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Final III

FINAL REPORT

Use of the LANDSAT-2 Data Collection System in the Colorado River Basin Weather Modification Program

(Follow-on Investigation)

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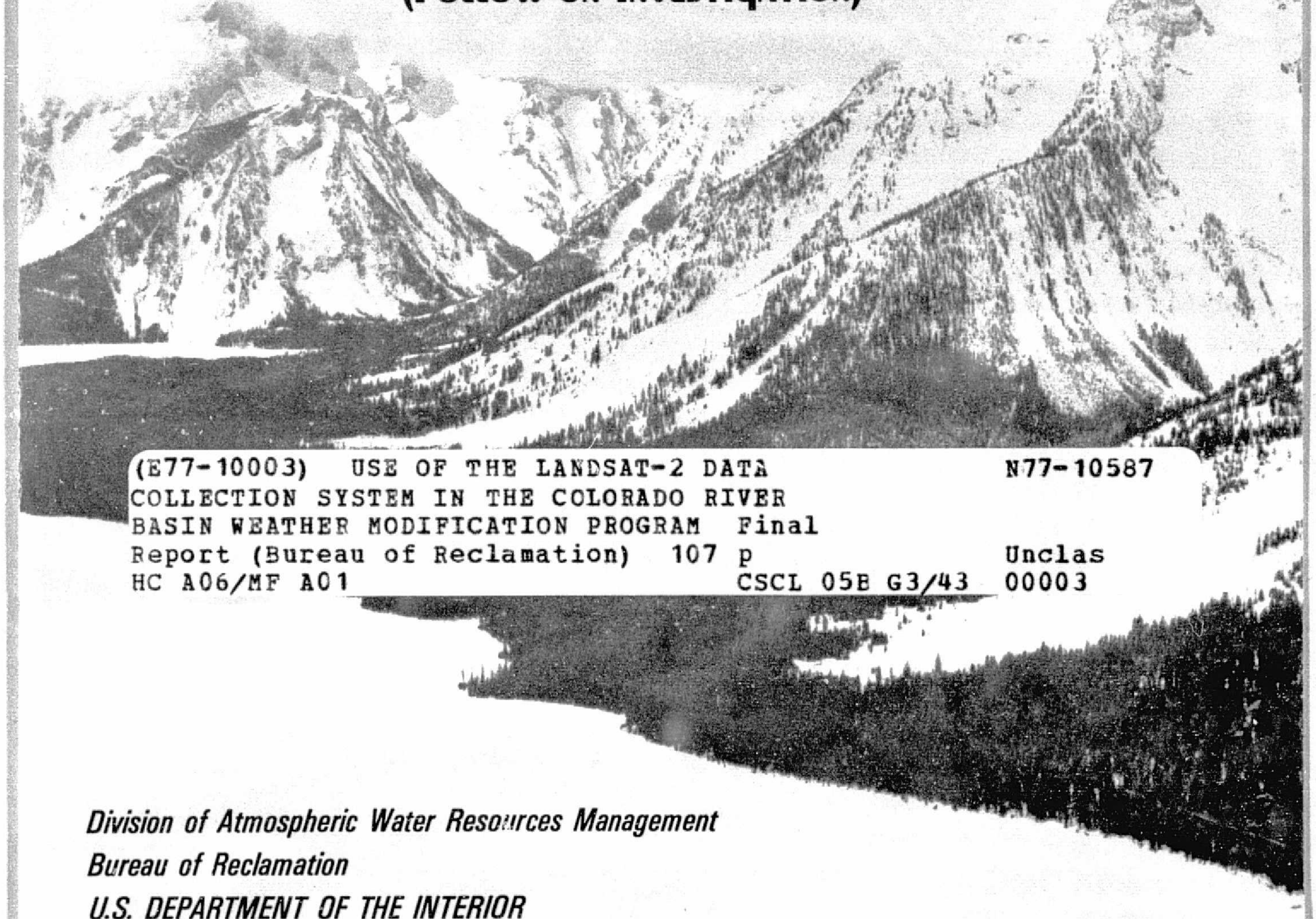

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16. ABSTRACT This report documents the results of a 12-month LANDSAT follow-on investigation which ended December 30, 1975. During this follow-on investigation, the LANDSAT DCS (data collection system) was used to relay data from remote, unattended field sites in the severe winter environment of the San Juan Mountains of southwest Colorado. The objectives for this follow-on investigation emphasized the operational use of the LANDSAT DCS in the Bureau of Reclamation's Colorado River Basin weather modification program, and the continued evaluation of the LANDSAT DCS from a user's viewpoint. An electronic wind data averaging system was developed to improve the LANDSAT system's usefulness by providing a history of averaged wind speed and wind direction data. Field testing of the wind averaging system demonstrated the feasibility of transmitting averaged wind data, stored over a period of several hours, from a remote site. This investigation has shown that the LANDSAT DCP's (data collection platforms) are reliable, weather resistant, and cost-effective units. Data from the LANDSAT DCS were available in near real time to aid in the daily operational decision, to quality check system performance, and to schedule special maintenance trips into remote areas. Further research should place continued emphasis on the development and application of the LANDSAT DCS for operational use.

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USE OF THE LANDSAT-2 DATA COLLECTION SYSTEM IN THE COLORADO RIVER BASIN WEATHER MODIFICATION PROGRAM

Final Report - February 1976

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Prepared for:

Goddard Space Flight Center
Greenbelt, Maryland 20771
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ABBREVIATIONS

A/D - analog to digital

CMOS - Complementary metal oxide semiconductor

CRBPP - Colorado River Basin Pilot Project

DAWRM - Division of Atmospheric Water Resources Management

DCP - data collection platform

DCS - data collection system

ERTS - Earth Resources Technology Satellite

G.m.t. - Greenwich mean time

GOES - Geostationary Operational Environmental Satellite

LANDSAT - new name for ERTS

m.s.t. - mountain standard time

NASA - National Aeronautics and Space Administration

NMC - National Meteorological Center

NWS - National Weather Service

PRR - pulse repetition rate

RAIN - Remote Auto-Initiated Network

SCS - USDA Soil Conservation Service

USDA - United States Department of Agriculture

USGS - United States Geological Survey

vhf - very high frequency

WSSI - Western Scientific Services, Inc.

CONVERSION FACTORS

The present Bureau of Reclamation policy is to use metric units to the maximum extent possible. However, this LANDSAT investigation was conducted simultaneously with the Bureau's Colorado River Basin Pilot Project which began in 1969 when English units were in common usage. Consequently, all data processing work was accomplished using English units and data examples in the text of this report have <u>not</u> been converted to the metric system. Conversion factors are listed below for use by the reader if desired.

1 statute mile (mi) = 1.6093 kilometres (km)

1 foot (ft) = 0.3048 metre (m)

1 inch (in) = 2.54 centimetres (cm)

1 mile per hour (mi/h) = 0.4470 metre per second (m/s)

Celsius (°C) = 5/9 x [Fahrenheit (°F) -32]

Fahrenheit (°F) = [9 x Celsius (°C)] ÷ 5 + 32

EXECUTIVE SUMMARY

This Type III Final Report by the DAWRM (Division of Atmospheric Water Resources Management), Bureau of Reclamation, is submitted to NASA/Goddard Space Flight Center to document the results of a 12-month LANDSAT follow-on investigation. The original 22-month investigation, which ended June 30, 1974, showed that the LANDSAT DCS (data collection system) was capable of producing high quality data. The final report on this work, "Use of the ERTS-1 Satellite Data Collection System in Monitoring Weather Conditions for Control of Cloud Seeding Operations," by Dr. Archie M. Kahan (Division of Atmospheric Water Resources Management - Bureau of Reclamation, July, 1974), contained recommendations directed toward upgrading the LANDSAT system from a semioperational test system to an operational mode.

During this follow-on investigation, the LANDSAT DCS was used to relay data from remote, unattended field sites in the severe winter environment of the San Juan Mountains of southwest Colorado. This rugged mountain range was also the study area for DAWRM's CRBPP (Colorado River Basin Pilot Project), a major winter orographic weather modification research program designed to determine the feasibility of enhancing runoff into the water-short Colorado River Basin.

The objectives for this follow-on investigation emphasized the operational use of the LANDSAT DCS in the CRBPP weather modification program, and the continued evaluation of the LANDSAT DCS from a user's viewpoint. Specifically, the objectives were divided into the following four areas:

(1) Utilize LANDSAT DCP's (data collection platforms) interfaced with existing hydrometeorological instruments to provide reliable and accurate data collection from remote mountain locations.

(2) Provide processing and applications procedures for typical data user agencies and groups, and develop operational calibration and maintenance procedures for the DCP/sensor units.

(3) Prepare cost-effectiveness comparisons between the LANDSAT DCS and alternate systems.

(4) Develop and apply new technology which will expand the LANDSAT system's data collection capabilities.

These tasks were performed from December 30, 1974 through December 30, 1975. Actual operational use of the LANDSAT DCS on the CRBPP was terminated on May 15, 1975 at the conclusion of CRBPP field operations. During the January-May 1975 period, data from the LANDSAT DCS were available in near real time to aid in the daily operational decision, to quality-check system performance, and to schedule special maintenance trips into remote areas.

Due to its polar orbit, the LANDSAT satellite is only in the correct position to relay data twice each day. This restriction allowed for instantaneous wind values at approximately 12-hour intervals for use in operational forecasting. The LANDSAT system's usefulness would therefore be improved if the DCP's with wind sensors could provide a history of averaged wind speed and wind direction data. Consequently, the two DCP's which had wind direction and wind speed sensors in previous years were not installed in the field until the necessary electronics which would generate and store hourly averaged values had been designed, fabricated, and tested by WSSI (Western Scientific Services, Inc.).

Field tests on the wind averaging system were initiated on May 12, 1975. Initial problems with the interface between the wind sensors and the LANDSAT DCP were identified and corrected during late June. Following these modifications, the wind averaging system operated in the design mode until the field tests were terminated in August. Subsequent work included the modification of the signal conditioner boards on the two wind averaging systems to allow the operation of analog channels for transmitting precipitation accumulation, temperature, and relative humidity data in addition to averaged wind data.

Based on experience gained during the project, the following statements can be made regarding the LANDSAT DCS:

(1) Many types of environmental sensors can be interfaced to the LANDSAT DCP.

(2) The LANDSAT field installations, as deployed in this investigation, proved to be remarkably reliable, weather resistant, and cost-effective units able to relay high quality data in near real time.

(3) The LANDSAT system is useful tool in providing data for activities such as weather forecasting and scheduling field operations.

(4) Testing of the wind averaging system demonstrated the feasibility of transmitting averaged wind data, stored over a period of several hours, from a remote site.

Further research should place continued emphasis on the application of the LANDSAT DCS for operational use. The technology has already been developed for providing a history of averaged wind data from remote sites for use in the preparation of operational forecasts. Other meteorological data received through the LANDSAT system have proved to be of high quality. Projects where the receipt of data at 12-hour intervals would be satisfactory should seriously consider the operational use of the LANDSAT DCS.

New technology acquired through satellite system development work would allow several remote sites to collect one or more meteorological parameters, and then transmit data collected to a single LANDSAT DCP on a "self-times" basis. This concept conserves the use of the DCP's, which normally have a higher data channel capacity than would be required, and makes it cost effective to collect data from a large number of sites utilizing a modified LANDSAT DCS. The development of such a modified LANDSAT system should be pursued with the system operationally tested on a large surface instrument network.

Information on the development and operational plans for the LANDSAT-GOES (Geostationary Operational Environment Satellite) compatible DCP's should be provided to present and potential users of the LANDSAT DCS so that they can develop long-range plans for data collection requirements.

The information contained in this report regarding commercial products or firms may not be used for advertising or promotional purposes and is not to be construed as an endorsement of any product or firm by the Bureau of Reclamation.

I. INTRODUCTION

The Bureau of Reclamation, through its contractors, conducted a winter orgraphic cloud seeding operational test known as the CRBPP (Colorado River Basin Pilot Project) in the San Juan Mountains of southwestern Colorado during the years 1969-1975. The major objective of the CRBPP was to demostrate the feasibility of increasing the amount of snowfall and, therefore, the amount of available runoff to consumers living in the Colorado River Basin. To conduct this type of project, meteorological and hydrometeorological parameters must be monitored, not only in an attempt to determine the effects of seeding the clouds, but also to assist in determining whether storm parameters are within the necessary specifications for effective cloud seeding. For both reasons, it was necessary to maintain a network of instruments which measure parameters such as precipitation, wind speed, wind direction, temperature, relative humidity, stream stage, and water temperature.

