((TSINCE-ZMIN)-IDINT(TSINCE-ZMIN))*24.
      IT2(4)=IDINT(XTIME)
      IT2(5)=(XTIME-DFLOAT(IT2(4)))*3600.
      IT2(6)=3
      IT2(7)=0
      IT2(11)=200
      CALL FQTASK(DUM,T2,IT2,IER,-1)
      IF(IER.NE.1)TYPE 'FQ2',IER
      IT3(2)=1
      IT3(4)=IT1(4)
      IT3(5)=IT1(5)
      IT3(6)=0
      IT3(7)=0
      IT3(11)=300
      CALL FQTASK(DUM,T3,IT3,IER,-1)
      IF(IER.NE.1)TYPE 'FQ3',IER
      IT5(2)=1
      IT5(4)=IT1(4)
      IT5(5)=IT1(5)
      IT5(6)=10
      IT5(7)=0
      IT5(11)=500
      CALL FQTASK(DUM,T5,IT5,IER,-1)
      IF(IER.NE.1)TYPE 'FQ5',IER
      IONE=0
      CALL REC(KEY1,IONE)
      CALL FDELY(120)  ;WAIT FOR ANT TO RCH STOW POS.
      II=1
```

```
      CALL ANT(II,II,II,II,II)  ;TURN OFF CIRCUITRY
      CALL CLOSE(5,IER)
      CALL CLOSE(7,IER)
      CALL CLOSE(12,IER)
      WRITE(10,70)
      WRITE(15,70)
70    FORMAT(/)
      CALL CHAIN('GD4.SV',IER)
      IF(IER.NE.1)TYPE 'CHER',IER
100   CALL EXIT
      CALL CLOSE(15,IER)
      END
R
TYPE T1
C TDB 9 DEC 75
C SENDS ANGLE INFORMATION TO 4065 DIGITAL I/O
C BOARD DURING SATELLITE PASS
      TASK T1
      COMMON/KEY/KEY1,KEY2,KEY3,KEY4
      COMMON/KBLK/IT1(11)
      I0=0
      KEY4=KEY4+1
      CALL CHK(KEY3)
      IF(KEY3.GE.0)GO TO 10
      KEY3=KEY3+1
      IT1(2)=IT1(2)+1
      GO TO 25
10    READ BINARY(5)K1
      IF(K1.EQ.-1)GO TO 30  ;END OF FILE?
      READ BINARY(5)K2,K3,K4  ;NO, GET 3 MORE NOS.
      CALL ANT(K1,K2,K3,K4,I0)  ;SEND THEM TO ANT
      IF(KEY3.LE.0)GO TO 25  ;ADJUST IF NECESSARY
      KEY3=KEY3-1
      IT1(2)=IT1(2)-1
      GO TO 10
25    CALL KILL
30    CALL XMT(KEY2,1,$50)  ;TELL WG TO DUMP TO DISC
      IONE=0
      CALL REC(KEY2,IONE)  ;WAIT FOR WG TO FINISH
      CALL XMT(KEY1,1,$50)   ;TELL LS1 EOF HAS BEEN REACHED
      CALL KILL
50    TYPE 'XMTERR1'
      CALL EXIT
60    I0=1
      TYPE 'ERRTN'
      CALL ANT(I0,I0,I0,I0,I0)
      WRITE(15,70)K1,K2,K3,K4
70    FORMAT(1X,'ERRTN FROM RD BINARY',4O18)
      CALL EXIT
      END
R
TYPE T2
C TDB 8/7/75
C SENDS ANGLE INFORMATION TO 4065 I/O BOARD
C DURING ORIENTATION BEFORE THE SATELLITE PASS
      TASK T2
      DIMENSION J(4)
      CALL APPEND(15,'TLOG',3,IER)
```

```
      I0=0
      READ BINARY(12)J  ;GET FIRST ANGLE PAIR
C                         FROM 'STARTANGLE'
      IPOINT=1
      GO TO 100  ;GO SEND  PAIR
10    CALL FDELY(20)  ;WAIT FOR ANTENNA TO GET THERE
      DO 20 I=1,21  ;SEND ANTENNA CCW TWICE
      READ BINARY(12)J
      IPOINT=2
      GO TO 100
15    CALL FDELY(21)
20    CONTINUE
      GO TO 21
100   CALL ANT(J(1),J(2),J(3),J(4),I0)
      WRITE(15,120)
      WRITE(10,120)
120   FORMAT(' .',Z)
      GO TO (10,15,25,35),IPOINT
21    DO 30 I=1,9  ;SEND ANTENNA CW ONCE
      READ BINARY(12)J
      IPOINT=3
      GO TO 100
25    CALL FDELY(21)
30    CONTINUE
      READ BINARY(5)J  ;FIRST LOOK ANGLE,
C                       THEN CONTROL GOES TO T1
      IPOINT=4
      GO TO 100
35    WRITE(10,130)
      WRITE(15,130)
130   FORMAT(' !')
      CALL KILL
      CALL CLOSE(15,IER)
      END
R
\
TYPE T3
      TASK T3
CALLS WG (WORDGETTER)
      CALL WG
      CALL KILL
      END
R
```

```
TYPE QD4
C:::::::::::::::::::::::::::::::::::::::::::::::::::::
C
C
C  TDB 13 APRIL 1977
C
C
C   PROGRAM TO CONVERT LANDSAT MSGS TO FORMAT INCLUDING
C  TIME, DCP NUMBER, AND 8 OCTAL TRIPLETS.

C  THIS PROVIDES INPUT TO 'P' OR 'P3'
C  PROGRAM ACCEPTS MSGS FROM ALL DCP'S AND SCREENS OUT
C  THOSE WHICH ARE NOT NED'S
C
C
C:::::::::::::::::::::::::::::::::::::::::::::::::::::
        DIMENSION IA(6),IB(12),IDATE(3),IA2(16),IB2(16)
        DIMENSION IDONE(0:199)
        INTEGER DAYSINMO
        COMMON/IBLK/DAYSINMO(12)
        DATA DAYSINMO/31,28,32,30,31,30,31,31,30,32,30,31/

        CALL APPEND(15,'TLOG',3,IER)
        IF(IER.NE.1)TYPE 'QLER',IER
        CALL OPEN(5,'SDF',1,IER)
        CALL DFILW('LS2DAT',IER)
        CALL CFILW('LS2DAT',2,IER)
        CALL OPEN(6,'LS2DAT',3,IER)
        CALL APPEND (7,'STORAGE',3,IER)
        CALL APPEND(8,'ESTORAGE',3,IER)

        IF(IER.NE.1)TYPE 'OPENERR'
        WRITE(10,10)
        WRITE(15,10)
10      FORMAT(//)
        NEDCOUNT=0
        ICOUNT=0
        ICT=0
        CALL DATE(IDATE,IER)
        IYR=IDATE(3)-IDATE(3)/10*10
        IF(IDATE(3)/4*4.EQ.IDATE(3).AND.IMONTH.EQ.2)
     $TYPE 'WATCH LEAP DAY!'
C       GET STARTING TIME  ----------
        READ BINARY (5,END=150)IMONTH,IDAY,IHR,IMIN,ISEC
        ISEC=ISEC+60*IMIN
1       READ BINARY(5)IA,ISC    ;GET DATA AND SECONDS COUNTER
        ISC=ISC+ISEC-ICT*3600
        IF(ISC.LT.3600)GO TO 4
        ICT=ICT+1
        ISC=ISC-ICT*3600
        IHR=IHR+1
        IF(IHR.LT.24)GO TO 4
        IRET=1
        GO TO 50
4       IMIN=(ISC/60)
        ISC=ISC-60*IMIN
        IF(IMIN.LT.60)GO TO 5
        IMIN=0
        IHR=IHR+1
        IF(IHR.LT.24)GO TO 5
        IRET=2
        GO TO 50
5       CONTINUE
        IF(IA(1).EQ.0)GO TO 100
        ICOUNT=ICOUNT+1

        DO 20 I=3,6
        ID=IA(I).AND.377K
        IC=ISHFT(IA(I),-8)
        IC=IC.AND.377K
        J=I*2-1
        IB(J)=IC
        J=J+1
        IB(J)=ID
20      CONTINUE

        ICHK=IA(2).AND.20000K
        IA(2)=IA(2).AND.7777K  ;STRIP EVERTHING BUT THE DCP #

        IF(IA(2).EQ.6063K.OR.IA(2).EQ.6504K)GO TO 25
        IF(IA(2).LT.7000K)GO TO 1
        IF(IA(2).EQ.7627K)GO TO 1
        IF(IA(2).EQ.7514K)GO TO 1
        IF(IA(2).EQ.7346K)GO TO 1

25      IER=8224  ;ASSUME NO ERROR, OUTPUT A BLANK
        IF(ICHK.GT.1)IER=17696  ;IF ERR IS FLAGGED OUTPUT AN
'E'
        NEDCOUNT=NEDCOUNT+1
        IF(IMONTH.EQ.1)IYR=7
        WRITE(6,35)IYR,IMONTH,IDAY,IHR,IMIN,ISC,IER,IA(2),(IB
(K),K=5,12)
X       WRITE(10,35)IYR,IMONTH,IDAY,IHR,IMIN,ISC,IER,IA(2),(I
B(K),K=5,12)
        WRITE(15,35)IYR,IMONTH,IDAY,IHR,IMIN,ISC,IER,IA(2),(I
B(K),K=5,12)
        CONTINUE
35      FORMAT(1X,I1,5I2,A1,O14,8O13)
        GO TO 1

50      IHR=IHR-24
        IDAY=IDAY+1
        IF(IDAY.LT.DAYSINMO(IMONTH))GO TO 55
        IDAY=1
        IMONTH=IMONTH+1
        IF(IMONTH.LT.13)GO TO 55
        IMONTH=1
        IYR=IYR+1
        IF(IYR.GE.10)IYR=IYR-10
55      GO TO (4,5),IRET

C::::::::::::::::::::::::::::::::::::::::::::::::::::
C
```

A-33

ORIGINAL PAGE IS
OF POOR QUALITY

```
C
C  ROUTINE TO COMPRESS IDENTICAL LANDSAT MSGS
C  INTO ONE RECORD IN 'STORAGE' WITH THE NUMBER
C  OF MESSAGES IN COLUMN 12.
C
C
C::::::::::::::::::::::::::::::::::::::::

100     DO 105 I=0,199
105     IDONE(I)=0

        CALL CLOSE(5,IER)
        CALL CLOSE(6,IER)
        CALL FOPEN(6,'LS2DAT',41)
        IREC=0
        ISREC=0

111     CALL FSEEK(6,IREC)
112     READ(6,115,END=300)IA2
115     FORMAT(I1,5I2,A1,OI4,8OI3)

        IREC=IREC+1
        IF(IDONE(ISREC).EQ.1)GO TO 118
        ISREC=IREC
        IF(IA2(7).NE.17696)GO TO 121 ;17696='E'
        WRITE(8,35)IA2  ;STASH ERRONEOUS MSGS IN 'ESTORAGE'
        IRR=IREC-1
        IDONE(IRR)=1
        GO TO 112
118     ISREC=IREC
        GO TO 112

121     IA2(7)=1

125     READ(6,115,END=250)IB2
        IREC=IREC+1
        IRR=IREC-1
        IF(IDONE(IRR).EQ.1)GO TO 125
        IF(IB2(7).NE.17696)GO TO 130
        WRITE(8,35)IB2
        IRR=IREC-1
        IDONE(IRR)=1
        GO TO 125

130     IF(IB2(8).NE.IA2(8))GO TO 125
        DO 135 I=9,16
        IF(IB2(I).NE.IA2(I))GO TO 125
135     CONTINUE
        GO TO 140
140     IA2(7)=IA2(7)+1
        IRR=IREC-1
        IDONE(IRR)=1
        GO TO 125

250     WRITE(7,251)IA2 ;PUT COMPRESSED MSGS IN 'STORAGE'
251     FORMAT(1X,I1,5I2,I1,OI4,8OI3)
        IREC=ISREC
        REWIND 6
        GO TO 111
300     WRITE(10,120)ICOUNT,NEDCOUNT
        WRITE(15,120)ICOUNT,NEDCOUNT
120     FORMAT(' TOTAL NUMBER OF MESSAGES = ',I3/' NUMBER OF
NED
      x MESSAGES = ',I3)
x       WRITE(10,110)
        WRITE(15,110)
110     FORMAT(//////)
150     IF(NEDCOUNT.EQ.0)GO TO 160
        CALL CHAIN('P3.SV',IER)
        IF(IER.NE.1)TYPE 'QDER',IER
        CALL EXIT
160     TYPE 'WAITING 1 MIN. FOR SATELLITE TO SET'
        CALL FDELY(600)  ;WAIT FOR SATELLITE TO SET
        CALL CHAIN('PREDICT.SV',IER)
        END
R
```

```
TYPE P3LOAD
RLDR P3 ERTDA BINA1 BINB1 DCBRY UTII UTQLY ^
FRAN LSTGE LAB SNOP STTO/L FORT.LB
R
TYPE P3
C  RMC 24 MAY 76
C PROGRAM TO DECODE LANDSAT MESSAGES AND PRINT
C THEM OUT WITH LABELS AND ENGINEERING UNITS

      DIMENSION IDX(14,50),ITEMP1(6),ITEMP2(12)
      COMMON/JBLK/NUM(24),SUM(12),X(8),JBIN(9),LBIN(3)
      COMMON/JBLK/J,K,S,F,JX,IX,NAME(12),CHK
      COMMON/JBLK/COND,DOX,TEMP,PH
      COMMON/KBLK/LS3(50),IQD
      CALL DFILW('DATA',IER)
      CALL CFILW('DATA',2,IER)
      CALL APPEND(5,'DATA',3,IER)
      CALL APPEND(6,'TLOG',3,IER)
      CALL OPEN(7,'INDX',1,IER)
      CALL OPEN(8,'DIRC',1,IER)
      CALL OPEN(9,'LS2DAT',1,IER)
      CALL OPEN(2,'QDIRC',1,IER)
      CALL FOPEN(13,'LS2DIS',492)
      IF(IER.NE.1)TYPE'OE= ',IER
      WRITE(6,21)
      WRITE(10,21)
21    FORMAT(' PLATFORM        LOCATION',/'  I.D. #'/)
      IX=0
C     READ ID'S OF GAGING STATIONS
      READ(2,17)IQD
17    FORMAT(I2)
      READ(2,10)(LS3(IJ),IJ=1,IQD)
      READ(7,17)IDC
      READ(7,16)((IDX(IK,IL),IK=1,14)IL=1,IDC)

16    FORMAT(I4,I2,1X,12A2)
4     IFLG=0
      LFG=0
      READ(8,10,END=150)IPD  ;READ ID FILE
10    FORMAT(I4)
      IF(IPD.EQ.7127.OR.IPD.EQ.7246.OR.IPD.EQ.7346.OR.IPD.EQ.
     $7254)GO TO 85
      GO TO 86
85    WRITE(6,8)  ;SKIP LINE BETWEEN STATES
      WRITE(10,8) ; "    "    "    "
86    CONTINUE
8     FORMAT(/)
      DO 30 I=1,IDC
      IF(IDX(1,I).EQ.IPD)GO TO 40
30    CONTINUE
      IDK=IDC+1
      IF(I.EQ.IDK)GO TO 150
40    IND=IDX(2,I)
      DO 45 J=3,12
      K=J-2
45    NAME(K)=IDX(J,I)
      WRITE(6,48)IPD,NAME
      WRITE(10,48)IPD,NAME
48    FORMAT(1X,I4,1X,12A2,4X,Z)
C     READ LS2DAT LOOKING FOR IPD
6     READ(9,18,END=11)ITEMP1,IPID,ITEMP2
18    FORMAT(6A2,I4,12A2)
C     SORT BY ID'S INTO 'DATA'
      IF(IPID.EQ.IPD)WRITE(5,19)ITEMP1,IPID,ITEMP2
      IF(IPID.EQ.IPD)IFLG=IFLG+1
19    FORMAT(1X,6A2,I4,12A2)
      GO TO 6
11    REWIND 9
      IF(IFLG.EQ.0)GO TO 39
      CALL CLOSE(5,IER)
      CALL OPEN(5,'DATA',2,IER)
      DO 15 IU=1,IFLG
      READ(5,20,END=145)IY,IMO,IDD,IHH,MM,ISS,IERR,IPID,NUM