Various data collection systems were employed in conjunction with the CRBPP. The primary system relied upon for recording hydrometeorological parameters consisted of manually operated recording precipitation gages which continuously monitor and store the data at each site in the network. To retrieve these data, service trips to field sites were required one to four times per month depending on site accessibility and weather conditions. The extended delay before data could be accessed meant that this system was not useful for determining whether the meteorological conditions were appropriate for effective cloud seeding on any given day. Thus, another type of system with at least near-real-time data retrieval was necessary. For this application two different data collection systems, the LANDSAT[1] system and a ground telemetry system, were used.

The LANDSAT system consists of ground-based meteorological and hydrometeorological sensors interfaced with DCP's. These platforms sample the sensor outputs every 180 seconds and broadcast via onsite transmitters to a satellite. The signal is then amplified and retransmitted to a ground receiving station. The polar orbit of the satellite generally allows for two relay periods each day. Thus, for each of these periods, data from remote locations can be accessed in near real time; i.e., data are available to users approximately 3 hours after transmission.

The ground telemetry system, like the LANDSAT system, is a remote data collection system. The meteorological and hydrometeorological sensors are interfaced with DCP's which transmit data via radio links through

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[1] As of January 13, 1975, the name Earth Resources Technology Satellite, or ERTS, was officially changed to LANDSAT. Therefore, all references to the system in this report will use the term LANDSAT. As part of this on-going data retrieval program, on January 22, 1975, LANDSAT-2 was launched and became the primary satellite for real-time coverage on or about April 1975.

various ground-based repeating stations to the master station. Hence, data are accessible in real time.

For the first 2 years in which the LANDSAT system was employed, the general objectives were to test the feasibility of the LANDSAT DCS and to help define the eventual justification and role of this system in water resources management, specifically in weather modification programs. The 2-year investigation, covering the 22-month period ending June 30, 1974, has shown the LANDSAT system is capable of producing high quality data in near real time. Recommendations from the final report [1][2] of the 22-month project were directed toward using the LANDSAT system operationally rather than as a semioperational test system.

II. OBJECTIVES

Formal authorization to conduct a 12-month LANDSAT follow-on investigation was received from NASA/Goddard Space Flight Center on December 30, 1974. The objectives for this follow-on investigation emphasized the operational use of the LANDSAT DCS in the CRBPP weather modification program, and the continued evaluation of the LANDSAT DCS from a user's

[2] Numbers in brackets are references in the bibliography at the end of this report.

viewpoint. Specifically, the objectives were divided into the following four areas:

(1) Utilize LANDSAT DCP interfaced with existing hydrometeorological instruments to provide reliable and accurate data collection from remote mountain locations.

(2) Provide processing and applications procedures for typical data user agencies and groups, and develop operational calibration and maintenance procedures for the DCP/sensor units.

(3) Perform cost and effectiveness comparisons between the LANDSAT DCS and alternate systems.

(4) Develop and apply new technology which will expand the LANDSAT system's data collection capabilities.

This report documents the results of this LANDSAT follow-on investigation. Tasks performed in realizing the above objectives are described and the degree to which these objectives were achieved is discussed.

III. DESCRIPTION OF FIELD OPERATIONS

During the 1973-74 winter season, a total of seven LANDSAT DCP's were maintained by WSSI within the San Juan project area of the CRBPP at Lime Mesa, Wolf Creek Pass, Wolf Creek North, Castle Creek, Palisade Lakes, Runlett Park, and Muleshoe (see fig. 1). The Palisade Lakes and

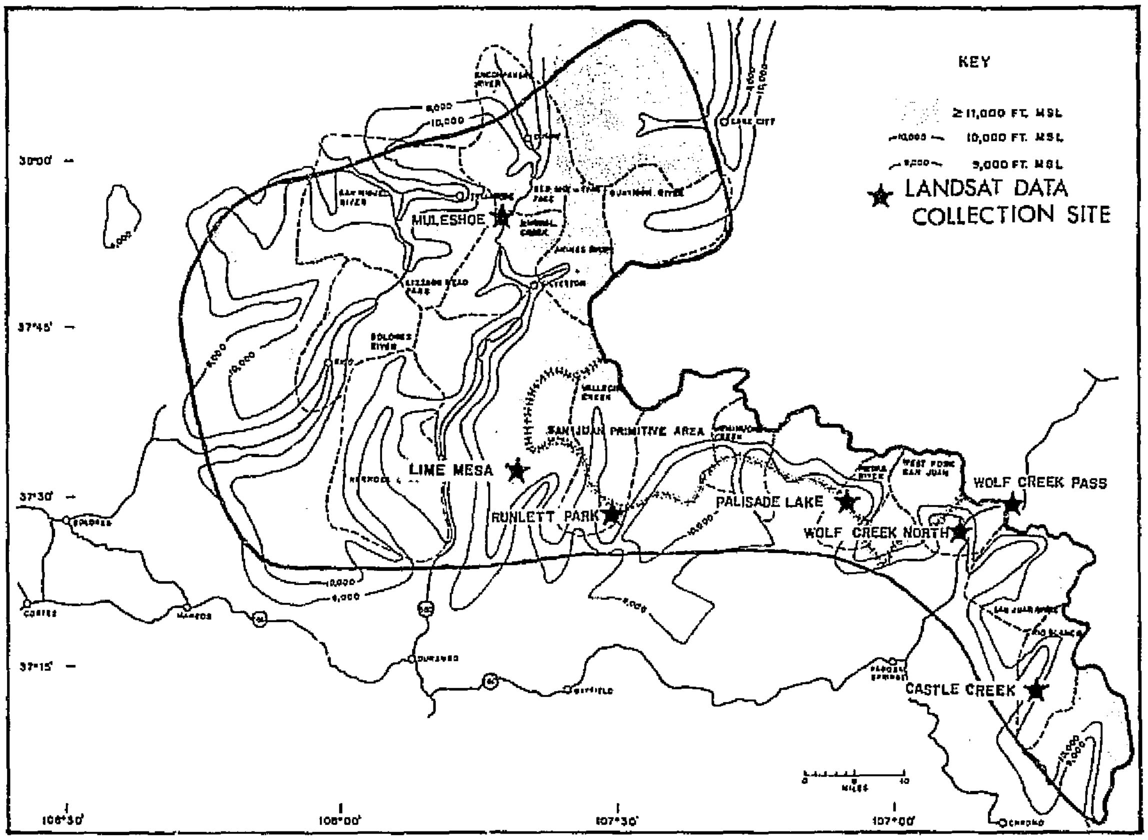

Figure 1. - Location of LANDSAT field sites, 1973-74.

Runlett Park sites contained both LANDSAT and ground telemetry DCP's to facilitate data quality tests of the LANDSAT system. In accordance with the objective of advancing the system to an operational phase for the 1974-75 winter season, the LANDSAT DCP's were removed from these two sites to eliminate duplication of observations. This made it possible to obtain near-real-time data for operational purposes from as many locations as possible. Figure 2 shows the locations of the seven LANDSAT DCP's as planned for the 1974-75 CRBPP operational season.

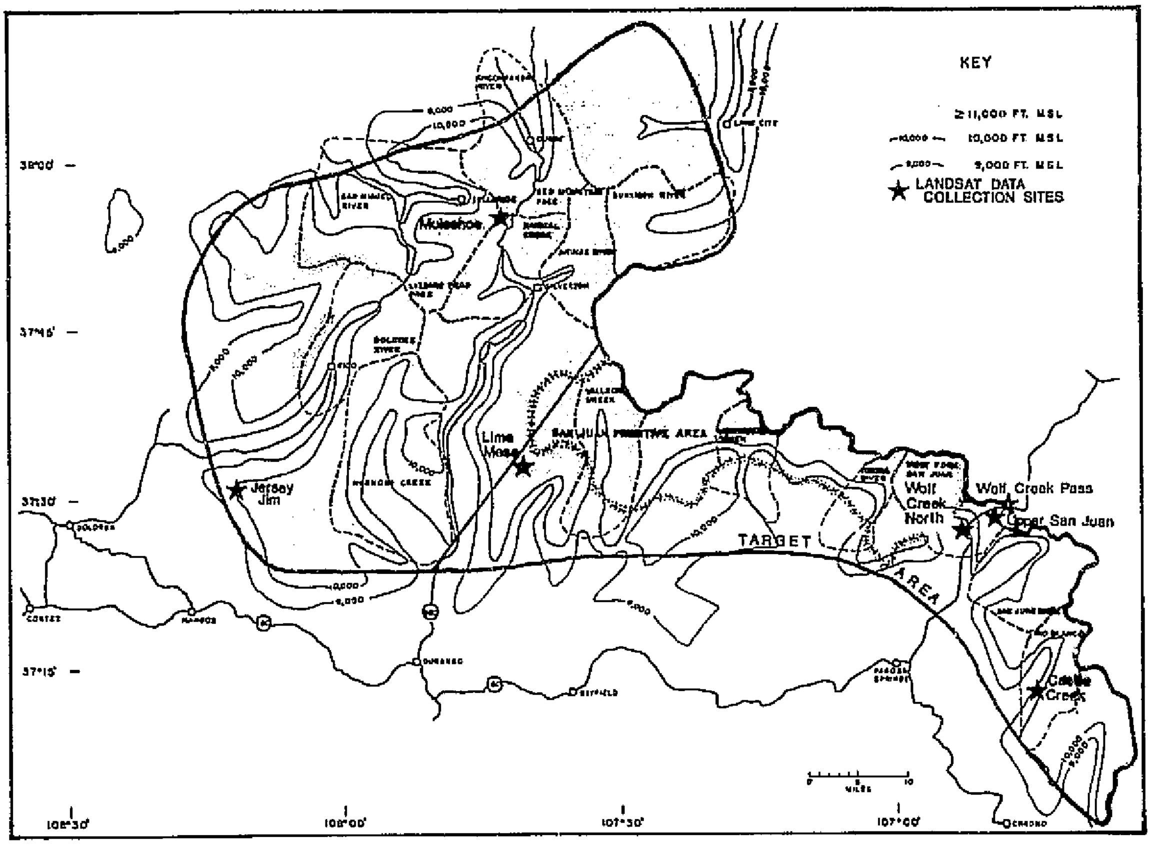

Figure 2. - Selected locations of LANDSAT field sites, 1974-75.

The Palisade Lakes DCP was relocated near an established Soil Conservation Service snow course (Upper San Juan) approximately 2 miles west of the Wolf Creek Pass summit. This location was chosen in order to provide near-real-time information from the heart of the CRBPP target area. The Runlett Park LANDSAT DCP was eventually installed near the Jersey

Jim lookout tower. This location, 25 miles due west of the CRBPP target area at an elevation of 10,000 feet, was chosen because it offered good exposure to approaching storms.

A list describing the parameters to be monitored at each site is given in table 1. Detailed descriptions of the LANDSAT DCP locations and operational periods are given in table 2. Five of the seven LANDSAT DCP's were installed and calibrated (sensor descriptions and calibration procedures are discussed in appendix A) prior to the beginning of

Table 1. - *LANDSAT follow-on program changes in station configuration.*

1973-74 Winter		1974-75 Winter	
Site (Elevation)	Parameters	Site (Elevation)	Parameters
Lime Mesa (11,700')	Air Temperature Precipitation Battery voltage	Lime Mesa (11,700')	Air Temperature Precipitation Battery Voltage
*Palisade Lakes (9,500')	Air Temperature Precipitation Snow Pillow Battery Voltage	Upper San Juan (10,200')	Air Temperature Precipitation Snow Pillow Battery Voltage
Wolf Creek Pass (10,810')	Air Temperature Precipitation Battery Voltage	Wolf Creek Pass (10,810')	Air Temperature Precipitation Battery Voltage
Wolf Creek North (7,800')	Streamflow Water Temperature Battery Voltage	Wolf Creek North (7,800')	Streamflow Water Temperature Battery Voltage
Castle Creek (9,100')	Air Temperature Precipitation Battery Voltage	Castle Creek (9,100')	Air Temperature Precipitation Battery Voltage
*Runlett Park (10,760')	Air Temperature Wind Speed Wind Direction Relative Humidity Battery Voltage	Jersey Jim (10,000')	Air Temperature Ave. Wind Speed Ave. Wind Direction Relative Humidity Battery Voltage
Muleshoe (12,800')	Air Temperature Wind Speed Wind Direction Solar Radiation Relative Humidity Rime Ice	Muleshoe (12,800')	Air Temperature Ave. Wind Speed Ave. Wind Direction Solar Radiation Relative Humidity Omit

*LANDSAT DCP relocated after 1973-74 winter season.

the follow-on program on December 30, 1974. These five DCP's were routinely serviced and maintained by WSSI through May 15, 1975.