20    FORMAT(I1,5I2,A1,I4,24I1)
      IF(IERR.EQ.17696.AND.IFLG.EQ.1)GO TO 39
      IF(IERR.EQ.17696)GO TO 15
      CALL UTII(IY,IMO,IDD,IHH,MM,ISS)
      IF(LFG.NE.0)GO TO 41
      WRITE(6,49)IMO,IDD,IY
      WRITE(10,49)IMO,IDD,IY
49    FORMAT(1H ,I2,'/',I2,'/',I2)
41    LFG=LFG+1
      WRITE(6,47)IHH,MM
      WRITE(10,47)IHH,MM
47    FORMAT(6X,I2,':',I2,' EST  ',Z)
      CHK=0.
      GO TO(61,62,63,64,65,66,67,68,69,70)IND
61    WRITE(6,51)NUM
      WRITE(10,51)NUM
51    FORMAT(2X,'TEST SET',1X,24OI1)
      GO TO 15
62    IF(IPID.EQ.6504)CALL FRAN(NUM,S)
      IF(IPID.NE.6504)CALL ERTDA
C     IF(CHK.EQ.1.)GO TO 125
      IF(IPID.EQ.7201)S=S-2.
      IF(IPID.EQ.7254.OR.IPID.EQ.7365)S=S-10.
      IF(IPID.EQ.7273.AND.S.GE.50)S=S-40.
      CALL LSTGE(IPID,S,Q,MANE,DA,J)
      CSM=Q/DA
      WRITE(6,54)S,Q,CSM
      WRITE(10,54)S,Q,CSM
54    FORMAT(13X,'STG=',F5.2,'FT',1X,F7.0,'CFS',1X,F4.1,' C
     $M')
      GO TO 15
63    CALL ERTDA
C     IF(CHK.EQ.1)GO TO 125
631   WRITE(6,55)S
      WRITE(10,55)S
55    FORMAT(2X,'PRC=',F6.2,'IN')
      GO TO 15
64    COND=0
      DOX=0
      TEMP=0
      PH=0
```

```
      CALL UTQLY
      IF(CHK.EQ.1.)GO TO 125
      WRITE(6,56)COND,DOX,TEMP,PH
      WRITE(10,56)COND,DOX,TEMP,PH
56    FORMAT(2X,'CD=',F6.1,2X,'DO=',F6.3,
     &2X,'WT=',F6.2,2X,'PH=',F6.3)
      GO TO 15
65    CALL SNOP(NUM,IPID,DEPTH)
C     IF(CHK.EQ.1)GO TO 125
      WRITE(6,57)DEPTH
      WRITE(10,57)DEPTH
57    FORMAT(2X,'WES=',F5.2,'IN')
      GO TO 15
66    WRITE(6,58)
      WRITE(10,58)
58    FORMAT(3X,'CRREL')
      GO TO 15
67    CALL ERTDA
      CALL LSTQE(IPID,S,Q,NAME,DA,J)
      CSM=Q/DA
      CALL SNOP(NUM,IPID,DEPTH)
C     IF(CHK.EQ.1)GO TO 125
      WRITE(6,59)DEPTH,S,Q,CSM
      WRITE(10,59)DEPTH,S,Q,CSM
59    FORMAT(2X,'WES=',F5.2,'IN',1X,'STG=',F5.2,'FT',
     &1X,F7.0,'CFS',1X,F5.2,'CSM')
      GO TO 15
68    CALL ERTDA
      COND=0
      DOX=0
      TEMP=0
      PH=0
      CALL UTQLY
C     IF(CHK.EQ.1)GO TO 125
      WRITE(6,60)S,COND,DOX,TEMP,PH
      WRITE(10,60)S,COND,DOX,TEMP,PH
60    FORMAT(3X,'STG=',F5.2,2X,'CD=',F6.1,2X,'DO=',F6.3,
     &2X,'WT=',F6.2,2X,'PH=',F6.3)
      GO TO 15
69    WRITE(6,52)
      WRITE(10,52)
52    FORMAT(2X,'DEMO. SET')
      GO TO 15
70    CALL LAB(NUM,S,ICHK)
      IF(ICHK.EQ.1)GO TO 125
      GO TO 631
125   WRITE(6,130)
      WRITE(10,130)
130   FORMAT(6X,'INVALID')
15    CONTINUE
      GO TO 145
39    WRITE(6,160)
      WRITE(10,160)
160   FORMAT(2X,'NO REPORT')
145   REWIND 5
      GO TO 4
150   CONTINUE
      CALL CLOSE(5,IER)
      CALL DFILW('DATA',IER)
      CALL CFILW('DATA',2,IER)
      CALL CLOSE(6,IER)
      CALL CLOSE(7,IER)
      CALL CLOSE(8,IER)
      CALL CLOSE(9,IER)
      WRITE(10,200)
200   FORMAT(//////)
      CALL CHAIN('PREDICT.SV',IER)
      CALL EXIT
      IF(IER.NE.1)TYPE'CE= ',IER
      STOP
      END
R
TYPE ERTDA
      SUBROUTINE ERTDA
      COMMON/JBLK/NUM(24),LBIN(3),JBIN(9),X(8),SUM(12)
      COMMON/JBLK/J,K,S,F,JX,IX,NAME(12),CHK
      COMMON/JBLK/COND,DOX,TEMP,PH
      JJ=3
      S=0
      F=1.
      J1=1
30    J2=J1+2
      K=-3
      T=0.005
      DO 10 I=J1,J2
      IF(NUM(I).GT.7) GO TO 40
      K=K+3
      CALL DCBRY(LBIN,NUM(I),JJ)
      DO 10 L=1,3
      J=L+K
10    JBIN(J)=LBIN(L)
      K1=2
      DO 20 I=2,9
      IF(I-6)31,32,31
32    F=10.*F
      T=0.005
      K1=6
31    IF(JBIN(I))20,25,20
25    T1=F*2.**(I-K1)
      T=T+T1
      IF(F*10.-T)40,26,26
26    S=S+T1
20    CONTINUE
      J1=4
      F=.01
      IF(J2-4)30,40,40
      RETURN
40    CHK=1.
      RETURN
      END
R
```

```
TYPE BINA1
C D C  1/1/75
      SUBROUTINE BINA1
      COMMON/JBLK/NUM(24),SUM(12),X(8),JBIN(9),LBIN(3)
      COMMON/JBLK/J,K,S,F,JX,IX,NAME(12),CHK
      COMMON/JBLK/COND,DOX,TEMP,PH
      K=-3
      DO 10 I=1,3
      IX=3*JX-(3-I)+6
      IF(NUM(IX)-7)45,45,55
45    K=K+3
      CALL DCBRY(LBIN,NUM(IX),3)
      DO 10 L=1,3
      J=L+K
      JBIN(J)=LBIN(L)
10    CONTINUE
55    RETURN
      END
R
TYPE BINB1
      SUBROUTINE BINB1
      COMMON/JBLK/NUM(24),SUM(12),X(8),JBIN(9),LBIN(3)
      COMMON/JBLK/J,K,S,F,JX,IX,NAME(12),CHK
      COMMON/JBLK/COND,DOX,TEMP,PH
      DO 45 I=2,9
      M=I-1
      IF(JBIN(I))40,10,40
10    IF(I-6)20,30,30
20    X(M)=2**(5-I)
      GO TO 45
30    X(M)=2**(9-I)
      GO TO 45
40    X(M)=0
45    CONTINUE
      M=0
      DO 80 N=1,2
      M=2*JX-(2-N)
      SUM(M)=0
      DO 60 L=1,4
      LX=4*N-(4-L)
      SUM(M)=SUM(M)+X(LX)
      X(LX)=0
60    CONTINUE
      IF(SUM(M)-10)80,70,70
70    K=2
80    CONTINUE
      RETURN
      END
R
TYPE DCBRY
C  D C 1/1/75
      SUBROUTINE DCBRY(LBIN,NUM,JJ)
      DIMENSION LBIN(3)
      DO 10 I=1,JJ
10    LBIN(I)=0
      IF(NUM)5,5,35
35    DO 30 KK=1,NUM
      DO 15 I=1,JJ
      J=JJ-I+1
      IF(LBIN(J))20,20,15
15    CONTINUE
20    DO 25 I=J,JJ
25    LBIN(I)=0
      LBIN(J)=1
30    CONTINUE
5     RETURN
      END
R
TYPE UTII
C  RMC 13 JAN 76
C CONVERTS ZULU TIME TO EASTERN STANDARD TIME (EST)
      SUBROUTINE UTII(IY,IMO,IDD,IHH,MM,ISS)
      INTEGER DAYSINMO
      COMMON/IBLK/DAYSINMO(12)
      DATA DAYSINMO/31,29,31,30,31,30,31,31,30,31,30,31/
      IHH=IHH-5   ;CHANGE THIS IN THE FALL AND SPRING
C
C     FOLLOWING STEP IS TYPICAL TRANSITION MEASURE
C     IF(IMO.EQ.11.OR.(IDAY.EQ.30.AND.IHR.GE.20)
C    *.OR.IDAY.EQ.31)IHH=IHH-1   ;MAKING A 5-HOUR DIFFERENCE
C             TEMPORARY STEP
      IF(ISS.GE.30)MM=MM+1
      IF(MM.GE.60)IHH=IHH+1
      IF(MM.GE.60)MM=MM-60
      IF(IHH.LT.0)IDD=IDD-1
      IF(IHH.LT.0)IHH=IHH+24
      IF(IDD.LT.1)IMO=IMO-1
      IF(IMO.LT.1)IMO=IMO+12
      IF(IDD.LT.1)IDD=DAYSINMO(IMO)
      IY=IY+70
      RETURN
      END
R
TYPE UTGLY
      SUBROUTINE UTGLY
      COMMON/JBLK/NUM(24),SUM(12),X(8),JBIN(9),LBIN(3)
      COMMON/JBLK/J,K,S,F,JX,IX,NAME(12),CHK
      COMMON/JBLK/COND,DOX,TEMP,PH
      DO 25 JX=1,6
      CALL BINA1
      CALL BINB1
25    CONTINUE
      IF(K-6)10,30,30
30    COND=0
      DOX=0
      PH=0
      TEMP=0
      COND=1.5*(100*SUM(4)+10*SUM(1)+SUM(2))
      DOX=0.02*(100*SUM(11)+10*SUM(12)+SUM(3))
      PH=0.014*(100*SUM(5)+10*SUM(6)+SUM(7))
      TEMP=0.04*(100*SUM(8)+10*SUM(9)+SUM(10))
      RETURN
10    CHK=1.
      RETURN
      END
R
```

```
TYPE FRAN
      SUBROUTINE FRAN(NUM,SUM)
      DIMENSION NUM(24),JBIN(9),LBIN(3)
      SUM=0
      DO 80 JX=1,2
      K=-3
      DO 10 I=1,3
      IX=3*JX-(3-I)
      IF(NUM(IX)-7)45,45,55
45    K=K+3
      CALL DCBRY(LBIN,NUM(IX),3)
      DO 10 L=1,3
      J=L+K
      JBIN(J)=LBIN(L)
10    CONTINUE
      DO 80 IW=1,2
      J1=2
      J2=5
      IF(IW.EQ.2)J1=6
      IF(IW.EQ.2)J2=9
      IE=2-IW-2*(JX-1)
      DO 80 IC=J1,J2
      IV=IC-2
      IF(IC.GE.6)IV=IC-6
      V=IV
      XE=IE
      SUM=SUM+(JBIN(IC)*(2**V)*(10**XE))
80    CONTINUE
55    RETURN
      END
R
TYPE LSTGE
C   SUBROUTINE TO CALCULATE DISCHARGES AND VALIDITY FROM
C   VALUES OF STAGE AND STATION NUMBER


      SUBROUTINE LSTGE(ISN,STAGE,Q,NAME,DA,J)
      DIMENSION DISCH(44),NAME(10)
      COMMON/KBLK/LS3(50),IQD


      DO 85 N=1,IQD
      IF(LS3(N).EQ.ISN)GO TO 8
85    CONTINUE
      GO TO 285
8     NN=N-1
      CALL FSEEK(13,NN)

C   T=INITIAL STAGE IN TABLE;  Q=STAGE INCREMENT IN 2ND LINE

      READ(13,3)NAME,DA,T,Q,DISCH
3     FORMAT(6X,10A2,24X,F6.0,12X,F6.0,6X/(8X,9F8.0))
C   J=0 FOR VALID OR    J=1 FOR NON VALID STAGE
      J=0
      IF(Q)50,50,21  ;FOR DUMMY FILE, INCRMNT (Q) WILL BE 0
21    IF(STAGE-T)51,22,22
51    Q=-.005
      GO TO 285
22    DO 60 N=1,43
      S=STAGE -T-N*Q
      R=(S+Q)/Q
      Z=DISCH(N)
      P=DISCH(N+1)-Z
      IF(P)24,60,65
65    IF(S)70,70,60
C   INTERPOLATE ON RATING TABLE
70    IF(Z)52,52,700
52    IF(R)51,152,152
152   Q=P*(R**1.5)
      GO TO 50
700   Q=Z+P*R+.005
      GO TO 50
60    CONTINUE
C   EXTRAPOLATE ON RATING TABLE
24    Q=Z+R*(Z-DISCH(N-1))+.005
285   J=1
50    RETURN
      END
R
TYPE LAB
      SUBROUTINE LAB(NUM,SUM,ICHK)
C  ROUTINE TO DECODE DATA FROM LABARGE CONVERTIBLE DATA
C  COLLECTION PLATFORMS.
C  EACH OF FOUR 16-BIT WORDS IS CODED BY THE DCP AS FOLLOWS:
C  .08 .04 .02 .01 .8 .4 .2 .1 8 4 2 1 80 40 20 10
C  FROM LEFT TO RIGHT.

C  INPUT TO THIS ROUTINE IS IN NUM(24),  24 SINGLE DIGITS
C  REPRESENTING DIGITS IN OCTAL TRIPLETS
C  THE 24 DIGITS MUST BE GROUPED HERE INTO 3'S
C  EACH TRIPLET IS EVALUATED IN OCTAL:  OCT(1) AND OCT(2)
C  BIT POSITIONS OF THESE OCTAL WORDS ARE TESTED AND
C  EVALUATED FOR BCD SIGNIFICANCE

      INTEGER OCT(2),NUM(24)
      ICHK=0
      DO 10 I=1,2
      OCT(I)=0
            DO 30 J=1,3
            JJ=(I-1)*3+J
      OCT(I)=OCT(I)+NUM(JJ)*(8**(3-J))   ;MAKE AN OCTAL TRIP
LET
                                 ;FROM 3 SINGLE DIGITS
30          CONTINUE
10    CONTINUE

      SUM=0.
      DO 40 I=1,2  ;OCT(1) OR OCT(2)
            DO 50 J=1,2  ;LEFT OR RIGHT
                  DO 60 K=1,4 ;BITS, L TO R

            KK=12-4*J-K  ;BIT MAPPING FROM 7 TO 0

            N=OCT(I)
CALCULATE THE DECIMAL AND BCD VALUES
            SUM=SUM-(ITEST(N,KK)*(10.**(((I-1)*2+J)-3))*
```

```
(2**(4-K))
60                                 CONTINUE
50                        CONTINUE
40        CONTINUE

          IF(SUM.LT.0.0.OR.SUM.GT.99.99)ICHK=1
          RETURN
          END
R
TYPE SNOP
          SUBROUTINE SNOP(NUM,IPID,DEPTH)
          DIMENSION NUM(24)
          COMMON/LBLK/IDS(5)
          COMMON/LBLK/COEFFS(5)
          COMMON/LBLK/XOFFSETS(5)
          DATA IDS/7147,7325,3*0/
          DATA COEFFS/.455,.521,3*0./
          DATA XOFFSETS/-.45,-.173,3*0./

          DO 30 I=1,5
          IF(IPID.EQ.IDS(I))GO TO 35
30        CONTINUE

35        CONTINUE
          D6=64*NUM(16)+8*NUM(17)+NUM(18)
          D7=64*NUM(19)+8*NUM(20)+NUM(21)
          IF(D6.NE.0.0)GO TO 40   ;AVOID DIVISION BY 0
          DEPTH=0.0
          GO TO 50
40        DEPTH=(D7/D6)*COEFFS(I)+XOFFSETS(I)
50        RETURN
          END
R
TYPE ANT
.TITL ANT
;SOFTWARE BETWEEN T1 OR T2 AND 4065 I/O BOARD
.ENT ANT
.EXTD .CPYL,.FRET
.NREL
I=-167   ;LO AZ
J=I+1    ;HI AZ
K=I+2    ;LO EL
L=I+3    ;HIEL
M=I+4
FS.=5  ;PROG/STDBY SWITCH
FS.
ANT:JSR @.CPYL
STA 3 RTN
LDA 0 0M 3
MOV 0 0 SZR  ;TURN OFF PEDESTAL?
JMP OFF   ;YES
LDA 0 ATB   ;NO, SEND ANGLES
STA 0 TTB
LDA 2 CN4
MOR: LDA 0 @I 3
LDA 1 @TTB
COM 0 0
AND 1 0
COM 0 0
ISZ TTB