Table 2. - *LANDSAT data collection platform locations - 1973 through 1975.*

Site Name	Computer ID	DCP ID	Lat. N.	Long. W.	Elev. (ft.)	County	Operational Period 1973-74	Operational Period 1974-75
Lime Mesa	LIMESA	6347	37°34	107°41	11,700	La Plata	9/27/73-5/16/74	10/26/74-5/16/75
Palisade Lakes	PALADE	6025	37°30	107°09	9,500	Hinsdale	9/25/73-6/5/74	Not In
Wolf Creek Pass	WLFCRP	6241	37°29	106°48	10,810	Mineral	3/23/73-6/30/74	10/25/74-5/16/75
Wolf Creek North	WLFCRN	6040	37°27	106°53	7,800	Mineral	4/27/73-6/30/74	10/25/74-5/16/75
Castle Creek	CASTLE	6143	37°12	106°45	9,100	Archuleta	12/10/73-5/24/74	10/24/74-5/16/75
Runlett Park	RUNPRK	6202	37°29	107°30	10,760	La Plata	11/7/73-6/6/74	Not In
Muleshoe	MULSUE	6212	37°52	107°45	12,800	San Juan	11/6/73-5/23/74	Not In
Upper San Juan	UPRSAJ	6025	37°29	106°50	10,200	Mineral	Not In	10/25/74-5/16/75
Jersey Jim	JERJIM	6202	37°30	108°11	10,000	Montezuma	Not In	5/12/75-8/10/75

All service trips to the LANDSAT DCP's under winter conditions required use of oversnow vehicles, except for extreme situations such as Lime Mesa which was accessible only by helicopter. Appropriate emergency supplies were always considered mandatory for every trip into the harsh winter environment of the San Juan Mountains. Routine service trips were required roughly once per month to empty the buckets in the precipitation gages and to visually inspect the DCP's. If data received from a DCP indicated potential problems at that site, an additional service trip was scheduled. The most frequent cause for scheduling an additional trip was due to periods of unusually heavy precipitation.

An important criterion for determining whether a day is appropriate for seeding is the direction and intensity of the surface winds; that is, the winds are required to be upslope so that when artificial ice nuclei are generated at ground level, the nuclei will be carried up to cloud level. During the 1973-74 CRBPP operational season, the two DCP's with wind sensors measured instantaneous values which could be accessed only when the satellite was in the correct orbital position. Instantaneous wind values at approximately 12-hour intervals are of little use in a weather modification program. The LANDSAT system's operational usefulness would therefore be improved if the DCP's could provide a history of averaged wind speed and direction. Consequently, the two DCP's which had wind direction and wind speed sensors in previous years were not installed in the field until the necessary electronics which would generate and store hourly averaged values had been designed, fabricated, and tested by WSSI. These DCP's were to be installed at the Jersey Jim and Muleshoe sites for the 1974-75 winter season. Due to delays in the design and construction of the wind averaging system, the Muleshoe DCP was never reinstalled in the field. The Jersey Jim DCP was first installed at its field location for system tests on May 12, 1975.

IV. DATA PROCESSING AND APPLICATIONS

The actual data path for the LANDSAT DCS is displayed in figure 3. The path starts with the remote sensors which monitor the environmental parameters such as precipitation. The signal conditioner converts the sensor output to a voltage level compatible with the DCP electronics.

The DCP converts this analog signal to an eight-bit digital data word. This data word and the data words corresponding to the other sensor outputs are assembled into a message which is transmitted to the satellite. The satellite amplifies and retransmits this message to one of several ground receiving sites.

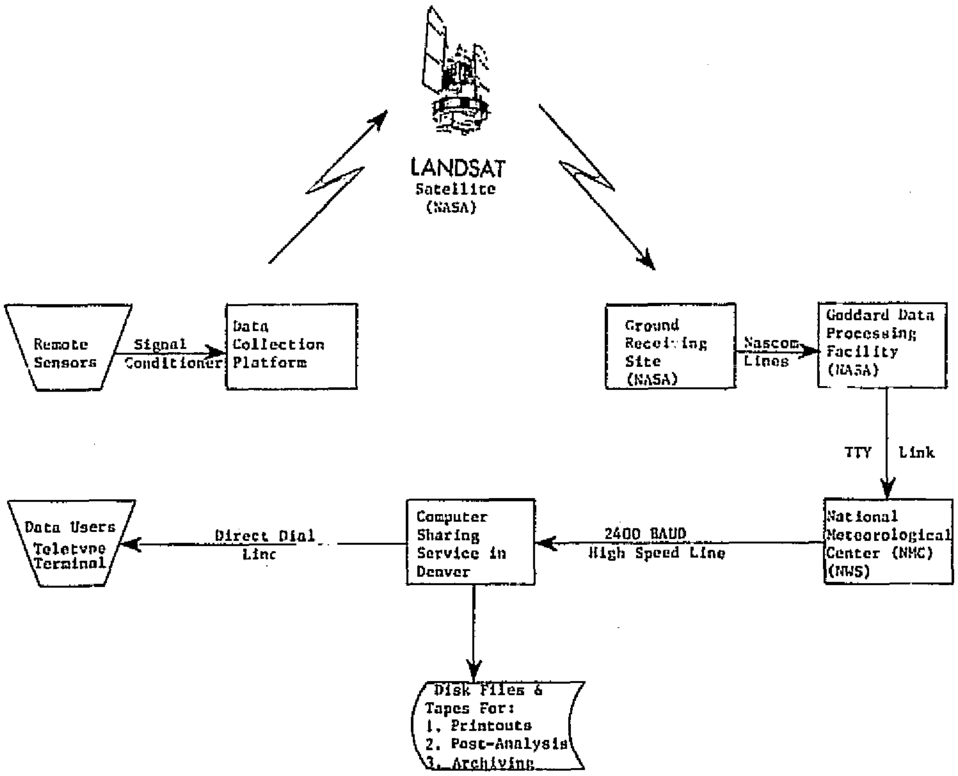

Figure 3. - Schematic of LANDSAT data flow from sensors to users.

Further details are discussed in the Type III report [1] covering the 22-month period ending June 30, 1974. To use already existing facilities, the data are then relayed to the computer at the National

Meteorological Center in Suitland, Md. Figure 4 depicts the Bureau of Reclamation computer network through which data from the LANDSAT DCP's are accessed. This network provides high-speed data transmission to the Denver computer where computer programs developed in the winter of 1972-73 convert the data from binary code to an egineering unit listing. To obtain these data, users must be able to access the Bureau of Reclamation computer, e.g., through a time-sharing terminal. A typical data

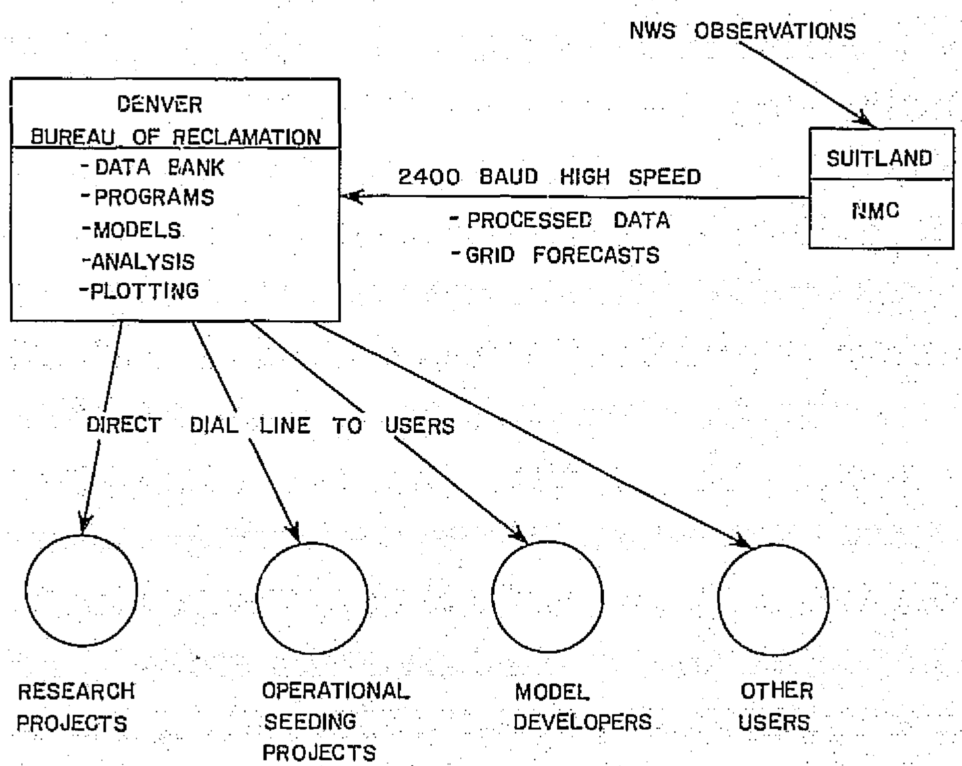

Figure 4. - Schematic of Bureau of Reclamation environmental computer network.

printout is given in table 3. Appendix B contains a listing of the computer programs. New programs were developed during 1975 to handle the revised data format from the wind averaging sites.

Table 3. - *Sample of computer printout containing Lime Mesa LANDSAT data for the period December 29 - 30, 1974.*

LIME MESA LAT 37.34'N LONG 107.41'W ELV 11700FT

DATE GMT	TIME GMT	C	TEMP C	TVO BIT	TVO BIT	TVO BIT	PCP IN	TVO BIT	HSV V	BAV V	JUL DAY	TIME RCVD
DEC 29	16.39	7	-11.9	1.0	1.00	1.0	2.31	1.0	2.5	1.8	363	11.50
DEC 29	16.39	7	-11.9	1.0	1.00	1.0	2.81	1.0	2.5	1.8	363	11.50
DEC 29	16.43	7	-12.2	1.0	1.00	1.0	2.31	1.0	2.5	1.8	363	11.50
DEC 29	16.43	7	-12.2	1.0	1.00	1.0	2.31	1.0	2.5	1.8	363	11.50
DEC 29	16.47	7	-12.2	1.0	1.00	1.0	2.81	1.0	2.5	1.8	363	11.50
DEC 29	18.22	7	-13.5	1.0	1.00	1.0	2.35	1.0	2.5	1.8	363	12.50
DEC 29	18.26	7	-12.9	1.0	1.00	1.0	2.35	1.0	2.5	1.9	363	12.50
DEC 29	18.29	7	-12.9	1.0	1.00	1.0	2.95	1.0	2.5	1.8	363	12.50
DEC 30	4.10	7	-17.6	1.0	1.00	1.0	2.89	1.0	2.5	1.8	363	23.17
DEC 30	4.14	7	-17.9	1.0	1.00	1.0	2.89	1.0	2.5	1.8	363	23.17
DEC 30	4.17	7	-17.6	1.0	1.00	1.0	2.99	1.0	2.5	1.9	363	23.17
DEC 30	4.21	7	-17.5	1.0	1.00	1.0	2.89	1.0	2.5	1.8	363	23.17
DEC 30	15. 6	7	-17.0	2.0	2.00	2.0	2.93	2.0	2.5	1.8	364	10.20
DEC 30	16.45	7	-9.7	0.0	0.00	0.0	2.89	0.0	2.5	1.8	364	12.15
DEC 30	16.43	7	-7.2	0.0	0.00	0.0	2.99	0.0	2.5	1.8	364	12.15
DEC 30	16.52	7	-7.5	0.0	0.00	0.0	2.99	0.0	2.5	1.8	364	12.16
DEC 30	16.55	7	-8.4	0.0	0.00	0.0	2.89	0.0	2.5	1.3	364	12.16
DEC 30	19.29	7	-9.3	0.0	0.00	0.0	2.99	0.0	2.5	1.9	364	12.26
DEC 30	18.32	7	-8.4	0.0	0.00	0.0	2.99	0.0	2.5	1.9	364	12.26

The date and time of data transmission are given in Greenwich mean time (GMT). Parameters monitored include air temperature (TEMP) in degrees Celsius, PCP (precipitation accumulation) in inches of water equivalent, HSV (half-scale voltage), and BAV (battery voltage). The Julian date and local time that data were received at the Bureau of Reclamation computer are also listed.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

The output data from the LANDSAT system were available for use by EG&G, the seeding contractor on the CRBPP, to aid in the daily operational decision. For example, if recent snowfall accumulations were heavy, seeding operations might be suspended due to avalanche hazard. Seeding operations were officially suspended on April 11, 1975, an entire month earlier than the original schedule, due to an extremely heavy snowpack and the potential spring flood threat. The data were also used by WSSI to quality-check system performance and schedule special maintenance trips.