DOAS 0 DVC
INC 3 3
INC 2 2 SZR
JMP MOR
BK: LDA 3 RTN
JSR @.FRET

OFF: LDA 0 B0
DOAS 0 DVC
JMP BK

;DATA AREA------------------
DVC=42
ATB:.+1
B5: 135777   ;0B1+0B5
B4: 133777   ;0B1+0B4
B3: 127777   ;0B1+0B3
B2: 117777   ;0B1+0B2
B0: 1B0+1B2

RTN:.-.
CN4: -4
TTB:.-.
;-----------------------
.END ANT
R
TYPE WG
.TITL WG
;ACCEPTS MESSAGES FROM CONVOLUTIONAL DECODER
;AND IS ACTIVATED BY AN EXTERNAL INTERRUPT
.ENT WG
.EXTN .UIEX,.REC,.IXMT,.TASK,.AKILL,.XMT
.EXTD .CPYL,.FRET
.COMM KEY 4  ;LABELLED COMMON AS IN LS
.TXTM 1
.NREL
;DEVICE CONTROL TABLE----------
IDDCT:DCT
DCT:.-.
1B7
ISR42
;-----------------------
;INTERRUPT SERVICE ROUTINE
;RESPONDS TO ONLY ONE INTERRUPT
;FROM 4065 INTFC.  LOADS 5 WORDS IN A
;ROW AS FAST AS DECODER PROVIDES THEM.
;TIMING MATCHES DECODER'S EXACTLY

ISR42: NIOC DVC
STA 2 URTN2
STA 3 URTN3
LDA 0 SYNC
JSR @.TOBUF

LDA 1 CN5
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
MOR: DIA 0 DVC
JSR @.TOBUF
JSR TMR
INC 1 1 SZR
JMP MOR
JMP OUT

.TOBUF: TOBUF
TOBUF: LDA 2 @.MBP
STA 0 0 2
INC 2 2
STA 2 @.MBP
JMP 0 3

TMR: LDA 2 CN15
INC 2 2 SZR
JMP .-1
JMP 0 3

OUT: LDA 0 @BMESS  ;GET TIME COUNTER
LDA 2 @.MBP
STA 0 0 2  ;STORE TIME WITH MSG
INC 2 2
STA 2 @.MBP

SUB 1 1
LDA 2 URTN2
LDA 3 URTN3

NIOS DVC
.UIEX
;---------------------------

URTN2:.-.
URTN3:.-.
SYNC: 12214
CN5: -5.
CN15: -15.
CN2100:-2100.
CTR:.-.
.MBP: MBP

WG:JSR @.CPYL
STA 2 AC2
STA 3 AC3
SUB 0 0   ;GEN A 0
LDA 2 CN2100
STA 2 CTR
LDA 2 PBUF
STA 0 0 2  ;INIT BUFFER TO ALL 0'S
INC 2 2
ISZ CTR
JMP .-3
LDA 0 DVCN   ;DEFINE 4065 DIGITAL I/O BOARD TO SYSTEM
LDA 1 IDDCT
.SYSTM
.IDEF
JMP @.ERT
.SYSTM
.GDAY
JMP @.ERT
MOV 2 3  ;NEXT 7 LINES STORE YR,MO,DAY IN SDF
LDA 2 PBUF
STA 2 MBP
STA 1 0 2
INC 2 2
STA 0 0 2
INC 2 2
STA 2 MBP
.SYSTM
.GTOD
JMP @.ERT
MOV 2 3  ;NEXT 7 LINES STORE HR,MIN,SEC IN SDF
LDA 2 @.MBP
STA 3 0 2
 INC 2 2
STA 1 0 2
INC 2 2
STA 0 0 2
INC 2 2
STA 2 @.MBP
LDA 0 AMESS
SUB 1 1
NIOS DVC
.REC  ;WAIT HERE FOR LAST LOOK ANGLE TO BE SENT
LDA 0 DVCN
.SYSTM
.IRMV
JMP @.ERT
LDA 0 ASDF  ;POINT TO FILE NAME
SUB 1 1  ;DEVICE CHARS
.SYSTM
.OPEN 6
JMP @.ERT
LDA 0 PBUF
MOVZL 0 0   ;BYTE POINTER
LDA 1 C4200  ;BYTE COUNT
.SYSTM
.WRS 6   ;DUMP THE BUFFER
JMP @.ERT
.SYSTM
.CLOSE 6
JMP @.ERT
LDA 2 AC2
LDA 3 AC3
LDA 0 AMESS
SUBZL 1 1
.XMT
JMP @.ERT
JSR @.FRET

;DATA AREA------------
AC2:.-.
AC3:.-.
```

A-41

```
AMESS:.GADD KEY,1  ;POINTS TO 2ND ELEMENT IN LABELLED COMMON,'KEY'
BMESS: .GADD KEY,3   ;POINTS TO TIME COUNTER (SECS) IN T1
ASDF: .+1*2
.TXT 'SDF'  ;SATELLITE DATA OUTPUT FILE
C4200: 4200.


DVCN:42
DVC=42
MBP:0   ;MOVABLE BUFFER POINTER
.ERT:ERT
ERT:.SYSTM
.ERTN
PBUF:BUF
BUF:  .BLK 2100.  ;BUFFER FOR 300 MSG*7WDS/MSG
.END WG
R
TYPE OFF
          I=1
          CALL ANT(I,I,I,I,I)
          STOP
          END
R
TYPE WHOSNEXT
          COMPILER DOUBLE PRECISION
          COMMON/IBLK/DAYSINMO(12)
          DIMENSION IT(3),ID(3)
          DATA DAYSINMO/31.,28.,31.,30.,31.,30.,31.,31.,30.,31.,
      $30.,31./
          I1=1
          XMARGIN=5./(60.*24.)
          XAFTER=23./(60.*24.)

          CALL OPEN(5,'WANTSTAGE',1,IER)
          IF(IER.NE.1)TYPE 'WS ERR',IER
          READ(5,10)IYN      ;NO=0,YES=1
10        FORMAT(I1)
          IF(IYN.EQ.0)CALL CHAIN('TRACK.SV',IER)
          IF(IER.NE.1)TYPE 'LS CHN ER',IER
          READ(5,15)INTRVL   ;HOURS BETW. INTERROGATIONS
15        FORMAT(I5)
          CALL OPEN(6,'BCDAZEL',1,IER)
          READ(6,20)TSINCE
20        FORMAT(F13.9)
          CALL CLOSE(6,IER)
          CURDATE=0.
          CURTIME=0.
          CALL TIME(IT,IER)
          IF(IER.NE.1)TYPE 'TIMERR',IER
          CURTIME=DFLOAT(IT(1))+(DFLOAT(IT(2))/60.)+(DFLOAT(IT(3))/
      $3600.)
          CALL DATE(ID,IER)
          IF(IER.NE.1)TYPE 'DE',IER
          II=ID(1)-1
          DO 6 J=1,II
6         CURDATE=CURDATE+DAYSINMO(J)
          CURDATE=CURDATE+DFLOAT(ID(2))
          IF((ID(3)/4*4.EQ.ID(3)).AND.(ID(1).GT.2))CURDATE=CURDATE+1.
          CURDATE=CURDATE+CURTIME/24.
C         ^
C         !
C         !
C         PRESENT JUL TIME SINCE 1 JAN (DAYS)
          XINTRVL=DFLOAT(INTRVL)/24.
          STAGETIME=CURDATE-DMOD(CURDATE,XINTRVL)
          IHOUR=(STAGETIME-IDINT(STAGETIME))*24 ;POTENTIAL
C         ^
C         !
C         !  STARTING HOUR FOR STAGE

C         READ STARTING TIME FROM 'WANTSTAGE'
          READ(5,30)IDUM,DSTGTIME
C         THAT WAS CALCULATED PREVIOUSLY AND STORED ON DISC
30        FORMAT(I5/F13.9)
          CALL CLOSE(5,IER)
          IF(STAGETIME.LT.DSTGTIME)STAGETIME=DSTGTIME
          IF(STAGETIME.LE.(TSINCE-XMARGIN))GO TO 200; XEQ 'STAG
E'
          IF(STAGETIME.GE.(TSINCE+XAFTER))GO TO 300   ;XEQ 'LS1'

          STAGETIME=STAGETIME+XAFTER  ;ADD A HALF HOUR
          IHOUR=(STAGETIME-IDINT(STAGETIME))*24

          CALL CLOSE(5,IER)
          CALL OPEN(5,'WANTSTAGE',3,IER)
          WRITE(5,40)IYN,INTRVL,IHOUR,STAGETIME
40        FORMAT(1X,I1/I6/I6/F14.9)
          CALL CLOSE(5,IER)
          CALL CHAIN('TRACK.SV',IER)

250       TYPE 'CHAIN TROUBLE'
          CALL EXIT
200       TYPE'LEAVING 'WHOSNEXT' AND CHAINING TO 'AUTOSTAGE''
          CALL OPEN(5,'WANTSTAGE',3,IER)
          WRITE(5,40)IYN,INTRVL,IHOUR,STAGETIME
          CALL CLOSE(5,IER)
          CALL CHAIN('AUTOSTAGE.SV',IER)
          GO TO 250
300       TYPE 'CHAINING TO 'LS1''
          CALL CHAIN('TRACK.SV',IER)
          GO TO 250
          END
R
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
TYPE SETSTAGE
        COMPILER DOUBLE PRECISION
        COMMON/IBLK/DAYSINMO(12)
        DIMENSION IT(3),ID(3)
        DATA DAYSINMO/31.,28.,31.,30.,31.,30.,31.,31.,30.,31.,
     $30.,31./                                              R
        ACCEPT 'USE DEFAULT TIMES? 1=YES,0=NO',IANS
        IF(IANS.EQ.1)GO TO 20
        ACCEPT 'INTERROGATION INTERVAL (HOURS):',INTRVL
        TYPE 'HOW MANY MINUTES AFTER 1130'S INTERROGATION?'
        ACCEPT '(30 MINUTES IS SUITABLE): ',XOFF
        XOFF=XOFF*.000695  ;CONVERT TO DAYS
        GO TO 50

20      INTRVL = 6
        XOFF=0.

50      I1=1

        CALL OPEN(5,'WANTSTAGE',2,IER)
        IF(IER.NE.1)TYPE 'WS ERR',IER
        CURDATE=0.
        CURTIME=0.
        CALL TIME(IT,IER)
        IF(IER.NE.1)TYPE 'TIMERR',IER
        CURTIME=DFLOAT(IT(1))+(DFLOAT(IT(2))/60.)+(DFLOAT(IT(3))/
     $3600.)
        CALL DATE(ID,IER)
        IF(IER.NE.1)TYPE 'DE',IER
        II=ID(1)-1
        DO 6 J=1,II
6       CURDATE=CURDATE+DAYSINMO(J)
        CURDATE=CURDATE+DFLOAT(ID(2))
        IF((ID(3)/4*4.EQ.ID(3)).AND.(ID(1).GT.2))CURDATE=CURDATE+1.
        CURDATE=CURDATE+CURTIME/24. ;TIME SINCE 1 JAN
        XINTRVL=DFLOAT(INTRVL)/24.
        STAGETIME=CURDATE+XINTRVL-DMOD(CURDATE,XINTRVL)+XOFF
        IHOUR=(STAGETIME-IDINT(STAGETIME))*24
C       ^
C       !
C       !  POTENTIAL STARTING HOUR FOR STAGE

        WRITE(5,30)I1,INTRVL,IHOUR,STAGETIME
        WRITE(10,40)STAGETIME,INTRVL
40      FORMAT(1X,'NEXT METS INTERROGATION IS AT ',F11.6/
     $1X,'AND EVERY ',I2,' HOURS THEREAFTER'/)
30      FORMAT(1X,I1/I6/I6/F14.9)
        CALL CLOSE(5,IER)
        TYPE 'CHAINING TO CLOCK'
        CALL CHAIN('CLOCK.SV',IER)
        END
R
TYPE CLEARSTAGE
        I0=0
        X0=0.
        CALL OPEN(5,'WANTSTAGE',3,IER)
        WRITE(5,10)I0,I0,I0,X0
10      FORMAT(1X,I1/I6/I6/F14.9)
        CALL CLOSE(5,IER)
        TYPE 'CHAINING TO CLOCK.SV'
        CALL CHAIN('CLOCK.SV',IER)
        STOP
        END
```

```
TYPE CLOCK
;7/1/75 TIM'S
;REVISED 6/14/76
;PROGRAM TO READ COORDINATED UNIVERSAL
;TIME FROM TIME CODE GENERATOR
;THE SIGNAL LEAD FROM THE TIME CODE GENERATOR
;MUST BE PLUGGED INTO SOCKET P7 OF THE
;COMMUNICATIONS MULTIPLEXOR PLUG STRIP
.TITL CL
.ENT CL
.EXTN .UIEX,.REC,.IXMT,.TASK,.REC,.KILL
.TXTM 1
.NREL

CL:JMP .+1
LDA 0 CLKD
LDA 1 ACDCT
.SYSTM
.IDEF ;DEFINE 4026
JMP .ERT

LDA 1 .S ;STRTG ADDR OF TASK
LDA 0 DPRI ;PRI=0
.TASK
JMP .ERT

.KILL

S:SUB 0 0
STA 0 I1 ;INIT BS FLAG

C: SUB 0 0 ;INIT COUNTER AND TIME VALUES
STA 0 CTR
STA 0 MIN
STA 0 HR
STA 0 DAY
STA 0 UT1C

D: LDA 0 AMLOC ;ADDR OF MSG LOCATION
MIOS DVC
.REC ;WAIT FOR MSG FROM ISR
LDA 0 BIT7
AND 0 1 SNR ;DATA IN AC1,CHECK FOR HI OR LOW
JMP LO ;LOW
LDA 0 CTR ;HIGH, INC THE COUNTER
INC 0 0
STA 0 CTR
JMP D
LO: LDA 1 CTR
LDA 0 C440
ADCZ# 1 0 SZC ;IS CTR>=440?
JMP CHK0 ;NO
SUBZL 1 1 ;YES,CHK I1 TO SEE IF ONE .BS ALRDY RCVD
LDA 0 I1
SUB# 0 1 SZR
JMP SET ;NOT SET,THIS IS THE FIRST .BS
JMP CHK1 ;SET,THIS IS THE SECOND .BS
CHK0: MOV 1 1 SZR ;AC1 HAS CTR TO SEE IF
; SIGNAL USED TO BE HIGH
JMP S ; NOT 0,USED TO BE HI
JMP D ;0,NEVER WAS HI
SET: SUBZL 1 1
STA 1 I1 ;FLAG RECEIPT OF FIRST .BS
JMP C ;GO WAIT FOR ANOTHER

.ERT: .SYSTM
.ERTN
;DATA AREA
K2: 2
;---------
.ZREL
.A: A
.CRST: CRST ;ADDR OF COUNTER RESET
.S: S ;ADDR TO START OVER
CTR: .-. ;STORES NO. OF 4026 TICKS THAT SIGNAL IS HIGH
M:.-. ;LOOP COUNTER FOR PROGRESSING THRU MINUTE
VAL:.-.
MIN:.-. ;CALCULATED MINUTE
HR:.-. ;CALC HR
DAY:.-. ;CALC DAY
UT1C:.-. ;CALC UT CORRECTION
BIT7: 1B7 ;DATA COMES IN ON LINE 7 OF 4026 BOARD
ANTBL: NTBL ;POINTER TO TBL OF SUBROUTINE NAMES
ABCD:BCD ;POINTER TO TBL OF BCD VALUES
;---------
IDLAY:.-. ;FLAGS WHETHER TO DELAY OR ADVANCE UT1C

.NREL

I1: .-. ;FLAG 1ST .BS
AMLOC: MLOC ;MSG LOCATION FOR .XMT,.REC
MLOC: .-.
AC2: .-. ;SAVE AC2
AC3: .-. ;SAVE AC3
DPRI: 0 ;TASK PRIORITY
CLKD: 24 ;4026 DEVICE CODE
DVC=24 ;4026 DEVICE CODE
C440: 400. ;LOWER LIMIT TO SIGNAL .BS
ACDCT: CDCT ;ADDR OF DEVICE CONTROL TABLE
CDCT: .-.
1B0
ISR