V. DATA

This section discusses the set of data collected via the LANDSAT system. Included are explanations for data gaps, all special problems encountered concerning data retrieval, and a quality comparison of the LANDSAT data with data from the manual DCS used in the CRBPP.

Since the DCP's in the LANDSAT system transmit information automatically, the data collected covers essentially the same period during which the platforms were in the field. As stated in Section III, only five LANDSAT DCP's were actually used during the CRBPP operational season. The LANDSAT data set consists of parameters monitored at these five sites, viz., Lime Mesa, Wolf Creek North, Wolf Creek Pass, Upper San Juan, and Castle Creek. The overall duration of the data set is from December 1974, until well past the end of the CRBPP seeding operations in May 1975. Although the DCP's were not removed from the field until August, the data quality deteriorated after May because maintenance was minimized in an effort to augment removal of other CRBPP DCS's from the field. Details of the data set will be discussed in the following paragraphs, which are a site-by-site summary of the performance of each LANDSAT DCP.

Lime Mesa transmitted quality data for the major portion of the operational season. The environmental parameters monitored at this site were air temperature and precipitation. A total of four helicopter service trips were required to maintain this site. The first trip was scheduled to eliminate intermittent periods of unusable 'ata. This

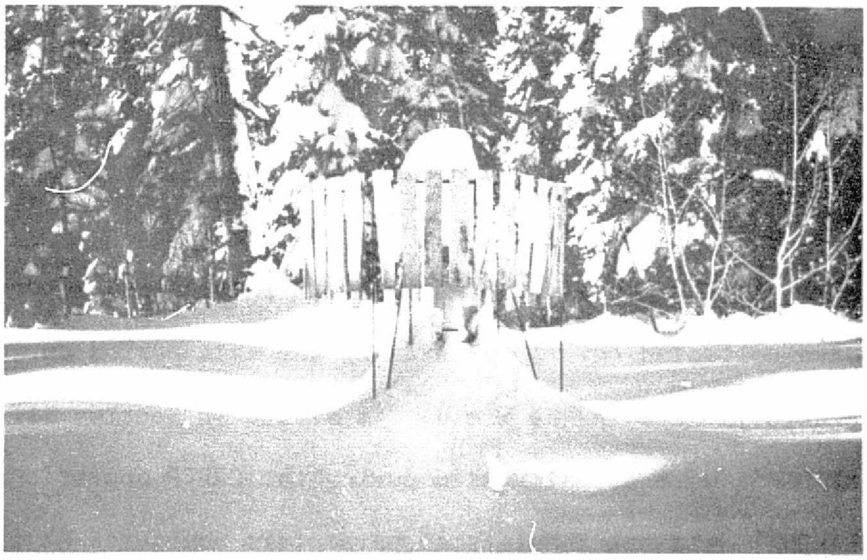

Figure 5. - Example of heavy snowfall capping (or bridging) a precipitation gage.

problem was eliminated on December 21, 1974, after repair of a faulty antenna connector and installation of fresh batteries. Routine servicing of the precipitation gage occurred early in February and again on March 5. Due to an abnormally heavy precipitation rate, the gage was snowcapped on March 11 (see fig. 5 for an example of snowcapping or bridging), causing inaccurate data. On March 14, the entire gage was irretrievably buried in the snowpack which ended the receipt of accurate precipitation data from this site for the remainder of the winter season. The temperature sensor, however, was not buried and continued to provide accurate data until the DCP was removed in August.

Wolf Creek North monitored only streamflow and water temperature. No problems were encountered with this unit until January 26, 1975, when the water temperature sensor malfunctioned. The heavy snowpack coupled with the DCP location made it impossible to remove the sensor. Onsite repair was not feasible; hence, valid water temperature data were not received after that date. Good streamflow data existed until April 22, when the LANDSAT equipment was disconnected from the USGS (United States Geological Survey) streamflow recorder to prevent a possible malfunction of the recorder due to limitations imposed by the LANDSAT interface. This action was taken on April 22 to insure that the anticipated unusually high spring runoff would be accurately monitored by the USGS onsite recorder.

Wolf Creek Pass, shown in figure 6, required servicing five times throughout the operational season. The environmental parameters measured at this site were air temperature and precipitation. On February 21, 1975, the precipitation gage was raised to keep it above the snowpack. The precipitation sensor cable was frozen under approximately 10 feet of snowpack; therefore, an additional cable section was added to reach the raised platform. Following this action, erroneous data were intermittently received. It is believed that moisture occasionally penetrated the cable splice, introducing error into the sensor output. There were no other problems encountered with this DCP, and data were received until the DCP was removed in August.

Figure 6. - Wolf Creek Pass LANDSAT DCP field site.
U.S. Highway No. 160 is visible in foreground.

Upper San Juan was located near a SCS (Soil Conservation Service) snowpillow and snow course. Cumulative water equivalent of the snowpack was monitored by the SCS snowpillow as well as by a standard weighing-type precipitation gage. This DCP also included an air temperature sensor. Readings received from the SCS snowpillow were erratic. An attempt at recalibration on January 7, 1975, proved unsuccessful. On January 31, a tree fell across the snowpillow recorder damaging it extensively and thereby effectively eliminating any other problems [2]. The Upper San Juan LANDSAT DCP and sensors are shown in figure 7, both in a photo and a corresponding sketch included for explanation. The cut fallen tree and bent recorder stand are evident. No other problems were encountered with this unit, and quality temperature and precipitation data were received until the platform was removed in August.

Castle Creek monitored air temperature and precipitation. DCP malfunctions detected during December 1974, resulted in the electronics being removed for shop test and repair. The electronics were reinstalled with precipitation data available beginning January 26, 1975, and temperature data on February 4. Figure 8 shows a WSSI technician working on the LANDSAT electronics at Castle Creek. The only other difficulty encountered with this unit occurred during early May when the precipitation record had fluctuations indicative of bridging of the gage (see fig. 6). Data from Castle Creek were received until August when the unit was removed from the site.

Throughout the follow-on program, LANDSAT data were compared with data obtained from conventional onsite recording sensors. Temperature and precipitation examples were provided which are indicative of the LANDSAT data quality. Figure 9 is a comparison of the temperatures recorded by the thermograph located near the Wolf Creek Pass LANDSAT DCP and the temperatures transmitted by the LANDSAT platform for the corresponding

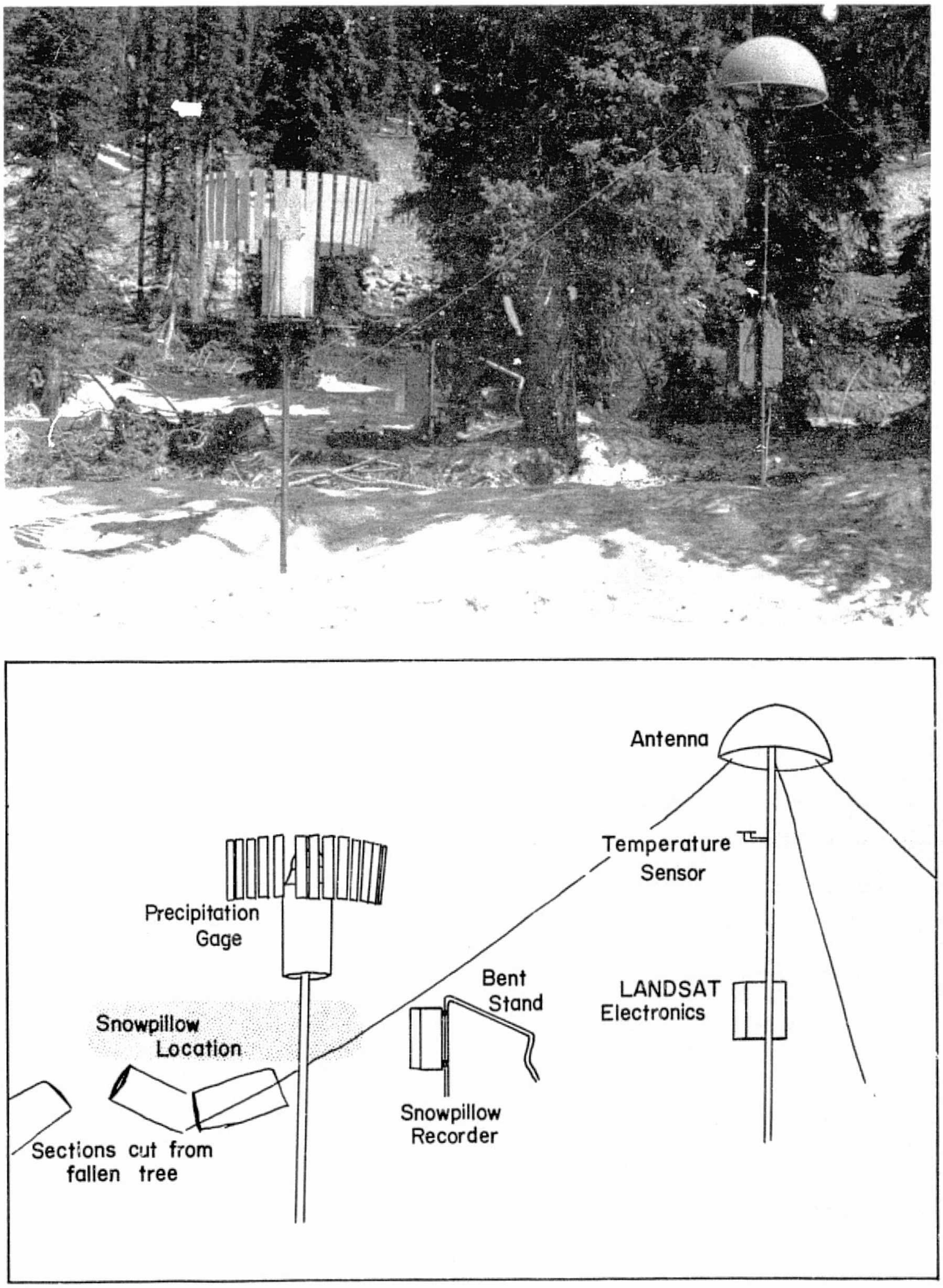

Figure 7. - Photo and corresponding sketch of Upper San Juan site showing LANDSAT DCP, sensors, fallen tree, and bent stand.

Figure 8. - Technician checking LANDSAT electronics at Castle Creek.