ISR: DIBC 1 DVC ;4026 ISR
STA 2 AC2
STA 3 AC3
LDA 0 BIT7
SUB# 0 1 SNR ;BIT 7 SET? SKIP IF NO
JMP XOUT ;OK AS IS
LDA 1 K2 ;NO, IT'S A 0 -- MAKE IT A 2.
XOUT:LDA 0 AMLOC
.IXMT ;SIGNAL MAIN PROG THAT INT HAS OCCURRED
JMP .ERT
LDA 2 AC2
LDA 3 AC3
SUBZL 1 1 ;FORCE RESCHEDULING
```

```
BLANK
MINAD
MINAD
MINAD
BLANK
CHK.8
HRAD
HRAD
HRAD
HRAD
BLANK
HRAD
HRAD
BLANK
BLANK
CHK.8
DAYAD
DAYAD
DAYAD
DAYAD
BLANK
DAYAD
DAYAD
DAYAD
DAYAD
CHK.8
DAYAD
DAYAD
;------------
;BCD VALUES
;------------
BCD:0
0
0
0
0
0
0
0
0
0
0
1
2
4
8.
0
10.
20.
40.
0
0
1
2
4
8.
0
10.
20.
```



```
0
0
0
1
2
4
8.
0
10.
20.
40.
80.
0
100.
200.
;-------------

ADIM: DIM  ;TABLE OF NO. OF DAYS IN MONTH
DIM: 31.
28.   ;XXXXXXXXXXXWATCH FOR LEAP YEARS!XXXXXXXXXXX
31.
30.
31.
30.
31.
31.
30.
31.
30.
31.
0
;----------

A:LDA 2 ADIM  ;NEXT 26 LINES CALC DAY NO. IN YR
CON: LDA 1 0 2
MOV 1 1 SZR
JMP CON1
SUBZL 3 3
SUB 3 2
JMP CON2
CON1: MOV 1 1 SNR
JMP CON2
LDA 0 DAY
SUB 1 0
STA 0 DAY
MOVZL# 0 0 SNC  ;IS DAY<0?
JMP MOR  ;NO
JMP CON2  ;YES
MOR:MOV 0 0 SNR  ;IS DAY DOWN TO ZERO?
JMP CON2  ;YES
 INC 2 2  ;NO
JMP CON
CON2: LDA 1 0 2
LDA 0 DAY
ADD 1 0  ;RESTORE DAY
LDA 1 ADIM
SUB 1 2
INC 2 2  ;MON. NO.
```

```
.UIEX

CHK1: SUB 0 0
STA 0 N
CHK2: JSR @.CRST
LDA 0 N
INC 0 0   ;N POINTS TO TABLE VALUES
STA 0 N
LDA 1 C42   ;AND SUBROUTINES TO CALC TIME
SUB 0 1 SNR ;DONE LOOPING THRU SUBROUTINES
JMP @.A   ;YES
R2: LDA 0 AMLOC   ;NEXT 24 LINES DET'N 0,1, OR MARK PULSE
NIOS DUC
.REC
LDA 0 BIT7
AND 0 1 SNR   ;DATA IN AC1
JMP LOW1
LDA 0 CTR
INC 0 0
STA 0 CTR
JMP R2
LOW1: LDA 0 CTR
MOV 0 0 SNR   ;CTR=0?
JMP R2   ;YES
LDA 1 LL275   ;NO,CHK FOR 275
SUBZ# 1 0 SZC   ;IS 270>CTR?
JMP CHK3   ;NO,.5 OR .8
JMP LD0   ;YES,.2, 0 RCVD
CHK3: LDA 1 UL275
SUBZ# 1 0 SNC   ;IS 200>CTR?
JMP LD1   ;NO, 1 RCVD
JMP LD2   ;YES, MARK PULSE RCVD

;NOW PASS 0,1, OR 2 TO SOME SUBROUTINE
LD0: SUB 0 0 ;GEN A 0
JMP STC
LD1: SUBZL 0 0 ;GEN A 1
JMP STC
LD2: SUB 0 0
INCZL 0 0 ;GEN A 2
STC: STA 0 TC   ;MAYBE NOT NEC IF AC0 PRESERVED
LDA 2 ANTBL   ;GET ADR OF SUBROUTINE TABLE
LDA 1 N   ;LOAD NO. OF STEPS WE HAVE GONE THRU TABLE
ADD 1 2   ;CALC ADDR WITHIN TABLE
LDA 1 0 2   ;GET SBRTN NAME IN AC1
STA 1 NAME   ;STORE IT
LDA 2 ABCD   ;GET ADDR OF BCD TABLE
LDA 1 N
ADD 1 2   ;DET'N ADDR WITHIN TABLE
LDA 1 0 2 ;GET BCD VALUE
STA 1 VAL ;FOR CURRENT SECOND WITHIN MINUTE
JSR @NAME   ;GO TO THAT SUBROUTINE
JMP CHK2   ;GO WAIT FOR NEXT SECOND

4
MINAD : LDA 0 TC ;GET TIME CODE RECEIVED
MOVZR 0 0 SNC ;WAS TC=1?
JMP BK ;NO
```

```
LDA 0 MIN ;YES
ADD 1 0 ;ACCUM MINS.
STA 0 MIN
JMP BK

HRAD : LDA 0 TC
MOVZR 0 0 SNC
JMP BK
LDA 0 HR
ADD 1 0
STA 0 HR
JMP BK

DAYAD : LDA 0 TC
MOVZR 0 0 SNC
JMP BK
LDA 0 DAY
ADD 1 0
STA 0 DAY
JMP BK

CHK.8:LDA 0 TC
SUB 1 1
INCZL 1 1 ;GEN A 2
AND 0 1 SNR ;IS .8 ON SCHEDULE?
JMP @.5   ;NO
JMP BK ;YES

BLANK: JMP .+1
JMP 0 3

BK: JMP 0 3   ;GENERAL RETURN
;DATA AREA

UL275:300.   ;UPPER LIMIT OF .5S
LL275: 200.   ;LOWER LIMIT OF .5S
C42: 42.   ;NO. OF SUBROUTINES
JMP .   ;TEMP
TC: .-.   ;TIME CODE 0,1,OR 2
NAME: .-.   ;VARIABLE SUBROUTINE NAME

;ACTION TABLE
-----------------
ATBL: 0   ;FIRST LOCATION IS DUMMY
BLANK
BLANK
BLANK
BLANK
BLANK
BLANK
BLANK
BLANK
CHK.8
MINAD
MINAD
MINAD
MINAD
```

```
MOV 2 1
LDA 2 YR
.SYSTM
.SDAY
JMP @.AERT

JMP F                                ;DATA
YR: 9.  ;DGC SAYS 1977 IS YR 9
.AERT: .ERT


CRST: SUB 0 0  ;COUNTER RESETTER
STA 0 CTR
JMP 0 3  ;RETURN

             ;DATA AREA
;----------------
S41:41.
C100:100.
C130:130.
C825:825.
C2000:2000.
SUM:.-.

DLCON: 2


F:LDA 1 DLCON
.SYSTM
.DELAY
JMP .+1
 LDA 0 S41  ;AT LAST!!  WE CAN SET THE REAL TIME CLOCK
LDA 1 MIN
LDA 2 HR
.SYSTM
.STOD
JMP @.AERT
LDA 0 BPSF
LDA 1 OB0
.SYSTM
.EXEC
JMP .AERT
OB0: 1B0
BPSF: .+1*2
.TXT /WHOSNEXT.SV/
.END CL
R
```

```
TYPE ELWRITE
        COMPILER DOUBLE PRECISION
        DIMENSION IDAY(3)
        CALL OPEN(5,'ELEMENTS',3,IER)
        IF(IER.NE.1)TYPE 'OE',IER
        TYPE 'ENTER EPOCH,NDOT0,I0,NODE0,E0,OMEG0,M0,N0'
        WRITE(10,567)
567     FORMAT(' DO YOU NEED FURTHER EXPLANATION? YES OR NO ',Z)
        READ(11,20)IANS
20      FORMAT(A1)
        IF(IANS.EQ.22816)GO TO 200
        TYPE 'ANSWER YES(Y) OR NO(N) TO OK?'
30      DO 50 I=1,8
31      READ(11)X
        WRITE(10,33)X
33      FORMAT(F20.9,'  OK?',Z)
        READ(11,29)IANS
29      FORMAT(A1)
        IF(IANS.NE.20000)GO TO 40
        TYPE 'ENTER IT AGAIN'
        GO TO 31
40      WRITE(5)X
50      CONTINUE
        CALL DATE(IDAY,IER)
        WRITE(5)IDAY(3)
        WRITE(5)IDAY(1)
        WRITE(5)IDAY(2)
        CALL CLOSE (5,IER)
        IF(IER.NE.1)TYPE 'CE',IER
        CALL EXIT

200     TYPE 'EPOCH - T0,JULIAN DATE OF EPOCH (DAYS) F20.8<15>'
        TYPE 'NDOT0 -  FIRST DERIV OF MEAN MOTION,+ OR - F8.8 <15>'
        TYPE 'I0 - INCLINATION AT TIME 0, DEGREES F7.4 <15>'
        TYPE 'NODE0 - RIGHT ASCENSION OF ASCENDING NODE AT T0,DEGS,F7.4 <15>'
        TYPE 'E0 - ECCENTRICITY AT T0, F7.7 <15>'
        TYPE 'OMEG0 - ARGUMENT OF PERIGEE AT T0, DEGREES,F7.4<15>'
        TYPE 'M0 - MEAN ANOMALY, DEGREES,F7.4<15>'
        TYPE 'N0 - MEAN MOTION, REVS/DAY, F10.8 <15>'
        GO TO 30
        CALL EXIT
        END
R
TYPE KOUR
C  JHB  6/30/75
        COMPILER DOUBLE PRECISION
        SUBROUTINE KOUR
        DIMENSION CORD(6)
        CALL APPEND(8,'COORD',3,IER)
        IF(IER.NE.1)TYPE 'OE',IER
        ACCEPT 'HOW MANY STATIONS? ',IJK
        DO 10 I=1,IJK
        ACCEPT 'LATITUDE:(D,M,S): ',PD,PM,PS
        PHI=PD+ (PM+(PS/60.))/60.
        ACCEPT 'WEST LONGITUDE(D,M,S): ',WD,WM,WS
        WL=WD + (WM+(WS/60.))/60.
        CONV=6.2831853072/360.
        PHI=PHI*CONV
        SNPHI=DSIN(PHI)
        CSPHI=DCOS(PHI)
        CORD(4)=SNPHI
        CORD(5)=CSPHI
        CORD(1)=360.-WL ;EAST LONGITUDE
        SNS=SNPHI**2
        F=1/298.3
        ES=2*F-F*F
        G1=1/DSQRT(1-ES*SNS)
        G2=((1-F)**2)/DSQRT(1-SNS*ES)
        CORD(2)=-G1*CSPHI
        CORD(3)=-G2*CSPHI
        CORD(6)=-G2*SNPHI
        DO 60 J=1,6
60      WRITE(8)CORD(J)
10      CONTINUE
        CALL CLOSE(8,IER)