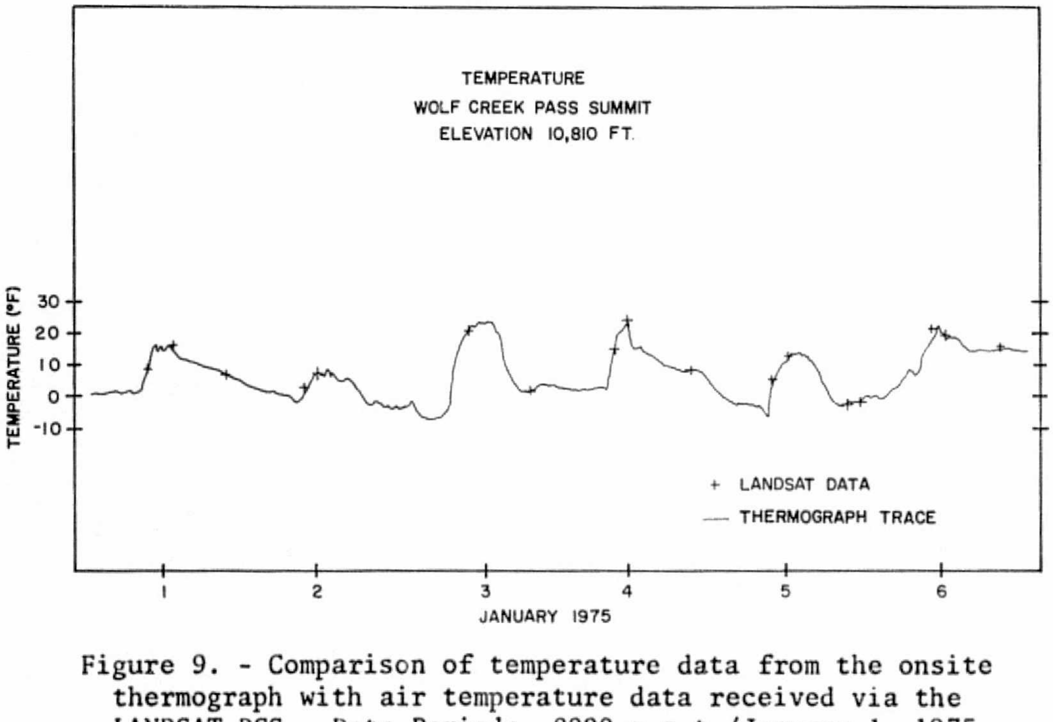

Figure 9. - Comparison of temperature data from the onsite thermograph with air temperature data received via the LANDSAT DCS. Data Period: 0000 m.s.t./January 1, 1975 - 2400 m.s.t./January 6, 1975.

times. Note the close agreement between the two instruments, which were separated by approximately 50 feet. Figure 10 shows the comparison of LANDSAT and standard recording gage precipitation data from the Wolf Creek Pass site for the 1-week period beginning at 1200 m.s.t. on January 1 and ending at 1200 m.s.t. on January 8, 1975. During this period the LANDSAT gage indicated an accumulation of 1.31 inches water equivalent, while the standard gage recorded an accumulation of 1.24 inches water equivalent, for a difference of 5.6 percent. This

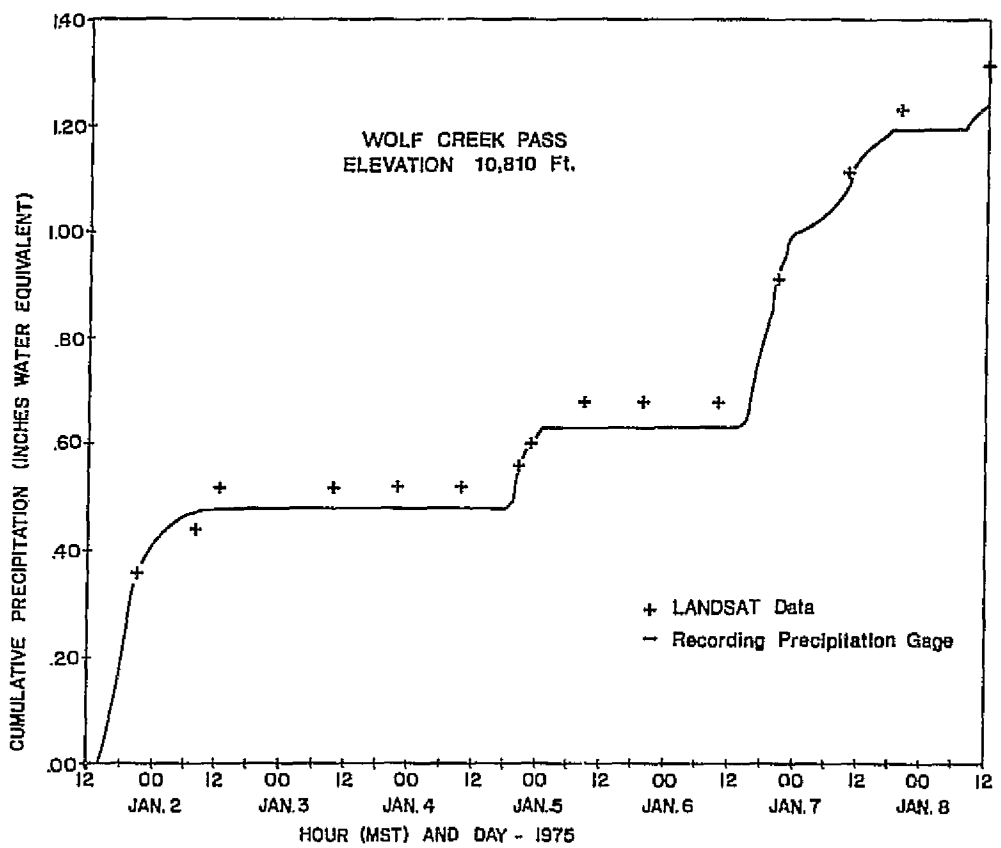

Figure 10. - Comparison of onsite recording gage and LANDSAT precipitation data. Data Period: 1200 m.s.t./January 1, 1975 - 1200 m.s.t./January 8, 1975.

difference could be the result of slightly different gage exposure and gage resolution.

Table 4 contains the daily precipitation amounts as measured at the Lime Mesa site by both the manual and LANDSAT systems between January 1 and

Table 4. - *Comparison of daily precipitation data sets from the manual and LANDSAT data collection systems.*

Date (1975) Mo.-Day	24-hr. PPT (inches) Manual	24-hr. PPT (inches) LANDSAT	*Difference (inches) M-L
1-2	.15	.12	.03
1-3	.02	.04	-.02
1-5	.10	.12	-.02
1-6	.06	.04	.02
1-7	.58	.60	-.02
1-8	.16	.16	0
1-9	.83	.80	.03
1-10	.05	.04	.01
1-11	.21	.20	.01
1-12	.08	.12	-.04
1-22	.07	.08	-.01
1-25	.72	.68	.04
1-28	.91	.80	.11
1-29	.01	.08	-.07
1-30	.19	.12	.07
1-31	.63	.56	.07
2-1	.02	.04	-.02
2-4	.08	.08	0
2-5	.59	.43	.16
2-6	.06	.04	.02
2-10	1.10	1.08	.02
2-11	.45	.44	.01
2-14	.47	.47	0
2-15	.37	.40	-.03
2-16	.21	.20	.01
2-17	.79	.84	-.05
2-18	.06	.08	-.02
2-20	.12	.12	0
2-21	.08	.08	0
2-22	.25	.24	.01
2-23	.03	.04	-.01
3-6	1.38	1.32	.06
3-7	.57	.56	.01
Totals	11.40	11.02	.38
(Beginning of inaccurate LANDSAT data due to heavy snowfall bridging gage)			
3-9	1.22	1.96	-.74
3-10	.21	.51	.30
3-11	1.07	.88	.19
3-12	.43	.04	.39
3-13	.46	.44	.02
3-14	.04	0	.04
3-15	.34	0	.34

*Mean of the differences = .0115 inches.
Standard deviation of the difference = .0447 inches.

March 15, 1975, when the LANDSAT gage became buried under the snowpack during a heavy snowfall. A statistical test was performed on all of these readings except the last seven, which were included to show the effect snowcapping (or bridging) has on the sensor output. The difference between daily totals measured by each gage was calculated for the 33 days between January 1 and March 7, 1976, on which measurable precipitation occurred. The Student t statistical test was applied to these values. The null hypothesis that there is no difference between the two population means was readily accepted at the 95-percent confidence level. The total precipitation accumulations recorded by the manual and LANDSAT systems were 11.40 and 11.02 inches, respectively, for a total difference of 0.38 inches (3.4 percent).

VI. COST EFFECTIVENESS COMPARISON OF ALTERNATIVE DATA COLLECTION SYSTEMS

A. Introduction

This section of the report represents an extension of a cost-effectiveness analysis of the ERTS (Earth Resources Technology Satellite) DCS presented to Goddard Space Flight Center in July 1974 [1]. The basic problem addressed in the earlier work was that of determining which of three data collection systems - the ERTS-1, manned, and remote ground telemetry - was the most effective in delivering a reasonably standard output for the least cost outlay. The previous analysis indicated that the ERTS and ground telemetry systems required greater initial cost outlays than the manned system, with the ground telemetry system being three times as expensive and the ERTS system nearly twice as expensive to install as the manned system. However, operation and maintenance costs for the manned system far exceed those of either the ERTS or ground telemetry system. The comparative analysis of costs for the three systems indicated that, under the assumptions made regarding the estimates of costs and under the requirements imposed on the systems with respect to the number of sites and the data collected, the ERTS-1[1] system was less costly than the other two, i.e., was more cost effective.

The present analysis again employs cost-effectiveness comparisons of alternative data collection systems. It differs from the previous work in two significant respects. First, the number of sites has been expanded from 7 to a more realistic network of 68 sites. This improvement in the reality of the analysis is made possible as a result of new technology acquired through system development work, which is herein referred to as the RAIN (Remote Auto-Initiated Network) concept. The second change was that the number of data gathering systems compared

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[1] See footnote on page 2.

was expanded to five. The RAIN concept was applied to all systems evaluated, with the exception of the manned system.

The RAIN concept allows several remote sites to collect one or more meteorological parameters and to transmit data collected to a single DCP on a "self-timed" basis. The DCP is modified to contain a micro-computer module and programed memory designed to receive and store data for specific sites. The DCP then retransmits data on a "self-timed" basis to the master data collection center via satellite relay or some other method. The RAIN concept conserves the use of DCP's which normally have a higher data channel capacity than would be required.

B. Description of the Data Collection Systems

The network to be evaluated consists of a total of 68 measuring sites; 15 meteorological stations with the capability to measure wind speed and direction, temperature, and precipitation, and with the remaining 53 sites collecting precipitation data only. The five data collection systems[2] included in the cost-effectiveness analysis for this 68-site

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[2] A sixth system, the LANDSAT DCS with one DCP located at each measurement site, was considered for inclusion in the analysis. However, this data collection system is not feasible for the measurement network being considered here. The major problem in using the LANDSAT with one DCP at each site is the obvious cost differential between this system and the LANDSAT/RAIN system. The latter employs a single relatively high-cost DCP to service several low-cost remote stations. The former uses 68 DCP's and incurs high individual site costs with no related cost reduction in maintenance or data processing.

network are: (1) LANDSAT modified to the RAIN concept; (2) GOES (Geostationary Operational Environmental Satellite) modified to the RAIN concept; (3) Meteorburst modified to the RAIN concept; (4) Ground Telemetry modified to the RAIN concept; and (5) the Manned Ground Network. Each of the five systems collects data on wind speed and direction, temperature, and precipitation. Each has a performance period of 9 months, and each system would include a field office rented for the purpose of conducting routine work associated with the system. The 15 meteorological stations with the LANDSAT/RAIN, GOES/RAIN, Meteorburst/RAIN and Ground Telemetry/RAIN systems all include modified DCP units interfaced to a digital cassette recorder system recording data for post analysis. The satellite and data retrieval system for LANDSAT/RAIN and GOES/RAIN would be provided by Government agencies. The Meteorburst/RAIN and Ground Telemetry/RAIN systems each require one ground receiving and data retrieval station and the Ground Telemetry/RAIN system would require five radio repeater sites.

The assumed field personnel, equipment, and onsite visits under normal circumstances are, with one exception, identical for the LANDSAT/RAIN, GOES/RAIN, and Meteorburst/RAIN systems. Each system would require two persons (full time) equipped with a large oversnow vehicle, 2-ton truck, 4-wheel drive pickup, 2 snowmobiles, and supplemental helicopter use for network servicing. Each site in each system would require one visit per month. The personnel requirement for the Meteorburst/RAIN system is slightly greater than for the other two because of maintenance of the ground receiving station. The Ground Telemetry/RAIN system would require two full-time and one part-time employees with the same vehicles cited previously. Again, each site would, under normal conditions, require on visit per month. The manned surface network requires four full-time employees and an additional four-wheel drive pickup. The other vehicle requirements are the same as for the other systems. Each of the 15 onsite wind speed and direction, temperature and precipitation stations would be serviced bimonthly, while each of the 53 precipitation sites would be serviced either one or two times per month, depending on site accessibility.

C. Effectiveness of the Systems

The output of each system is measured in terms of seven parameters: type of data, frequency of sample, effective frequency, frequency of reception, accuracy, resolution, and ease of manipulation. These items constitute the effectiveness side of the cost-effectiveness analysis and are summarized in table 5.

In the LANDSAT/RAIN system, the DCP collects sample readings from the sensors once each hour and transmits this data set to a satellite for relay to a ground receiving station. Due to its polar orbit, however,

Table 5. - *Output parameters for data collection systems.*

Collection System	Type of Data	Frequency of Sample	Effective Frequency	Frequency of Reception	Accuracy	Resolution	Ease of Manipulation
LANDSAT/RAIN 2/	Precip. Temp. Wind	Hourly	2 per day	2 per day	±.05 inches ±.3° C ±.5 mph	±.04" ±.23° C ±.4 mph	High 3/
MANNED	Precip. Temp. Wind	Continuous	Hourly	Biweekly	±.05 inches ±1° C ±2 mph	±.01" ±.5° C ±1 mph	Low
GROUND 2/ TELEMETRY/ RAIN	Precip. Temp. Wind	Programmable	Programmable	Programmable	±.05 inches ±.5° C ±1 mph	±.01" ±.25° C ±.5 mph	High 3/
GOES/RAIN 2/	Precip. Temp. Wind	Programmable	Programmable	Programmable	±.05 inches ±.3° C ±.5 mph	±.04" ±.23° C ±.4 mph	High 3/
METEORBURST/ 2/ RAIN	Precip. Temp. Wind	Programmable	1 per day (min.) to 1 per hr. (max.)	1 per day (min.) to 1 per hr. (max.)	±.05 inches ±.5° C ±1 mph	±.01" ±.25° C ±.5 mph	High 3/

1/ All networks are based on 68 field sites; 53 sites collect precipitation only, 15 sites collect precipitation, temperature, wind speed and direction. Hydrological data are not considered but could be included.

2/ These systems, based on the RAIN concept, utilize 15 DCPs each incorporating a digital cassette. The tapes would be collected monthly and would require additional manipulation prior to use as an analytical aid.

3/ Processing data from cassette backup recorders not considered.

the satellite is only in position to relay data twice each day. Therefore, while the frequency of the sample is once every hour, the effective frequency is once every 12 hours, the same as the frequency of reception. The data received every 12 hours at the ground receiving station are then routed (see fig. 3) to Denver in near real time. The accuracy and resolution of each of the three types of data are summarized in table 5. The degree of ease of data manipulation is rated high since the data are received by the user in a digital format.

Data are collected by the manned system automatically and continuously, but are reduced only on an hourly basis. On the average, data are retrieved manually every 2 weeks. Thus, the frequency of the sample is continuous, but the effective frequency is hourly, and the frequency of reception is bimonthly. The ease of manipulating data collected from the manned system is low, since the data must be reduced to a digital format. While data collected by the LANDSAT/RAIN system are almost immediately available for use, data collected with the manned system are only available once every 2 weeks. The greater sample frequency, but smaller reception frequency, makes the manned system more useful from an analytical perspective, but less useful from an operational perspective, than the LANDSAT/RAIN system.

The GOES/RAIN system improves upon the LANDSAT/RAIN system in that it provides both high analytical and operational capabilities. The essential difference between the two is that the former utilizes a stationary satellite over the equator while the latter uses a polar orbiting satellite. This system allows all data collected to be transmitted and received as often as once per hour. In practice, the GOES/RAIN system would operate similarly to the existing LANDSAT/RAIN system, with the important exception of its improved reception frequency.

The Ground Telemetry/RAIN system differs from the LANDSAT/RAIN and GOES/RAIN systems in that it transmits data via ground-based radio lines rather than by satellite. The frequency of the samples is programmable so that data can be collected as frequently as desired, subject to station power limitations. The power capabilities are currently such that a maximum of three observations per hour can be obtained;

operationally, data are collected and transmitted once every 3 hours. The effectiveness of the Ground Telemetry/RAIN system is comparable to that of the GOES/RAIN system. Cost differences arise, however, due to differences in the transmission structures of the systems.

Finally, the effectiveness of the Meteorburst/RAIN system is limited by its power requirements and the statistical nature of the Meteorburst transmission path. These limitations restrict both the effective frequency of the sample and the frequency of reception to a range of between once per hour to once per day. The accuracy, resolution, and ease of manipulation of this system are similar to the other automated systems.

In summary, the GOES/RAIN and Ground Telemetry/RAIN systems have the largest range of capabilities. They are favorably comparable to all the other systems in terms of the accuracy, resolution, and ease of manipulation of the data collected and, in addition, are valuable for both analytical and operational purposes. The LANDSAT/RAIN system is limited primarily in terms of its analytical usefulness, a limitation imposed by the current satellite system.

D. Costs of the Systems

Since only the manned system actually exists in the form specified, it is necessary to estimate the costs of the other four systems. The estimates of costs distinguish between costs incurred during the initial phase of operation (termed first-year costs) and costs for operation and maintenance in future years (termed subsequent-year costs). First-year costs are broken into procurement, fabrication, and testing costs and installation, operation, and maintenance costs. Each of these two broad categories is further subdivided into hardware, software, and labor costs. Costs in subsequent years are basically those incurred for reinstallation, operation and maintenance, and, again, are subdivided into hardware, software, and labor costs. Reinstallation costs are incurred because ground equipment must be removed during the summer months of high tourist use. Table 6 presents a summary of the annual cost estimates for the first and subsequent years for each of the five DCS's.

Table 6. - *Estimates of annual costs of alternative.*

SYSTEM	First Year									Subsequent Years			
	Procurement, Fabrication and Testing				Installation, Operation and Maintenance				TOTAL	Reinstallation, Operation and Maintenance			
	Hardware	Software	Labor	Total	Hardware	Software	Labor	Total		Herdware	Software	Labor	Total
LANDSAT/RAIN	$281,718	$6,095	$61,972	$349,785	$84,599	$1,829	$ 45,945	$132,373	$482,158	$32,474	$1,219	$37,017	$ 70,710
Manned	145,627	500	12,277	158,404	89,109	2,634	103,519	195,262	353,666	34,437	2,604	76,688	113,729
Ground Telemetry/RAIN	335,185	3,657	81,591	420,433	85,452	1,829	74,829	162,110	582,543	32,474	1,219	56,204	89,897
GOES/RAIN	269,316	6,095	64,112	339,523	76,507	1,829	45,945	124,281	463,804	33,279	1,219	37,017	71,515
Meteorburst/RAIN	492,001	7,314	69,548	568,863	78,504	1,829	54,507	134,840	703,703	21,503	1,219	41,143	63,865

The estimates presented in table 6 indicate that the first-year costs for the Meteorburst/RAIN system are by far the greatest ($704,000), followed by Ground Telemetry/RAIN ($583,000), LANDSAT/RAIN ($482,000), GOES/RAIN ($464,000), and the Manned system ($354,000). Subsequent-year costs are greatest for the Manned system with annual recurring costs estimated at $114,000, followed by Ground Telemetry/RAIN ($90,000), GOES/RAIN ($72,000), LANDSAT/RAIN ($71,000), and Meteorburst/RAIN ($64,000). Generally, the more technologically sophisticated systems are more costly to install but require less operation and maintenance expenditures.

If a decision is made on the basis of only the initial expenditure (outlay), the Manned Data Collection System, no doubt, would be selected. However, all the systems considered have some future period of use, and operation and maintenance costs cannot be ignored. Table 7 presents a summary of the total, undiscounted costs for the alternative DCS's assuming a 5- and a 10-year system life. There is a dramatic difference in the relative ordering of the systems in terms of these cost totals. The Manned system no longer appears as the least costly system. Under an assumed life of 5 years, the GOES/RAIN system is least costly ($750,000), followed by LANDSAT/RAIN ($765,000), the Manned system ($809,000), Ground Telemetry/RAIN ($942,000), and Meteorburst/RAIN ($959,000).

A further reorganization is noted when the system life is expanded to 10 years. Under this assumed life, GOES/RAIN ($1,107,000) and

Table 7. - *Total undiscounted costs for alternative data collection systems.*

	Total Undiscounted Costs			
	Five Year Project Life		Ten Year Project Life	
System	Dollars	Rank 1/	Dollars	Rank 1/
LANDSAT/RAIN	$764,998	2	$1,118,548	2
Manned	808,582	3	1,377,227	4
Ground Telemetry/RAIN	942,131	4	1,391,616	5
GOES/RAIN	749,864	1	1,107,439	1
Meteorburst/RAIN	959,163	5	1,278,488	3

1/ Ranked in terms of least costly to most costly alternatives.

LANDSAT/RAIN ($1,119,000) remain the first and second least costly alternatives. However, Meteorburst/RAIN ($1,278,000) moves into the third position, the Manned system moves into the fourth position, and the Ground Telemetry/RAIN system is the least desirable alternative.

While the use of the total undiscounted costs is preferable to a comparison of the initial cost outlays as a decisionmaking tool, it does not provide a means for comparing the costs of each system in present value terms; that is, it is necessary to be able to compare a dollar invested today with future dollar investments. To place the costs of each alternative on a strictly comparable basis, it is necessary to discount future operation and maintenance costs for each system back to the present. This has been accomplished by assuming two discount rates, 6 and 10 percent (roughly equivalent to a public sector and private sector discount rate) and applying these rates to the 5- and 10-year system life periods. The total discounted costs for each system are summarized in table 8.

Table 8. - *Total discounted costs for alternative data collection systems.*

System	Discount Rate	Yearly Present Cost Values										Total Discounted Cost			
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	5 Year Total Dollars	5 Year Total Rank[1]	10 Year Total Dollars	10 Year Total Rank[1]
LANDSAT/RAIN	6%	$402,158	$ 66,708	$ 62,932	$59,368	$56,009	$52,842	$49,851	$44,363	$41,853	$39,477	$727,175	2	$ 955,561	2
	10%	402,158	64,282	58,435	53,124	48,330	44,031	39,923	36,317	32,965	30,038	706,329	2	889,603	2
Manned	6%	353,666	107,292	101,219	95,487	90,073	84,990	80,179	75,641	71,354	67,316	747,740	3	1,127,220	3
	10%	353,666	103,391	93,986	85,444	77,734	70,819	64,211	58,411	53,020	48,312	714,221	3	1,[illegible]08,994	3
Ground Telemetry/ RAIN	6%	582,543	84,808	80,008	75,478	71,207	67,171	63,377	59,782	56,401	53,210	894,044	4	1,193,985	5
	10%	582,543	81,725	74,291	67,540	61,444	55,979	50,756	46,171	41,910	38,188	867,643	4	1,100,547	5
GOES/RAIN	6%	463,804	67,467	63,648	60,044	56,647	53,436	50,418	47,557	44,868	42,330	711,610	1	[illegible]0,219	1
	10%	463,804	65,014	59,100	53,729	48,880	44,532	40,377	36,730	33,340	30,380	690,527	1	87[illegible],886	1
Meteorburst/RAIN	6%	703,703	60,250	56,840	53,621	50,587	47,720	45,025	42,470	40,069	37,802	925,001	5	1,138,087	4
	10%	703,703	58,060	52,778	47,982	43,652	39,769	36,058	32,801	29,774	27,130	906,175	5	1,071,707	4

1/ Ranked in terms of least costly to most costly alternatives.

Table 8 indicates that the GOES/RAIN and LANDSAT/RAIN systems are the first and second least-cost alternatives for both discount rates and project life periods. The differences in their costs are not comparatively large, nor are they expected to be, since their fundamental difference is the orbit of the satellite utilized. The relative change in rankings of the Ground Telemetry and Meteorburst/RAIN systems for the two project life periods is attributable to the higher operation and maintenance costs of the former system. The present value of costs of the Manned system are approximately 4 to 15 percent higher than the

GOES/RAIN system, depending upon the project life period. In the shorter life period, this difference may not be significant. However, significant differences do exist in their comparative effectiveness.

A comparison of the results presented in table 8 with those of table 7 indicates that, for a 5-year project life and for both discount rates, the relative ordering of the alternative systems is the same. However, some differences are noted when the projected system life is expanded to 10 years.

Under the assumed 10-year system life, the GOES/RAIN and LANDSAT/RAIN are still the first and second most desirable systems (in terms of costs), but the Manned system moves from the fourth position (table 7) to the third position (table 8). Meteorburst/RAIN moves from the third most desirable position to the fourth. The Ground Telemetry/RAIN system is the most costly alternative.

E. Cost-effectiveness Comparison

Tables 5 and 8 provide the basis for a cost-effectiveness comparison. The results of this comparison clearly indicate that the GOES/RAIN data collection system is the most cost effective. It provides the greatest quantity and quality of output at the lowest cost. Even where cost differences are not highly significant, this general conclusion still follows due to the GOES/RAIN system's higher degree of effectiveness.