        END
R
```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```
TYPE PREDICTLOAD
RLDR PREDICT OT1 TCALC SGP SRU INCT SEMI EXANM PEAK ^
GARB/L FORT.LB;DELETE/C GARB
R
TYPE PREDICT
C       TDB 4DEC75
        COMPILER DOUBLE PRECISION
        DIMENSION TT(6),ID(3)
        CALL FGTIM(I,J,K)
        TT(4)=I
        TT(5)=J
        TT(6)=0
        CALL DATE(ID,IER)
        TT(1)=ID(3)
        TT(2)=ID(1)
        TT(3)=ID(2)
        CALL OT1(TT)
        END
R
TYPE OT1
C       TDB 4DEC75
        COMPILER DOUBLE PRECISION
        SUBROUTINE OT1(T)
        DIMENSION T(6),TS(6)
        REAL I0,IM,M0,NDOT0,M0,NODE0,NODEM,LM,NM,NDOTM,LLONG,
     $L0,NODDT,J2,J3,MU,IS,NODES,LAMBDA E
        EXTERNAL SEMI
        INTEGER YR
        COMMON EPOCH,YR,M0,NODE0,OMEG0,NDOT0,
     $AM,EM,IM,NODEM,OMEGM,LM,NM,NDOTM,E0,N0,I0,L0,A0,
     $ELONG,LLONG,EXLNG,OMEGL,TRUEU,RMAG,RDOT,NODDT,OMGDT,
     $UX,UY,UZ,RX,RY,RZ,RDOTX,RDOTY,RDOTZ
        COMMON/IBLK/DAYSINMO(12)
        DATA DAYSINMO/31.,28.,31.,30.,31.,30.,31.,31.,30.,31.,
     $30.,31./
        CONV=.01745329251 ;DEGREES TO RADS
        ICOUNT=0
        J2=.00108248
        Q=-1.
        J0=1
        AE=1.
        IMANY=0
        X2=0.
        Z=0.
        X=0
        IW=1
        TWOPI=6.2831853072
        CALL APPEND(15,'TLOG',3,IER)
        IF(IER.NE.1)TYPE 'TLER',IER
        CALL OPEN(5,'ELEMENTS',1,IER)
        CALL DFILW('PTAE',IER)
        CALL CFILW('PTAE',2,IER)
        CALL OPEN(4,'PTAE',3,IER)
        IF(IER.NE.1)TYPE 'OE',IER
C INPUT FROM NORAD
        READ(5)EPOCH,NDOT0,I0,NODE0,E0,OMEG0,M0,N0
        OMEG0=OMEG0*CONV
        I0=I0*CONV
        NODE0=NODE0*CONV
        M0=M0*CONV
        N0=N0*TWOPI
        NDOT0=NDOT0*TWOPI
        CALL CLOSE(5,IER)
        IF(IER.NE.1)TYPE 'CE',IER
        L0=M0+NODE0+OMEG0
        A0=SEMI(E0,N0,I0)
        TEMP=1.5*N0*J2*(AE/(A0*(1.-E0**2)))**2
        NODDT=-TEMP*DCOS(I0)
        OMGDT=TEMP*(2.-2.5*(DSIN(I0))**2)
        BDT=300.
        SDT=10.
        DT=BDT
        X1=DT
        CALL OPEN(8,'COORD',1,IER)
        IF(IER.NE.1)TYPE 'COE',IER
        READ(8)LAMBDA E,G1CSPHI,G2CSPHI,SNPHI,CSPHI,G2SNPHI
        LAMBDA E=LAMBDA E-.99077
C       E.L. CORR TO COINCIDE WITH  NORAD PREDICTION
        IPASS=1
        WRITE(10,69)
        WRITE(15,69)
69      FORMAT(' SATELLITE RISE TIME   PASS #   PEAK  DURATION')
        DO 25 I=1,6
25      TS(I)=T(I)
20      CALL TCALC(T,TSINCE,THETA,LAMBDA E)
        TSINCE=TSINCE-EPOCH
C       NO. OF DAYS SINCE MOST RECENT NORAD EPOCH
        CALL SGP(TSINCE)
        CALL SRU(THETA,H,A,G1CSPHI,G2CSPHI,SNPHI,CSPHI,G2SNPHI)
        IF(X2.NE.X1)GO TO 889
        IGO=0
        Z=0
        X=0
        IMANY=IMANY+1
        J0=1
        A=0.0
        STEL=90.00    ;STOW ANGLE
        WRITE(4,339)A,STEL
        IF(IMANY.NE.IPASS)GO TO 990
        CALL CLOSE(4,IER)
        CALL CLOSE(8,IER)
        CALL CLOSE(15,IER)
        CALL OVERFLOW($997,$995,'S')
995     CALL CHAIN('INTERP1.SV',IER)
        IF(IER.NE.1)TYPE 'LSCE'
        CALL EXIT
997     CALL CHAIN('TRACK.SV',IER)
        IF(IER.NE.1)GO TO 997
CHECK TO SEE IF SATELLITE IS ABOVE THE HORIZON
990     X2=0
889     IF(H.LT.0.)GO TO 250
        IF(Q.GE.0..OR.IFLAG.EQ.1)GO TO 190
        IFLAG=1
        DO 150 I=1,6
```

```
150     T(I)=TS(I)
        DT=SDT
        H=Q
        X2=DT
        GO TO 20
190     Q=H
        IOVER=1
        CALL PEAK(IMANY,H,Z,X,ICOUNT,A,DT,IOVER)
        IFLAG=0
        I4=T(4)
        I5=T(5)
        I6=T(6)
        IF(JO.EQ.1)WRITE(15,135)I4,I5,I6
        IF(JO.EQ.1)WRITE(10,135)I4,I5,I6
135     FORMAT(1X,2(I2":"),I2,Z)
        JO=2
        TSS=TSINCE+EPOCH
        IF(IW.EQ.1)WRITE(4,333)TSS,DT
333     FORMAT(1X,F14.9/1X,F6.1)
        WRITE(4,339)A,H
339     FORMAT(2H A,F6.2,1HE,F6.2,': ')
        IW=2
290     DO 300 I=1,6
300     TS(I)=T(I)
        CALL INCT(T,DT)
        GO TO 20
250     IF(Q.GT.0.)DT=BDT
        IF(X2.EQ.0)GO TO 887
        IF(Q.GT.0)X2=DT
887     Q=H
        IW=1
        GO TO 290
        END
R
TYPE TCALC
C TDB 2/28/75
        COMPILER DOUBLE PRECISION
        SUBROUTINE TCALC(T,TSINCE,THETA,LAMBDA E)
        REAL LAMBDAE
        DIMENSION T(6)
        COMMON /IBLK/DAYSINMO(12)
        EP=2442413.5  ;1 JAN 75
        EPYR=75.
        TWOPI=6.2831853072
        DTHDT=.25068447  ;DTHETA/DT
        XJD=EP+(T(1)-EPYR)*365. ;ADD 365 DA/YR THRU LAST YR

        TYJD=0.  ;THIS YEAR'S JULIAN DATE

        N=T(1)-1.  ;N=LAST YEAR
        DO 100 I=75,N  ;CHECK FOR LEAP YEARS THRU LAST YR
        IF(I/4*4.NE.I)GO TO 100
        XJD=XJD+1.
100     CONTINUE

        N=T(2)-1.
        DO 50 I=1,N  ;DAYS IN MONTH THRU LAST MO
        TYJD=TYJD+DAYSINMO(I)
```

```
50      CONTINUE
        N=T(1) ;NOW LOOK AT THIS YR
        IF(N/4*4.NE.N)GO TO 200  ;IS THIS NOT A LEAP YR?
        IF(T(2).LE.2.)GO TO 200  ;ARE WE BEYOND 2/29?
        TYJD=TYJD+1.  ;YES, ADD A LEAP DAY
200     TYJD=TYJD+T(3)
C     JULIAN DATE AT INSTANT
        TSINCE=TYJD+T(4)/24.+(T(5)+T(6)/60.)/1440.
        DT=T(4)*60. + T(5)+T(6)/60.    ;(HR,MIN,SECS) AS MINS
        TU=(XJD+TYJD-2415020.0)/36525.
        THETA G0=DMOD((99.6909833+(36000.7689*TU)+.000387080*
     $TU**2),360.)
        THETA G=DMOD((THETA G0+DT*DTHDT),360.)
C     SIDEREAL TIME IN RADIANS
        THETA=(DMOD((THETA G+LAMBDA E),360.))*TWOPI/360.
        RETURN
        END
R
TYPE SGP
C SGP BY TDB  -- REV 2 14 75 AT 1430
        COMPILER DOUBLE PRECISION
        SUBROUTINE SGP(TSINCE)
C----THIS ROUTINE COMPUTES SATELLITE POSITION USING A SIMPLIF
IED
C     GENERAL PERTURBATIONS METHOD,CLASSICAL MEAN ELEMENTS ARE

C     INPUT;  AND POSITION, VELOCITY, & OSCULATING ELEMENTS AR
E
C     RETAINED

        REAL I0,IM,N0,NDOT0,M0,NODE0,NODEM,LM,NM,NDOTM,LLONG,

     $NDOT6,L0,NODDT,J2,J3,MU,IS,NODES
        EXTERNAL EXANM
        INTEGER YR


C       INPUT PARAMETERS
        COMMON EPOCH,YR,M0,NODE0,OMEGO,NDOT0,
     $AM,EM,IM,NODEM,OMEGM,LM,NM,NDOTM,E0,N0,I0,L0,A0,
     $ELONG,LLONG,EXLNG,OMEGL,TRUEU,RMAG,RDOT,NODDT,OMGDT,
     $UX,UY,UZ,RX,RY,RZ,RDOTX,RDOTY,RDOTZ
        J2=.00108248
        J3=-.000002562
        NDOT6=0.
        AE=1.
        MU=1.
        TWOPI=6.2831853072

COMPUTE TIME VARIANT MEAN ELEMENTS AT TSINCE
        TT=TSINCE ;TIME SINCE EPOCH (DAYS)
C  DELETED '+NDOT6*TT**3'  FROM THE NEXT LINE
        DM=N0*TT+NDOT0*TT**2 ;CHG IN MEAN ANOMALY
        DOMEG=OMGDT*TT ;D ARG PER
        DNODE=NODDT*TT ;D ASC NODE
        LM=DMOD((L0+DM+DOMEG+DNODE),TWOPI) ;MEAN ORBITAL LNGT
UDE
        OMEGM=DMOD((OMEGO+DOMEG),TWOPI) ;A.P.
```

```
      NODEM=DMOD((NODE0+DNODE),TWOPI) ;RA OF AN
      IM=I0 ;INCLINATION UNCHNGD
      SINI=DSIN(IM)
      COSI=DCOS(IM)
C  DELETED '+3.*NDOT6*TT**2' FROM THE NEXT LINE
      NM=N0+2.*NDOT0*TT
      AM=A0*(((N0/NM)**.3333333333)**2)
      EM=1.-A0/AM*(1.-E0)
      IF(EM)10,10,20
10    EM=0.00001

COMPUTE AND APPLY LONG PERIODIC TERMS (SUBSRCPTD 'L')
20    TEMPL = (J3/J2)*(AE/AM)*SINI/(1.-EM**2)
      AXNL=EM*DCOS(OMEGM)
      AYNL=EM*DSIN(OMEGM)-.5*TEMPL
      ELONG=DSQRT(AXNL**2+AYNL**2)
      OMEGL=DMOD((DATAN2(AYNL,AXNL)),TWOPI); PRESERVE QUAD
C  LONG PERIODIC ON L IS:
      LLONG=DMOD((LM-.25*TEMPL*AXNL*(3.+5.*COSI)/(1.+COSI)),
     $TWOPI)

C  SOLVE KEPLER'S EQUATION AND OTHER TWO-BODY FORMULAE

C  LONG PERIODIC ECC ANOM:
      EXLNG=EXANM(LLONG-OMEGL-NODEM,ELONG)
C TRUE ARG OF LATITUDE:
      TRUEU=2.*DATAN(DSQRT((1.+ELONG)/(1.-ELONG))*(DSIN(.5*
     $EXLNG)/DCOS(.5*EXLNG)))+OMEGL
      RMAG=AM*(1.-ELONG*DCOS(EXLNG)) ;R SUB L
C  TRANSVERSE COMPONENT OF VEL VECTOR
      RVDT=DSQRT(MU*AM*(1.-ELONG**2))*(1./RMAG)
C  RADIAL COMP OF VEL VECTOR
      RMGDT=DSQRT(MU*AM)*ELONG/RMAG*DSIN(EXLNG)

COMPUTE AND APPLY SHORT PERIODIC TERMS

      TEMPS=.25*J2*(AE/(AM*(1.-ELONG**2)))**2 ;PERTURBATION
      SIN2U=DSIN(2.*TRUEU)                    ;CONSTANT
      COS2U=DCOS(2.*TRUEU)
      RMAG=RMAG+TEMPS*SINI**2*COS2U*(AM*(1.-ELONG**2))
      TRUEU=DMOD((TRUEU-.5*TEMPS*(6.-7.*SINI**2)*SIN2U),TWOPI)
      IS=IM+3.*TEMPS*SINI*COSI*COS2U
      NODES=NODEM+3.*TEMPS*COSI*SIN2U

COMPUTE QUANTITIES FOR OUTPUT
      SNODE=DSIN(NODES)
      CNODE=DCOS(NODES)
      SINI=DSIN(IS)
      COSI=DCOS(IS)
      SINU=DSIN(TRUEU)
      COSU=DCOS(TRUEU)
C  UNIT VECTOR POINTING TOWARD SATELLITE:
C   SEE P.104 IN ESCOBAL, 'METHODS OF ORBIT DETERMINATION',
C   TO CHECK VALUES
      UX=COSU*CNODE-SINU*SNODE*COSI
      UY=COSU*SNODE+SINU*CNODE*COSI
      UZ=SINU*SINI
```

```
C        UX=-SINL*CNODE-COSU*SNODE*COSI
C        UY=-SINU*SNODE+COSU*CNODE*COSI
C        UZ=COSU*SINI
C        WX=SINI*SNODE
C        WY=-SINI*CNODE
C        WZ=COSI
         RX=RMAG*UX
         RY=RMAG*UY
         RZ=RMAG*UZ
C        RDOTX=RMGDT*UX+RVDT*UX
C        RDOTY=RMGDT*UY+RVDT*UY
C        RDOTZ=RMGDT*UZ+RVDT*UZ
C        RDOT=DSQRT(RDOTX**2+RDOTY**2+RDOTZ**2)
         RETURN
         END
R
TYPE SRU
C        SRU (SLANT RANGE VECTOR) TDB (6/27/75)
C        COMMENTS AFTER LINES IN THIS SUBROUTINE
C        ARE EQUATIONS IN APPENDIX OF ESCOBAL,
C        "METHODS OF ORBIT DETERMINATION"
         COMPILER DOUBLE PRECISION
         SUBROUTINE SRU(THETA,H,A,G1CSPHI,G2CSPHI,SNPHI,CSPHI,

      $G2SNPHI)
         REAL I0,IM,N0,NDOT0,M0,NODE0,NODEM,LM,NM,NDOTM,LLONG,

      $L0,NODDT,LX,LY,LZ,LXH,LYH,LZH
         INTEGER YR
         COMMON EPOCH,YR,M0,NODE0,OMEG0,NDOT0,
      $AM,EM,IM,NODEM,OMEGM,LM,NM,NDOTM,E0,N0,I0,L0,A0,
      $ELONG,LLONG,EXLNG,OMEGL,TRUEU,RMAG,RDOT,NODDT,OMGDT,
      $UX,UY,UZ,RX,RY,RZ,RDOTX,RDOTY,RDOTZ
         TWOPI=6.2831853072
         X=(G1CSPHI)*DCOS(THETA)  ;1A.62
         Y=(G1CSPHI)*DSIN(THETA);1A.63
         RHOX=RX+X   ;1A.68
         RHOY=RY+Y   ;1A.69
         RHOZ=RZ+G2SNPHI   ;1A.70
         RHOH=DSQRT(RHOX**2+RHOY**2+RHOZ**2)   ;1A.71
         LX=RHOX/RHOH ;UNIT VECTOR FROM SITE  1A.72 TO SATELLI

         LY=RHOY/RHOH ;DITTO 1A.73
         LZ=RHOZ/RHOH; DITTO  1A.74
         COSTH=DCOS(THETA)
         SINTH=DSIN(THETA)
         LXH=LX*SNPHI*COSTH+LY*SNPHI*SINTH-LZ*CSPHI   ;1A.75
         LYH=-LX*SINTH+LY*COSTH   ;DITTO
         LZH=LX*COSTH*CSPHI+LY*SINTH*CSPHI+LZ*SNPHI   ;DITTO
         COSH=DSQRT(1.-LZH**2)
         H=DATAN(LZH/COSH) ;1A.76 IN MOOD
CORRECTION FOR REFRACTION FOLLOWS ;COURTESY OF RALPH PASS (GS
FC)
         H=H+.0007*DCOS(H)/(DSIN(H)+DSQRT(.04+(DSIN(H))**2))
         H=360.*H/TWOPI ;+ OR - DEGREES FROM HORIZON
         A=DATAN2(LYH,-LXH)   ;1A.77
         A=360.*A/TWOPI ;DEGREES CW FROM NORTH
         IF(A.LT.0.)A=A+360.   ;ADJUST COORDINATE SYSTEMS
```

```
      PETURN
      END
R
TYPE INCT
C  TDB  2/28/75
      COMPILER DOUBLE PRECISION
      SUBROUTINE INCT(T,DT)
      DIMENSION T(6)
      COMMON/IBLK/DAYSINMO(12)
      IF(DT.GE.60.)GO TO 600
      T(6)=T(6)+DT ;INCR SECONDS
      IF(T(6).LT.60.)GO TO 350
      T(6)=T(6)-60.  ;RESET SECONDS
600   IF(DT.GE.60.)T(5)=T(5)+DT/60.
      IF(DT.GE.60.)GO TO 700
      T(5)=T(5)+1  ;INCR MINUTES
700   IF(T(5).LT.60.)GO TO 350
      T(5)=T(5)-60.  ;RESET MINUTES
      T(4)=T(4)+1.   ;INCR HOUR
      IF(T(4).LT.24.) GO TO 350
      T(4)=T(4)-24   ;RESET HRS
      I=T(2)   ;PTR TO MO
      T(3)=T(3)+1. ;INCR DAY
      IYR=T(1)
      ILEAP=0
      IF(I.EQ.2.AND.IYR/4*4.EQ.IYR)ILEAP=1
      DAYSINMO(2)=28+ILEAP
      IF(T(3).LE.DAYSINMO(I))GO TO 350
      T(3)=1.   ;RESET DAYS
      DAYSINMO(2)=28.   ;RESET FEB
      T(2)=T(2)+1.   ;INCR MO
      IF(T(2).LE.12.)GO TO 350
      T(2)=1.   ;RESET MO
      T(1)=T(1)+1.   ;INCR YR
350   RETURN
      END
R
TYPE SEMI
C  TDB 2/28/75
      COMPILER DOUBLE PRECISION
      DOUBLE PRECISION FUNCTION SEMI(EE,XNN,XII)
COMPUTES THE MEAN (KOZAI) SEMI-MAJOR AXIS OF A SATELLITE
      YY=.3333333333
      XJ2=.00108248
      XMU=11467.25298
      AA=(XMU/XNN**2)**YY
      DD=-1.5*XJ2*((1./AA)**2)/((DSQRT(1.-EE**2))**3)
      DD=DD*(1.-1.5*(DSIN(XII))**2)
      SEMI=AA*(1.+YY*DD-YY*DD**2)
      RETURN
      END
R
TYPE EXANM
C  TDB 2/28/75
      COMPILER DOUBLE PRECISION
      DOUBLE PRECISION FUNCTION EXANM(XMM,ECC)
COMPUTES ECCENTRIC ANOMALY USING KEPLER'S EQUATION
      TWOPI=6.2831853072
      EXANM=DMOD(XMM,TWOPI)
      DO 10 I=1,50
      AA=ECC*DSIN(EXANM)
      DELM=XMM-EXANM+AA
      ZZ=1.-ECC*DCOS(EXANM)
      DELE=DELM/(ZZ+((.5*DELM)/ZZ)*AA)
      IF(DABS(DELE)-1.)30,30,20
20    DELE=DELE/DABS(DELE)
30    EXANM=EXANM+DELE
      IF(DABS(DELE)-.000001)40,10,10
10    CONTINUE
40    CONTINUE
      RETURN
      END
R
TYPE PEAK
C  JHB  6/30/75
      COMPILER DOUBLE PRECISION
      SUBROUTINE PEAK(IMANY,H,Z,X,ICOUNT,A,DT,IOVER)
      CALL APPEND(15,"TLOG",3,IER)
      ICOUNT=ICOUNT+1
      IF(H.LT.Z)GO TO 333
      Z=H
      RETURN
333   IF(X.EQ.1)GO TO 1
      IM=IMANY+1
      ZNUM=ICOUNT-1
      ICOUNT=0
      XNUM=(ZNUM*2*DT)/60.
      IF(IOVER.EQ.0)GO TO 10
      IF(Z.EQ.0 .OR.X.EQ.0)WRITE(15,222)IM,Z,XNUM
10    IF(Z.EQ.0 .OR.X.EQ.0)WRITE(10,222)IM,Z,XNUM
222   FORMAT(11X,I3,5X,F7.2,2X,F5.0///)
      X=1
      IF(Z.LT.15.AND.A.LT.0)CALL FCHAN("WAIT20.SV")
1     CONTINUE
      CALL CLOSE(15,IER)
      RETURN
      END
R
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
TYPE LS2DIS
 1 46 ST JOHN R,NINEMILEBR                               1290.            0.
 2 46        0.3       43       84      147      243      375      546      766     1060
 3 46       1420     1810     2240     2720     3290     3950     4700     5540     6420
 4 46       7380     8410     9520    10700    11900    13000    14200    15400    16600
 5 46      17800    19200    20600    22100    23600    25200    26700    28300    29900
 6 46      31600    33200    35000    35600    36200    36800    37400    38000    38600
 1 47 ST JOHN R. DICKEY                                  2700.            3.5
 2 47        0.5      160      560     1140     2020     3120     4450     6050     7800
 3 47       9800    11800    13800    16100    18600    21000    23600    26400    29700
 4 47      32900    36200    39400    42700    46600    50100    54200    58700    63200
 5 47      67700    72200    76700    81200    85700    90200    94700    99200
 6 47
 1 48 ST JOHN R, FORT KENT                               5690.            0.5
 2 48        1.0      450     1280     2280     3600     5310     7490    10100    13000
 3 48      16000    19700    23700    28000    33000    38000    44000    50000    56500
 4 48      63500    71000    79000    87000    95000   140000   113000   123000   133000
 5 48
 6 48
 1 49 PENOBSCOT, W.ENFIELD                               6670.            1.
 2 49        0.5     1860     2660     3590     4630     5750     6960     8270     9700
 3 49      11200    12900    14600    10600    18600    20700    23000    25500    28000
 4 49      30700    33500    36500    39500    42500    45500    49000    52500    56200
 5 49      60000    63900    67800    71800    75900    80000    84000    88200    92500
 6 49      97000   101500   106200   111000   116000   121000   126000   131000   136500
 1 50 CARABASSET R, N.ANSON                               354.            2.
 2 50        0.5        0       50      128      270      490      795     1160     1550
 3 50       2030     2590     3230     3880     4530     5270     6070     6870     7670
 4 50       8520     9400    10300    11200    12200    13100    14100    15000    16000
 5 50      17000    18100    19200    20300    21400    22600    23700    24800    26000
 6 50      27200    28500    29800    31000    32300
 1 51 SACO R, CORNISH                                    1290.            1.        7
 2 51        0.5      215      351      531      761     1080     1440     1930     2550
 3 51       3240     4040     4950     5950     7000     8130     9360    10600    11700
 4 51      12900    14100    15400    16600    17900    19200    20500    21800    23200
 5 51      24500    25800    27200    28600    29900    31200    32600    34000    35300
 6 51      36700    38100    39600    40900    42400    43800    45300    46800    48300
 1 32 PLYMOUTH               8 2 8 1                     622.0     0.0  11.0   -1.0   12.6
02 32         .5                50      198      430      980     1700     2340     2790
 3 32       3250     3750     4290     4860     5480     6160     6900     7710     8580
 4 32       9480    10410    11360  12350.0  13350.0  14350.0  15370.0  16420.0  17470.0
 5 32    18570.0  19670.0  20770.0  21900.0  23050.0  24200.0  25400.0  26600.0  27850.0
 6 32    29100.0  30350.0  31650.0  32960.0  34310.0  35710.0    37110    38510    39910
 1  9 GOFFS FALLS           4 2 3 7                      3092.0     0.0   12.     1.0    14.
 2  9        1.0    115.0    454.0   1110.0   2380.0   4780.0   8200.0  12500.0  17240.0
 3  9    22040.0  26840.0  31640.0  36440.0  41240.0  46040.0  50840.0  55640.0  60440.0
 4  9    65240.0  70040.0  74800.0  79400.0  84000.0  88800.0  93600.0  98400.0103200.0
 5  9   108000.0113000.0118000.0123000.0128000.0133000.0138000.0143000.0148000.0
 6  9   153000.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
 1 52 IPSWICH R, IPSWICH                                  124.            2.0
 2 52        0.2        0     0.76     3.39     17.5       32       52       82      122
 3 52        174      240      325      430      550      685      825      950     1055
 4 52       1150     1240     1340     1440     1540     1640     1740     1845     1955
 5 52       2065     2175     2290     2410     2530     2670     2810
 6 52
 1 53 N.NASHUA R,FITCHBURG                                63.6            2.1
 2 53         .2       17       31       52       80      120      175      242      323
 3 53        416      530      650      770      890     1010     1130     1260     1400
```

```
4 53      1540      1680      1820      1980      2140
5 53
6 53
1 55 BRANCH R, FORESTDALE                           91.2                1.60
2 55       0.4         6        26        65       122       200       299       421       560
3 55       720       880      1040      1215      1395      1580      1780      1985      2205
4 55      2425      2650      2890
5 55
6 55
1 56 PAWTUXET R, CRANSTON                           200.                3.2
2 56       0.2        19        47        89       140       207       287       368       450
3 56       530       605       675       740       800       860       925       995      1065
4 56      1135      1205      1275      1345      1415      1485      1555      1625      1696
5 56      1765      1835      1910      1990      2070      2150      2230      2310      2390
6 56      2470      2550      2630      2715      2805      2895      2985      3075      3165
1 19 HARTFORD            4 1 9 1                   10480       0.0  16.0     0.0      22.0
2 19       1.0       0.0    2000.0    4000.0    7000.0   10000.0   12000.0   16000.0   20000.0
3 19   23000.0   28000.0   32000.0   37000.0   42000.0   47000.0   54000.0   60000.0   66000.0
4 19   71000.0   80000.0   89000.0   96000.0  105000.0  114000.0  124000.0  134000.0  143000.0
5 19  153000.0  162000.0  172000.0  182000.0  192000.0  203000.0  214000.0  226000.0  237000.0
6 19  250000.0  267000.0  295000.0       0.0       0.0       0.0       0.0       0.0       0.0
1 45 CONN. R, MIDDLETOWN                           10082.
2 45
3 45
4 45
5 45
6 45
1 57 MANCHESTER, CONN.                                1.
2 57
3 57
4 57
5 57
6 57
1 58 ST. FRANCIS R., N.B.                             1.
2 58
3 58
4 58
5 58
6 58
1 59 SHIELDS BROOK, ME.                               1.
2 59
3 59
4 59
5 59
6 59
1 60 ALLAGASH RIVER,ME.                             1250.                1.5
2 60       0.5        86       263       585      1070      1690      2470      3320      4200
3 60      5170      6150      7260      8540     10000     11700     13800     14800     16500
4 60     18200     20300     22800     25300     27800     30300
5 60
6 60
R
```