Finally, two further qualifications are necessary. First, the cost estimates do not include an inflation factor. Since the annual expenditures beyond the initial year for the Manned system exceed that of the other four systems, inflation will have the greatest effect on the Manned system. Second, if the costs of placing a satellite into orbit must be borne by the user, then the relative positions of the satellite-using DCS's could very well be altered.

VII. NEW TECHNOLOGY

A major portion of the LANDSAT follow-on program involved the application of new technology to weather-modification-oriented data collection through the LANDSAT system. The measurement of wind speed and wind direction along with accuracy and stability problems associated with relative humidity measurements were two areas of weakness identified in instrumentation previously used on the CRBPP program. Collection of useful wind data was considered to be the problem area in which new technology could best be applied. Work performed in developing a wind averaging system is described in this section. The status of relative humidity sensor technology was also investigated and is reported in appendix C.

As discussed in section III, wind data previously obtained through the LANDSAT DCS consisted of instantaneous values sampled at times as far apart as 12 hours. To provide wind data which would be of more operational value to the user, WSSI developed a wind averaging and data storage module which is directly compatible with the LANDSAT DCS. This module digitally averages wind speed and wind direction for approximately 8.5 minutes at 1-hour intervals. An internal memory stores the eight most recent hourly samples. These data are then transmitted by the LANDSAT DCP under control of the wind module. Using this technique, averaged hourly wind data are available for at least 16 of every 24 hours.

A. System Description

A block diagram of the complete wind averaging system is shown in figure 11. The wind sensor used in the system is an MRI model 1022. The model 1022 instrument set consists of a cup and vane sensor using a common crossarm for mounting. The anemometer cups are positioned 40 inches horizontally from the azimuth vane so that data may be obtained with minimum interference. Designed for continuous monitoring in all climates, the instrument combines rugged durability with sensitive responses to wind speed and wind direction.

The wind speed sensor utilizes a chopper disk attached to the lower end of the anemometer shaft. As the anemometer shaft rotates, the chopper disk interrupts the light path between a light-emitting diode and a

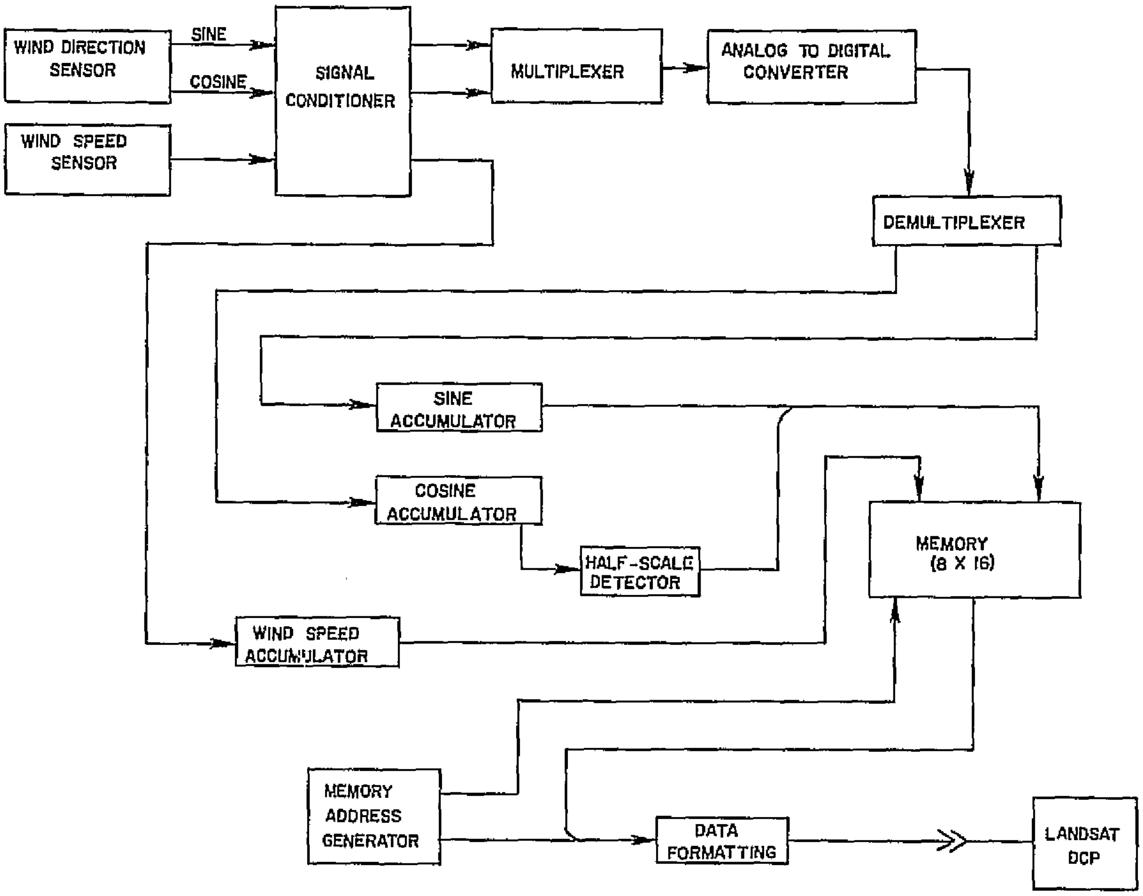


Figure 11. - Block diagram of LANDSAT wind averaging system.

photo-transistor, causing the photo-transistor to alternately turn on and off. The sensor electronics utilize this switching action to produce a sine wave whose frequency is proportional to the speed of rotation of the chopper disk.

The wind direction sensor is a sine/cosine transducer. A precision low-torque, sine/cosine function potentiometer is mounted with a solid coupler to the vane idler shaft inside the sensor main housing. This potentiometer is a continuous-rotation, 360-degree device geared one-to-one with the sensing vane. It has a center tap with two wipers set at 90 degrees relative to one another. When the vane is rotated clockwise, the cosine wiper trails the sine wiper by 90 degrees. For reasons that will be discussed later in this section, the system performance can be improved significantly by using a slightly different potentiometer in the wind direction transducer. This potentiometer should maintain the center tap, dual wiper configuration, but the resistance function should be linear rather than sinusoidal. The output of the sensor in either case is two voltages, one of which is proportional to the magnitude of the angular rotation from zero degrees, while the second indicates the direction of rotation. The relation between the sensor output voltages and wind direction is shown in figure 12. (Fig. 12a is for the sinusoidal potentiometer; fig. 12b is for the linear potentiometer.)

The signal conditioner of figure 11 converts the wind speed and wind direction sensor outputs to levels compatible with the averaging circuits. The signal conditioning board previously used by WSSI with the LANDSAT DCP's was modified for use with the wind module. This signal conditioning board also includes a voltage regulator which provides a stable excitation signal for the wind sensors.

The two-channel multiplexer is a low-power CMOS (complementary metal oxide semiconductor) analog switch. This switch is controlled by the

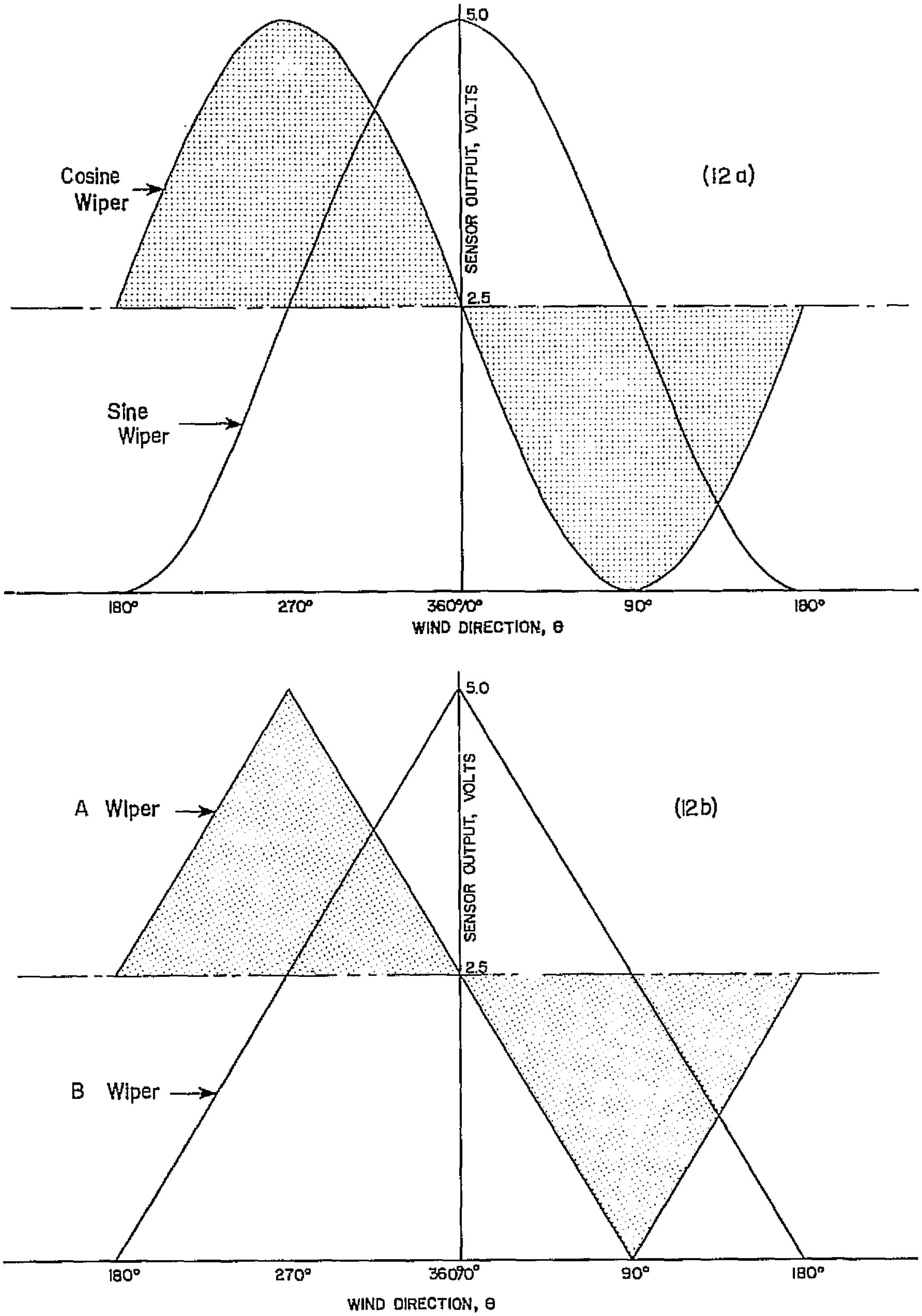


Figure 12. - Wind direction sensor outputs
(12a) Sine/cosine potentiometer
(12b) Linear potentiometer.

timing logic of the wind module and enables a single A/D (analog-to-digital) converter to operate on both outputs of the wind direction sensor.

The A/D converter also utilizes CMOS technology to provide low-power operating characteristics. This converter is especially well suited to averaging of slowly varying parameters, such as wind direction, because the converter output is a serial pulse stream, with the PRR (pulse repitition rate) being directly proportional to input voltage. Input signal variations during a conversion period vary the PRR so that the total number of pulses generated during the conversion period is directly proportioned to the average value of the input signal during that period.

Because the wind direction signals are multiplexed onto a single line prior to A/D conversion, it is necessary to separate the two signals after digitizing to permit further processing. This is accomplished by the demultiplexer of figure 11. The demultiplexer basically acts as a single-pole, double-throw switch which gates the A/D converter output into one accumulator when the sine output from the direction sensor is being digitized, and into a second accumulator when the cosine output is being digitized. This makes it possible to average both the sine and cosine outputs separately over the entire 8.5-minute averaging period.

The two wind direction accumulators are binary counters which are designed so that a full-scale signal on either of the wind direction sensor outputs for the entire averaging period will completely fill the corresponding accumulator. The seven most significant bits from the sine accumulator are combined with the half-scale detector output of the cosine accumulator to form an eight-bit data word which is related to the wind direction by the equations of figure 13. Figure 14 gives the equations for converting the eight-bit data word to wind direction if a linear potentiometer is used in the wind direction sensor.