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TYPE INDX
21
7012 2 NINEMILE BR., ME.
7207 2 ALLAGASH RIVER, ME.
7110 1 ALLAGASH FALLS,MAINE
7273 2 FORT KENT, ME.
7071 2 WEST ENFIELD, ME.
7272 2 NORTH ANSON, ME.
7356 2 CORNISH, ME.
7127 3 SOUTH MT., N.H.
7201 2 PLYMOUTH, N.H.
7021 2 GOFFS FALLS, N.H.
7103 1 CRREL, NORTH DAKOTA
7104 1 CRREL, NORTH DAKOTA
7105 1 CRREL, NORTH DAKOTA
7125 1 CRREL-SUGARLOAF, ME.
7246 3 WACHUSETT MT., MA.
6063 2 IPSWICH, MA.
7271 2 FITCHBURG, MA.
7345 2 CRANSTON, R.I.
7254 2 HARTFORD, CT.
7355 2 MIDDLETOWN, CT.
7206 2 MANCHESTER, CT.
R
TYPE DIRC
7012
7207
7110
7273
7071
7272
7356
7127
7201
7021
7103
7104
7105
7125
7246
6063
7271
7345
7254
7355
7206
R
TYPE QDIRC
18
7012
7777
7273
7071
7272
7356
7201
7021
6063
7271
7777
7345
7254
7355
7206
6504
7777
7207
R
```

```
TYPE STARTERS
0.0
0.0
A   0.00E 60.00:
A330.00E 40.00:
A300.00E 20.00:
A270.00E 10.00:
A240.00E  8.00:
A210.00E  6.00:
A180.00E  4.00:
A150.00E  3.00:
A120.00E  0.00:
A 90.00E  0.00:
A 60.00E  0.00:
A 30.00E  0.00:
A   0.00E  0.00:
A330.00E  0.00:
A300.00E  0.00:
A270.00E  0.00:
A240.00E  0.00:
A210.00E  0.00:
A180.00E  0.00:
A150.00E  0.00:
A120.00E  0.00:
A 90.00E  0.00:
A120.00E  0.00:
A150.00E  0.00:
A180.00E  0.00:
A210.00E  0.00:
A240.00E  0.00:
A270.00E  0.00:
A300.00E  0.00:
A330.00E  0.00:
A   0.00E  0.00:
A999.00E999.00:
R
```

```
TYPE DTABST
C  TDB 30 JULY 75    PROGRAM TO CONVERT DECIMAL AZIMUTH AND
C      ELEVATION ANGLES TO BCD SUITABLE FOR INPUT TO INTERFACE
C     TO 1848 DIGITAL COMPARATOR
        COMPILER DOUBLE PRECISION
        DIMENSION X(2),IBCDH(2),IBCDL(2)
        COMMON/IBLK/BCDHIGH(10),BCDLOW(8)
        DATA BCDHIGH/200.,100.,80.,40.,20.,10.,8.,4.,2.,1./
        DATA BCDLOW/.8,.4,.2,.1,.08,.04,.02,.01/    ;BCD TABLE
        CALL OPEN(5,'STARTERS',1,IER)
        CALL OPEN(6,'STARTANGLE',3,IER)
        IF(IER.NE.1)TYPE 'OE',IER
        M1=-1

5       READ(5,10,END=500)TSINCE,DT,X ;READ 1ST RECORD ON FILE
10      FORMAT(F14.9/F5.1/2(1X,F6.2))
        GO TO 15
        WRITE(6,11)TSINCE,DT
11      FORMAT(F14.9,F6.1)

15      DO 100 I=1,2    ;AZ ,EL
        IHIGH=0
        ILOW=0
        DO 30 J=1,10
        IF(BCDHIGH(J).LE.X(I))GO TO 20  ;CHECK BCD TABLE
        GO TO 30  ;SMALLER THAN VALUE IN TABLE

20      X(I)=X(I)-BCDHIGH(J)   ;>=VALUE IN TABLE
        II=J+8-(J-1)*2  ;MAPPING FROM DO LOOP INDEX TO BIT POSITION
        CALL ISET(IHIGH,II)  ;BIT ORDER ON P.9-11 OF FORT IV
30      CONTINUE

        DO 50 J=1,8
        IF(BCDLOW(J).LE.X(I))GO TO 40
        GO TO 50
40      X(I)=X(I)-BCDLOW(J)
        II=J+6-(J-1)*2  ;BIT MAPPING
        CALL ISET(ILOW,II)
50      CONTINUE
        IBCDH(I)=IHIGH
        IBCDL(I)=ILOW
100     CONTINUE
        WRITE BINARY(6)IBCDL(1),IBCDH(1),IBCDL(2),IBCDH(2)
        READ(5,110)X
110     FORMAT(2(1X,F6.2))
        IF(X(1).EQ.999.)GO TO 120
        GO TO 15
120     WRITE BINARY(6)M1
        GO TO 5
500     CALL CLOSE(5,IER)
        CALL CLOSE(6,IER)
        IF(IER.NE.1)TYPE 'CE',IER
        STOP
        END
R
```

```
TOTAL NUMBER OF MESSAGES =  64
NUMBER OF NED MESSAGES =  46
PLATFORM        LOCATION
 I.D. #

7171 MINEMILE BR., ME.            5/26/77
       8:30 EST                 STG= 2.25FT   1240.CFS  1.0 CSM
       8:33 EST                 STG= 2.25FT   1240.CFS  1.0 CSM
7304 SHIELDS BROOK, ME.           5/26/77
       8:31 EST                 STG= 7.98FT      0.CFS  0.0 CSM
       8:34 EST                 STG= 7.98FT      0.CFS  0.0 CSM
       8:37 EST                 STG= 7.98FT      0.CFS  0.0 CSM
7273 FORT KENT, ME.               5/26/77
       8:29 EST                 STG= 7.70FT  13600.CFS  2.4 CSM
       8:35 EST                 STG= 7.70FT  13600.CFS  2.4 CSM
       8:38 EST                 STG= 7.70FT  13600.CFS  2.4 CSM
7147 ALLAGASH FALLS,ME.           5/26/77
       8:30 EST    WES=-0.45IN
       8:33 EST    WES=-0.45IN
7071 WEST ENFIELD, ME.            5/26/77
       8:27 EST                 STG= 5.15FT  11710.CFS  1.8 CSM
       8:31 EST                 STG= 5.15FT  11710.CFS  1.8 CSM
       8:34 EST                 STG= 5.15FT  11710.CFS  1.8 CSM
       8:37 EST                 STG= 5.15FT  11710.CFS  1.8 CSM
7272 NORTH ANSON, ME.             5/26/77
       8:32 EST                 STG= 3.55FT    292.CFS  0.8 CSM
7356 CORNISH, ME.                 5/26/77
       8:30 EST                 STG= 3.75FT   1685.CFS  1.3 CSM
       8:33 EST                 STG= 3.75FT   1685.CFS  1.3 CSM
       8:36 EST                 STG= 3.75FT   1685.CFS  1.3 CSM

7127 SOUTH MT., N.H.              5/26/77
       8:29 EST    PRC=  0.33IN
       8:32 EST    PRC=  0.33IN
       8:35 EST    PRC=  0.33IN
       8:38 EST    PRC=  0.33IN
7201 PLYMOUTH, N.H.               5/26/77
       8:30 EST                 STG= 0.58FT    518.CFS  0.8 CSM
       8:33 EST                 STG= 0.58FT    518.CFS  0.8 CSM
7207 GOFFS FALLS, N.H.            NO REPORT
7103 CRREL, NORTH DAKOTA          NO REPORT
7104 CRREL, NORTH DAKOTA          NO REPORT
7105 CRREL, NORTH DAKOTA          NO REPORT
7125 CRREL-SUGARLOAF, ME.         NO REPORT

7246 WACHUSETT MT., MA.           5/26/77
       8:34 EST    PRC=  0.82IN
6063 IPSWICH, MA.                 5/26/77
       8:31 EST                 STG= 3.92FT    201.CFS  2.3 CSM
       8:36 EST                 STG= 3.92FT    201.CFS  2.3 CSM
7271 FITCHBURG, MA.               5/26/77
       8:32 EST                 STG= 6.00FT   1900.CFS 29.9 CSM
       8:35 EST                 STG= 6.00FT   1900.CFS 29.9 CSM
       8:38 EST                 STG= 6.00FT   1900.CFS 29.9 CSM
7142 CHICOPEE, MA.                NO REPORT
7021 WESTFIELD, MA.               NO REPORT

7325 NED,WALTHAM, MA.             NO REPORT
7187 NED,WALTHAM, MA.             NO REPORT

7220 FORESTDALE, R.I.             NO REPORT
7345 CRANSTON, R.I.               5/26/77
       8:30 EST                 STG= 3.22FT     22.CFS  0.1 CSM
       8:36 EST                 STG= 3.22FT     22.CFS  0.1 CSM
       8:39 EST                 STG= 3.22FT     22.CFS  0.1 CSM

7254 HARTFORD, CT.                5/26/77
       8:32 EST                 STG= 5.63FT  14520.CFS  1.4 CSM
       8:35 EST                 STG= 5.63FT  14520.CFS  1.4 CSM
       8:38 EST                 STG= 5.63FT  14520.CFS  1.4 CSM
7242 MIDDLETOWN, CT.              NO REPORT
7206 MANCHESTER, CT.              5/26/77
       8:32 EST                 STG= 2.11FT      0.CFS  0.0 CSM
       8:35 EST                 STG= 2.11FT      0.CFS  0.0 CSM
```

Sample output from P3.

APPENDIX B

APPENDIX B

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 DCP. There were 28 thermocouples used at the Sugarloaf Mountain installation and, as a result, four banks were used.

The reference thermocouple junction is compensated to within $\pm 0.3^{o}C$ over a temperature range of -50^{o} to $+40^{o}C$ using a combination of five thermistors. The normal measurement temperature range is -34^{o} to $+32^{o}C$ with a resolution of $\pm 0.25^{o}C$ or 10 mv. 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 volts (nominal) at 0.5 ampere and 5 volts at 1.0 milliampere. The 12-volt 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 (figure B-1):

- 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 (figure B-2 through B-5). Seven input signals are read during one DCP update sequence.

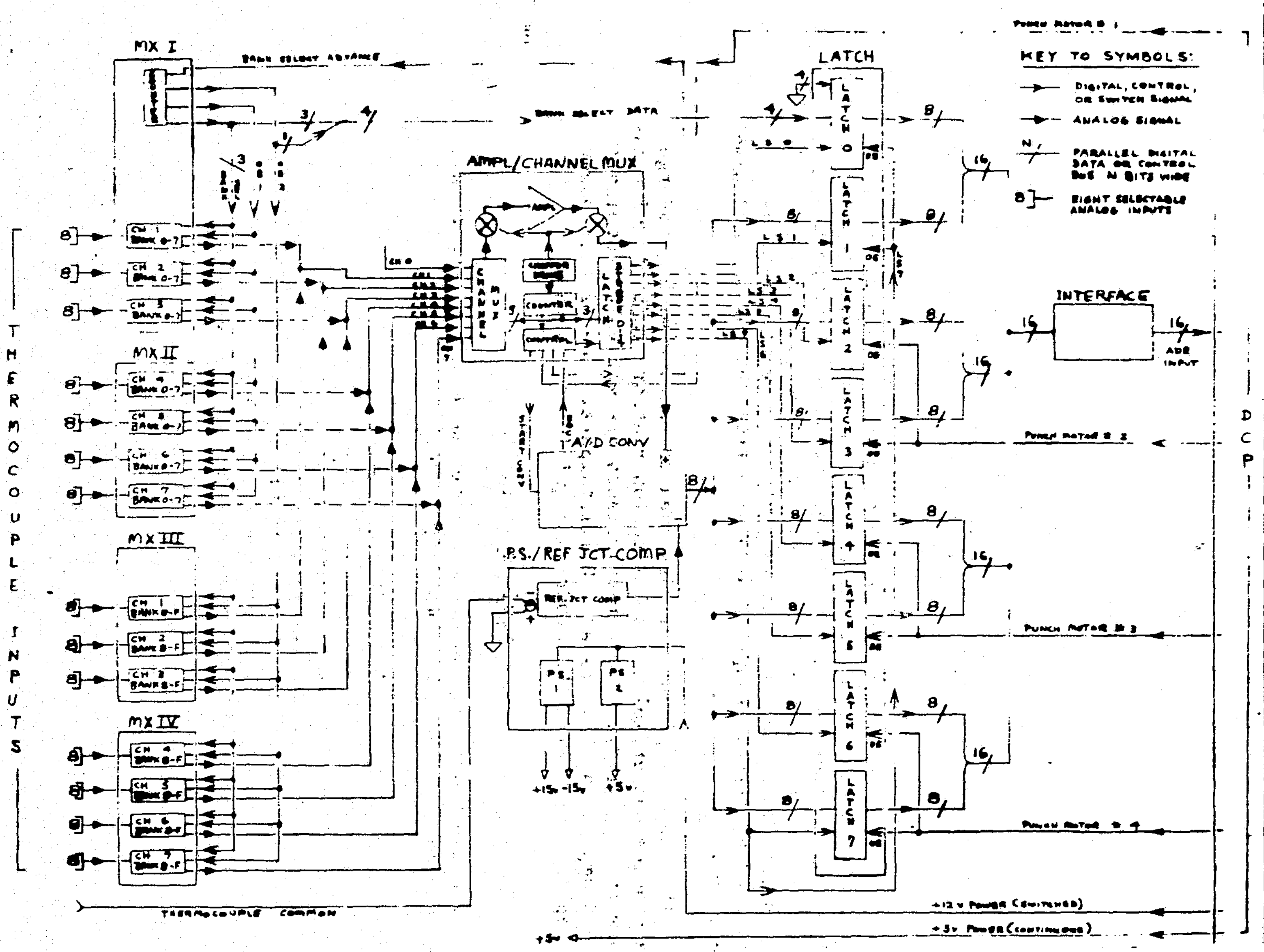

Figure B-1 Functional diagram of thermocouple interface arranged on nine circuit cards.

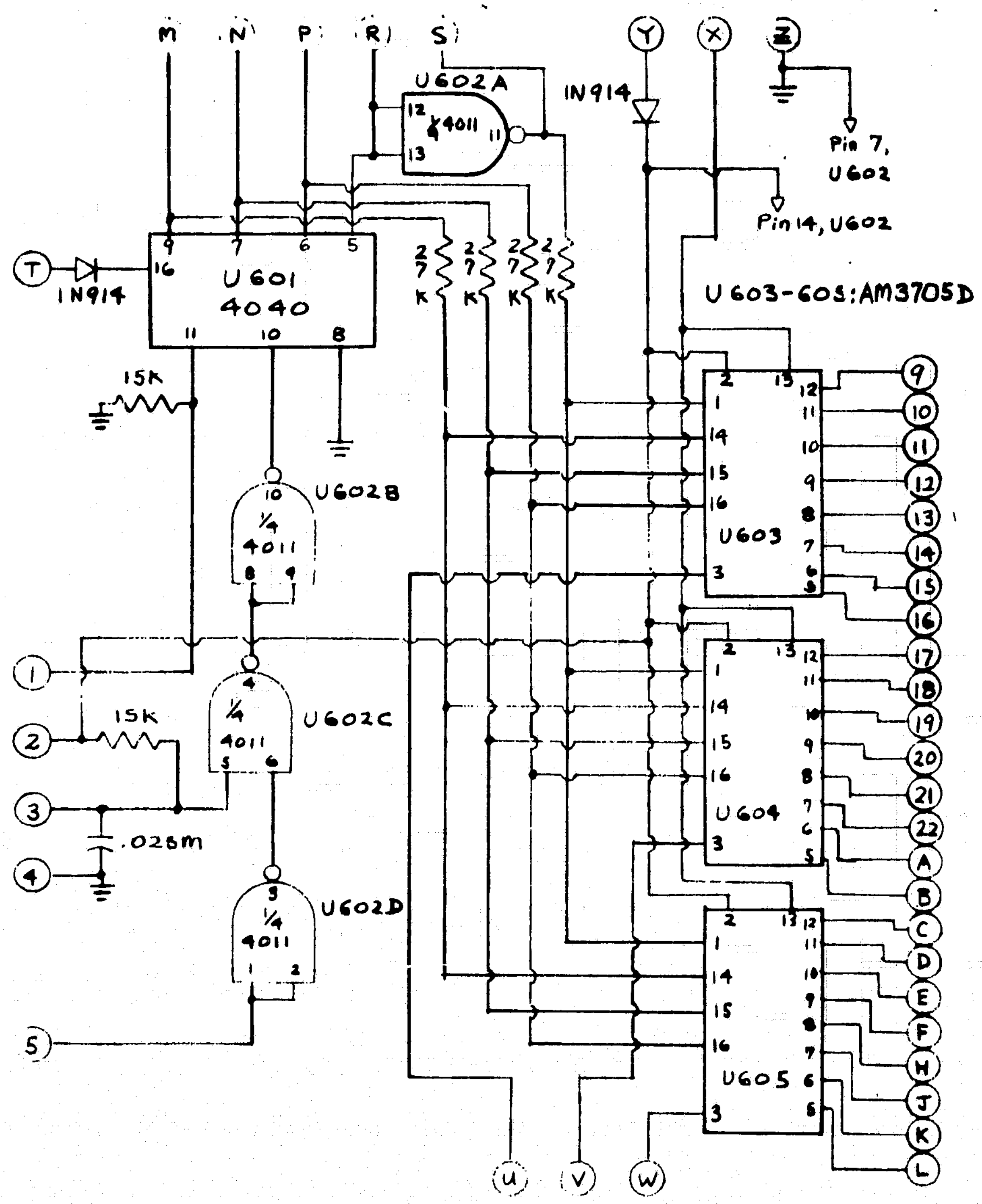

Figure B-2 Input multiplexer, group I (MX I).

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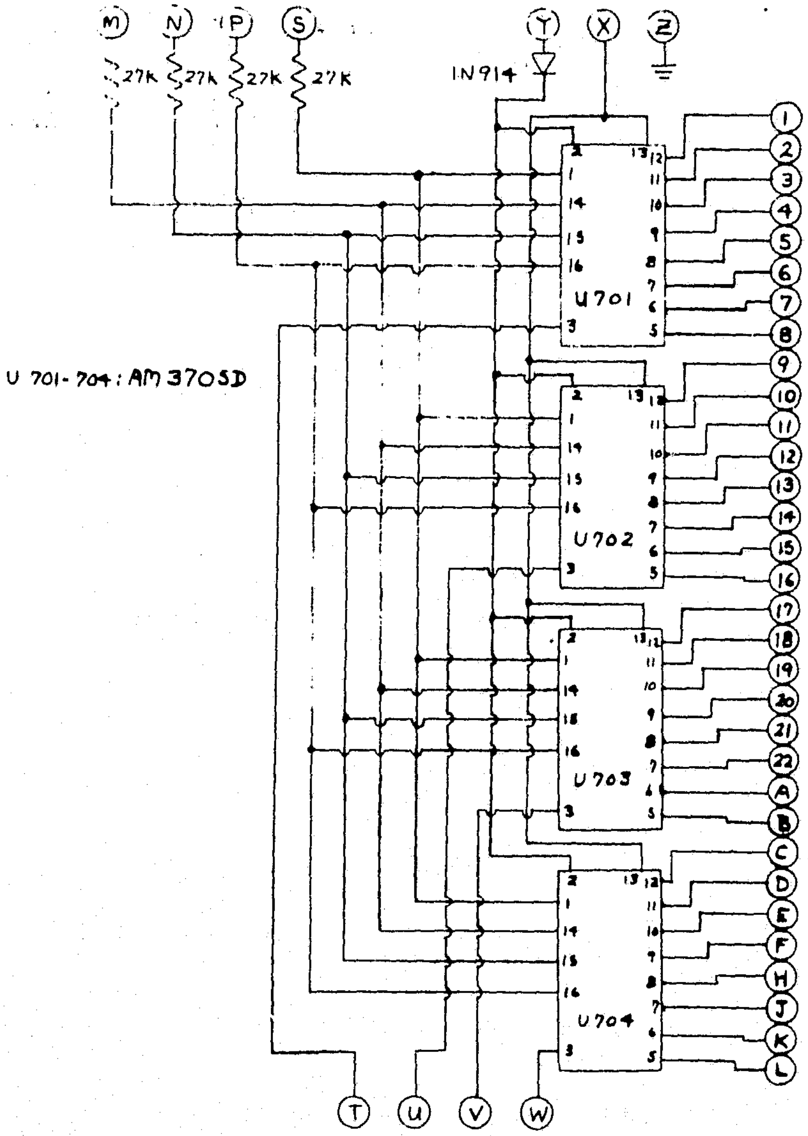

Figure B-3 Input multiplexer, group II (MX II).

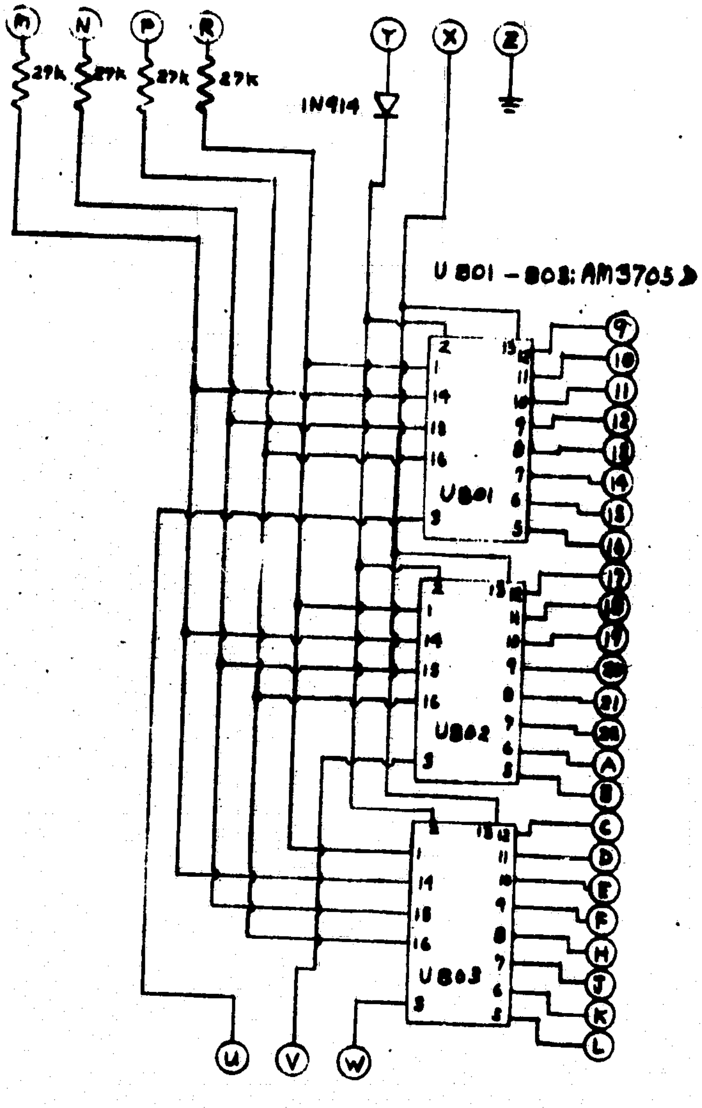

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Figure B-4 Input multiplexer, group III (MX III).

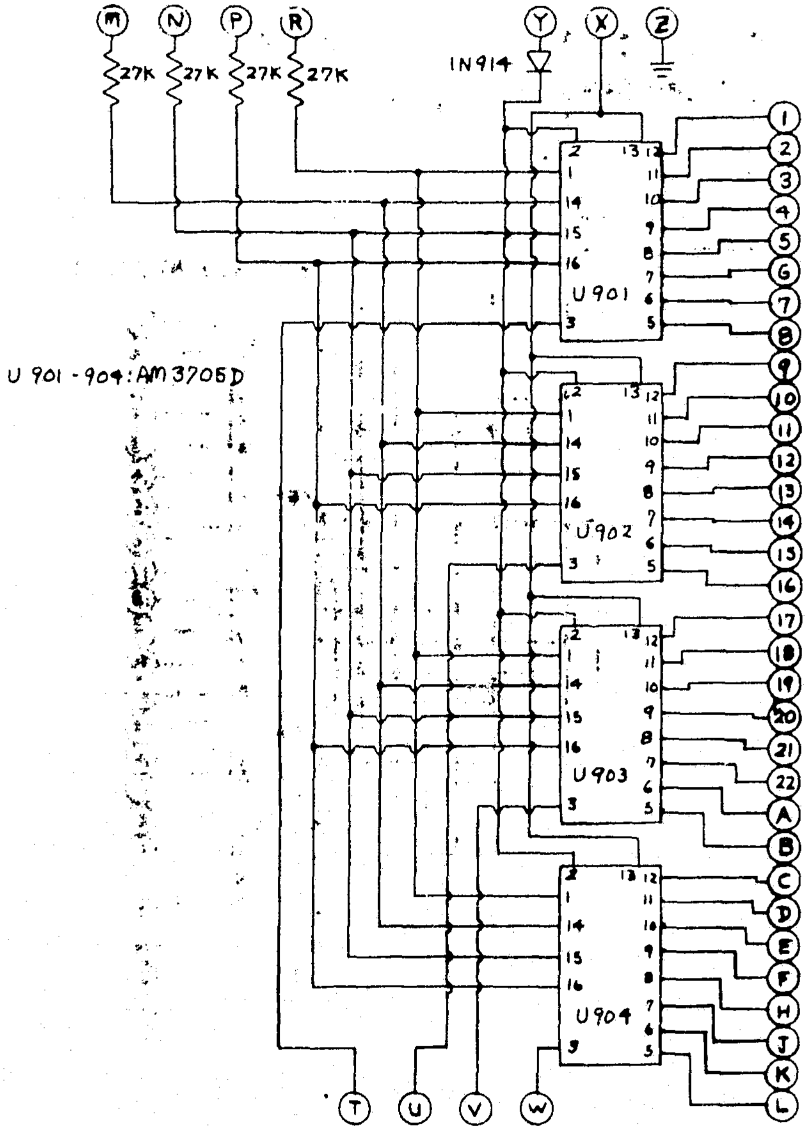

Figure B-5 Input multiplexer, group IV (MX IV).

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.

Each of the seven inputs of the selected bank occupies an 8-bit word of DCP data and 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 DCP data word.

The amplifier/channel multiplexer, consisting of one card (AMPL/CHANNEL MUX), scans the seven channels and amplifies their signals to a suitable level for digitizing (figure B-6). 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 (figure B-7).

The A/D CONV is a prepackaged unit mounted on a separate card (B-7). 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 reference junction compensator and system power supply modules (P.S./REF JCT COMP) are mounted on one card (figure B-8). The reference junction compensator generates a voltage which matches that produced by the reference junction itself over the temperature range of -50^{o} to $+40^{o}$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 (figure B-9). 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.

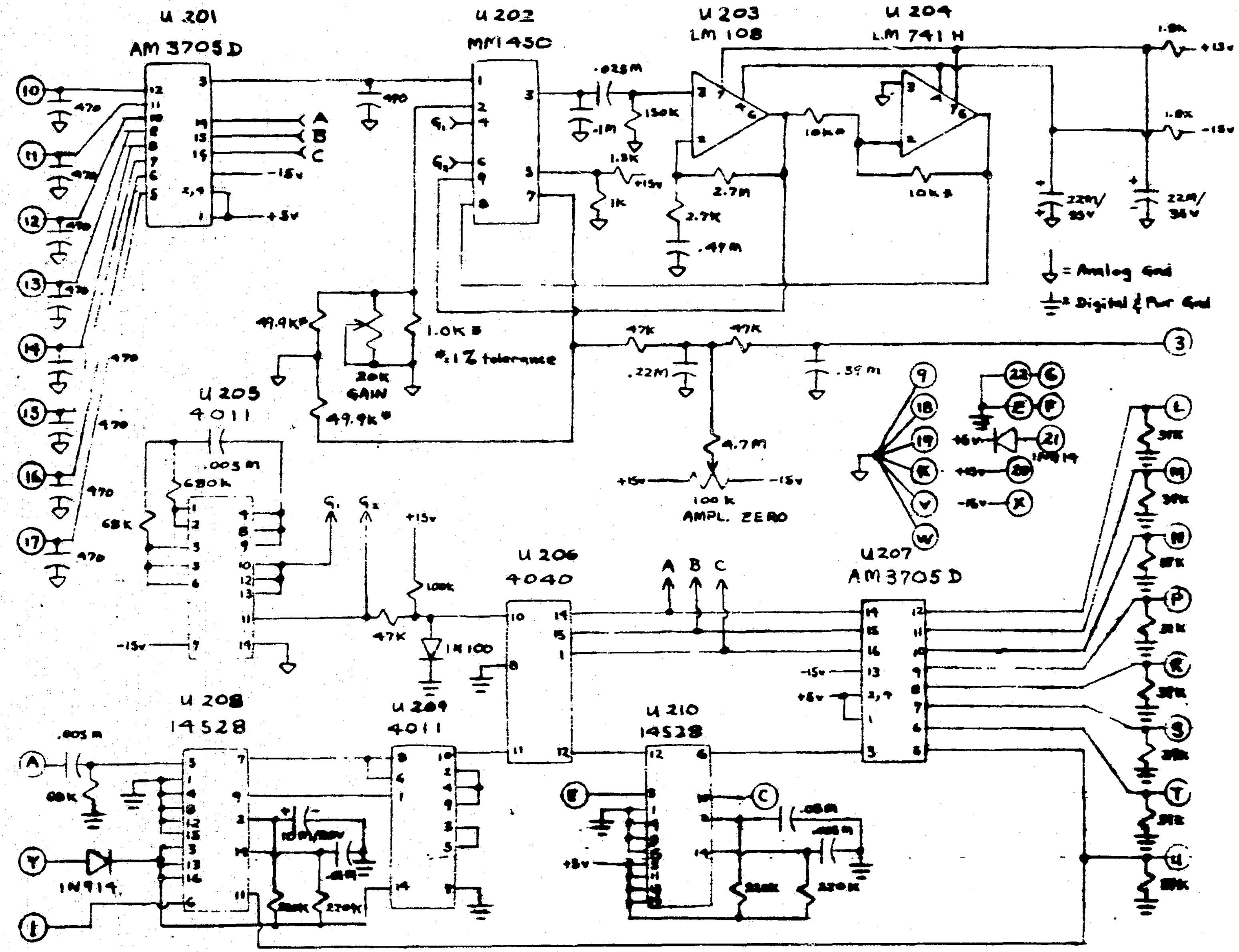

Figure B-6 Amplifier and channel multiplexer (AMPL/CHANNEL MUX).

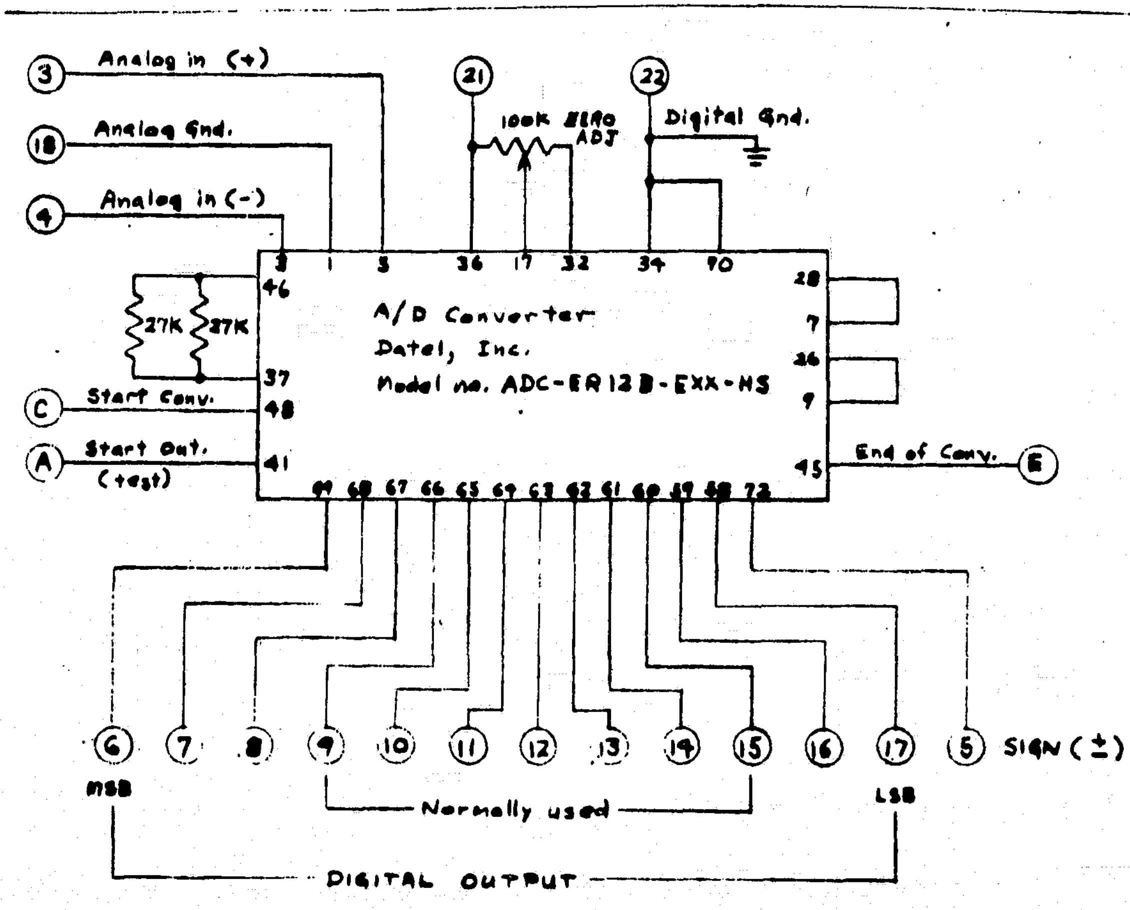

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Figure B-7 Analog-to-digital converter (A/D CONV).

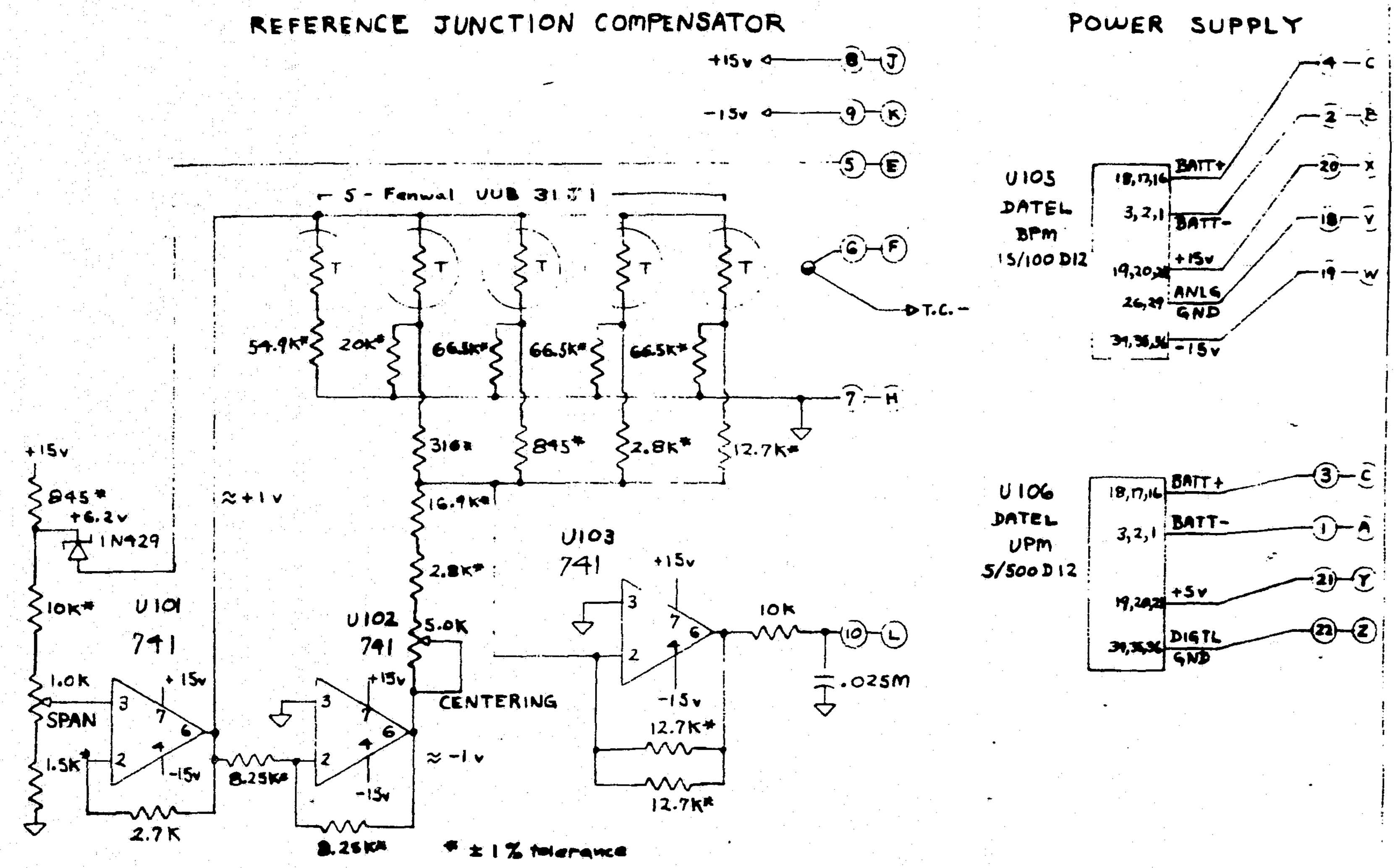

Figure B-8 | Power supply and reference junction compensator (P.S./REF JCT COMP).

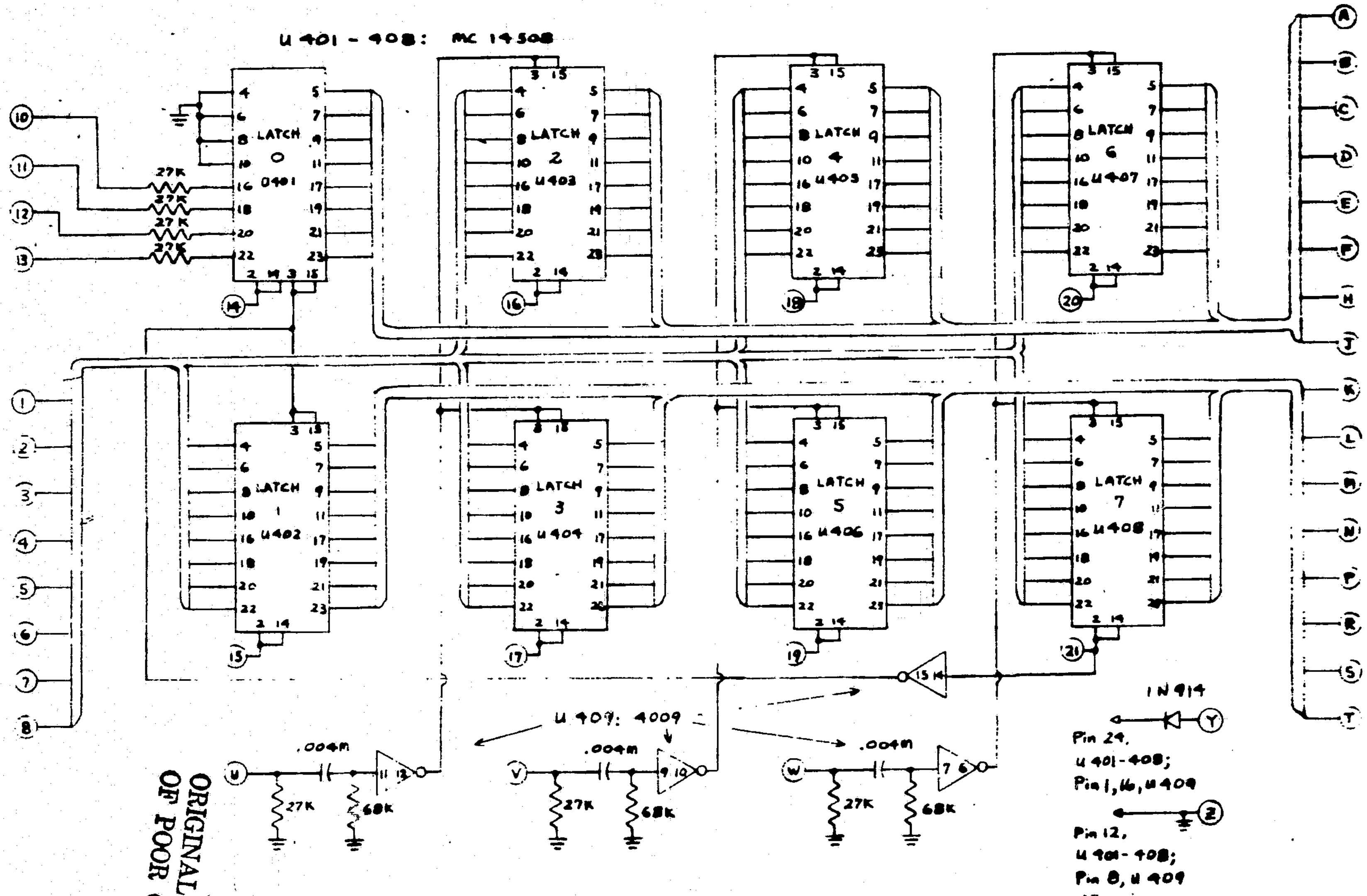

Figure B-9 | Latch (LATCH).

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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 (ADR's) operated by the U.S. Geological Survey. These are labeled "Punch Motor No. 1", "Punch Motor No. 2", etc., in all instructions and diagrams. 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 consists 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 (figure B-10). The transistors invert the polarity of the data signals and also simulate the grounding-type signal that would come from an ADR.

The primary power supply is 12 volts 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 12V supply powers a ±15V and a +5V supply which are electrically isolated from each another to avoid current loops. The bank select counter and certain parts of the control portion of the amplifier/channel multiplexer require +5V 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 12V input to the ±15V and +5V power supplies, and initializing a "Punch Motor No. 1" trigger pulse to the control portion of the amplifier/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.

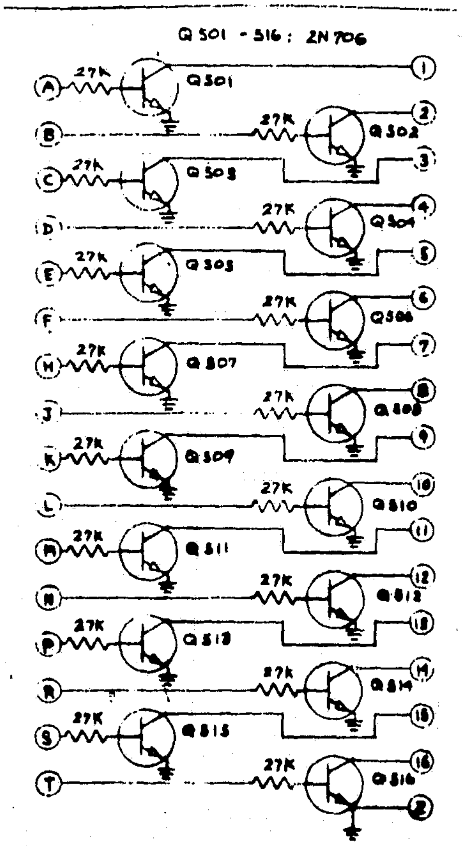

Figure B-10 Interface (INTERFACE).

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2. The channel multiplexer scans the seven channels of the bank selected. It remains on each channel for about 0.5 seconds, 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 is 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 9 is 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.

4. Upon completion of the update sequence, which requires about 90 seconds, the C/DCP removes the 12-volt power from the unit. The C/DCP continues to supply 5-volt power to the bank select counter and certain other circuits that must remain energized.