Averaging of the wind speed sensor output is accomplished in essentially the same manner as the wind direction averaging. The major difference is that the wind speed signal does not require digitizing, due to the digital characteristics of the wind speed sensor. As mentioned earlier, the sinusoidal signal produced by the wind speed sensor is converted to voltage levels compatible with the averaging circuits by the signal conditioner. The signal conditioner output is a serial pulse stream with the PRR proportional to wind speed. The total pulse count during a sample period is accumulated in a binary counter in the same manner that the wind direction outputs are accumulated. At the end of the sample period, this accumulator contains an eight-bit data word which is directly proportioned to the average wind speed during the sample period.

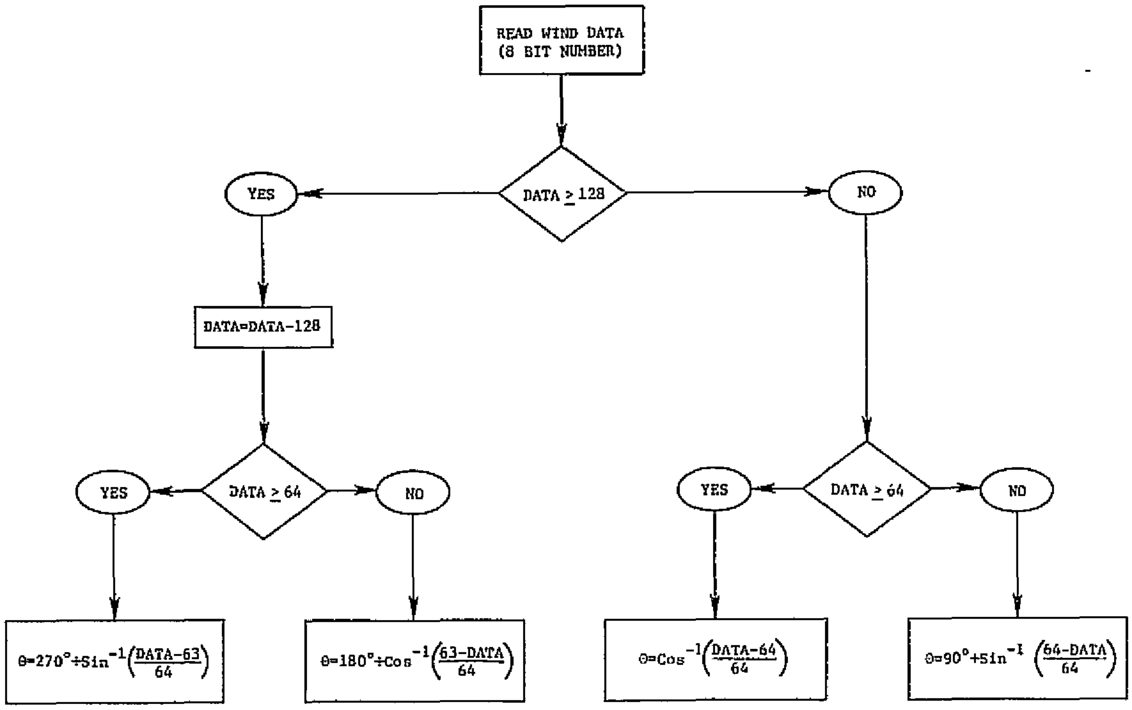


Figure 13. - Wind direction conversion equations for sensor with sine/cosine potentiometer.

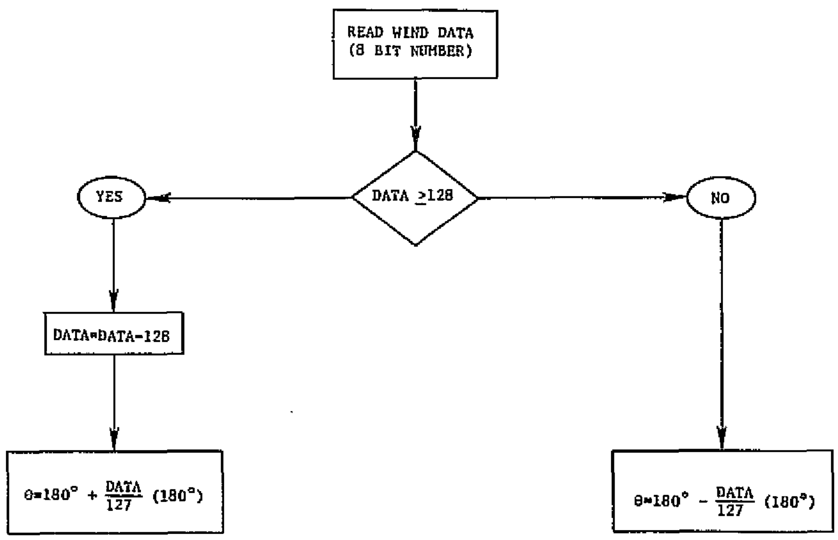


Figure 14. - Wind direction conversion equations for sensor with linear potentiometer.

At the end of the sample period, the wind speed data word and the wind direction data word are written into the 8-hour memory. The address pointer advances the memory address immediately prior to writing these data into the memory. At 1-minute intervals, a temporary address pointer moves through the memory in the opposite direction, transferring two sets of hourly data samples (wind direction and wind speed are combined to form one set) to the LANDSAT serial data interface. Under control of the LANDSAT DCP electronics, these data are then assembled into the LANDSAT message format and transmitted to the satellite. A detailed circuit diagram and the wire wrap board layout for the LANDSAT wind averaging system are included in appendix D.

B. Data Format

The data format generated by the wind averaging and data storage module requires additional processing software to that developed for the previous LANDSAT data. The full data set covering the most recent 8-hour period is transmitted by four separate LANDSAT transmissions. A data block ID (identifier) is included as the first data word in each transmission. This ID indicates the memory location of the most recent data sample and the memory locations of the two data samples included in the transmission. Decoding of this ID permits the user to obtain a direct printout of wind data on an hourly basis. Examples showing the relation between memory location of the data sample, time corresponding to the data sample, and data block ID are shown in figure 15. The LANDSAT

	Memory location	Hourly sample	Data block ID	Memory locations transmitted
	1	1200		
	2	1300	42	2,1
	3	1400		
Most recent data →	4	1500	44	4,3
	5	0800		
	6	0900	46	6,5
	7	1000		
	8	1100	48	8,7

(15a)

	Memory location	Hourly sample	Data block ID	Memory locations transmitted
	1	1200	51	1,8
	2	1300		
	3	1400	53	3,2
	4	1500		
Most recent data →	5	1600	55	5,4
	6	0900		
	7	1000	57	7,6
	8	1100		

(15b)

Figure 15. - ID/Data relationships for LANDSAT wind data
a) Data received between 1500 and 1600 G.m.t.
b) Data received between 1600 and 1700 G.m.t.

software developed for the wind data by the Bureau of Reclamation (see appendix B) assumes that the hour during which data are received corresponds to the hour of the most recent sample, i.e., all data transmissions received between 1500 and 1600 G.m.t. hours are a part of an 8-hour data block in which the most recent sample in the block occurred at 1500 G.m.t. This example is shown in figure 15a. The 1500 G.m.t. sample is stored in location 4 (identified by the first digit of the ID). Each transmission includes two samples, and the second digit of the ID identifies the location of the latest sample included in that transmission. The second sample in the transmission is 1 hour older than the first. Looking at figure 15a again, it can be seen that ID 46 identifies the most recent data as being stored in memory location 4, while the two samples included in this transmission are stored in memory locations 6 and 5.

Figure 15b shows the sample time, ID, and memory location relationships for data blocks transmitted between 1600 and 1700 G.m.t. hours. The most recent hourly sample occurred at 1600 and is stored in memory location 5. The ID's of all data blocks transmitted during the 1600-1700 G.m.t. interval will have 5 as the first digit and 1, 3, 5, or 7 as the second digit, as shown in figure 15b. A sample data printout is shown in table 9. The temperature, relative humidity, and precipitation data are acquired using analog sensors and signal conditioning and are digitized by the LANDSAT electronics as in the previous LANDSAT instrumentation.

Table 9. - *Sample of computer printout showing time of data (G.m.t.), averaged wind direction and speed (deg and mi/h), precipitation accumulation (in), relative humidity, and temperature (°C).*

040 JERSY JIM LAT 37.34'N LONG 107.41'W ELV 11700FT

DATE TIME XMITTED TO SAT GMT			CON LVL	TIME OF DATA	CURRENT WIND DIR	CURRENT WIND SPEED	PREV HR WIND DIR	PREV HR WIND SPEED	CURRENT PRECIP (IN)	CURRENT RH	CURRENT TEMP (C)
JAN	16	05:32	7	0500	000	006	342	006	6.9	.10	17.10
JAN	16	05:33	7	0300	319	011	331	013	6.9	.10	17.10
JAN	16	05:34	7	0100	000	007	309	005	6.9	.10	17.10
JAN	16	05:35	7	2300	319	009	297	022	6.9	.10	17.10
JAN	16	05:36	7	0500	000	006	342	006	6.9	.10	17.10
JAN	16	14:36	7	1400	129	003	154	002	6.9	.10	16.00
JAN	16	14:37	7	1200	169	005	194	006	6.9	.10	16.00
JAN	16	16:13	7	1400	129	003	154	002	6.9	.10	16.00
JAN	16	16:14	7	1200	169	005	194	006	6.9	.10	16.00
JAN		16:15	7	1000	197	007	197	009	6.9	.10	16.00
JAN	16	16:16	7	1600	000	002	001	002	6.9	.10	16.00
JAN	16	16:16	7	1600	000	002	001	002	6.9	.10	16.00
JAN	16	16:17	7	1400	129	003	154	002	6.9	.10	16.00
JAN	16	16:17	7	1400	129	003	154	002	6.9	.10	16.00
JAN	16	16:18	7	1200	169	005	194	006	6.9	.10	16.00
JAN	16	16:18	7	1200	169	005	194	006	6.9	.10	16.00
JAN	16	16:19	7	1000	197	007	197	009	6.9	.10	16.00
JAN	16	16:19	7	1000	197	007	197	009	6.9	.10	16.00
JAN	16	16:20	7	1600	000	002	001	002	6.9	.10	16.00
JAN	16	16:20	7	1600	000	002	001	002	6.9	.10	16.00
JAN	16	16:21	7	1400	129	003	154	002	6.9	.10	16.00
JAN	16	16:21	7	1400	129	003	154	002	6.9	.10	16.00
JAN	16	16:22	7	1200	169	005	194	006	6.9	.10	16.00
JAN	16	16:22	7	1200	169	005	194	006	6.9	.10	16.00
JAN	16	16:23	7	1000	197	007	197	009	6.9	.10	16.00
JAN	16	16:23	7	1000	197	007	197	009	6.9	.10	16.00
JAN	16	16:24	7	1600	000	002	001	002	6.9	.10	16.00
JAN	16	16:24	7	1600	000	002	001	002	6.9	.10	16.00
JAN	16	17:57	7	1500	001	002	129	003	6.9	.10	16.50
JAN	16	17:58	7	1300	154	002	169	005	6.9	.10	16.00
JAN	16	17:59	7	1100	202	006	202	007	6.9	.10	16.00
JAN	16	18:01	7	1600	000	002	001	002	6.9	.10	16.00
JAN	16	18:03	7	1200	169	005	194	006	6.9	.10	16.00
JAN	16	18:04	7	1300	144	002	000	002	6.9	.10	16.00
JAN	16	18:05	7	1600	000	002	001	002	6.9	.10	16.00
JAN	16	18:07	7	1200	169	005	194	006	6.9	.10	16.00
JAN	17	05:32	7	0500	301	004	001	001	6.9	.10	16.50
JAN	17	05:33	7	0300	117	002	000	005	6.9	.10	16.50
JAN	17	05:34	7	0100	162	002	315	006	6.9	.10	16.50
JAN	17	05:35	7	2300	299	009	294	011	6.9	.10	16.50
JAN	17	05:36	7	0500	301	004	001	001	6.9	.10	16.50
JAN	17	05:37	7	0300	117	002	000	005	6.9	.10	16.50
JAN	17	05:38	7	0100	162	002	315	006	6.9	.10	16.50
JAN	17	05:39	7	2300	299	009	294	011	6.9	.10	16.50
JAN	17	05:40	7	0500	301	004	001	001	6.9	.10	16.50
JAN	17	05:41	7	0300	117	002	000	005	6.9	.10	16.50
JAN	17	05:42	7	0100	162	002	315	006	6.9	.10	16.50
JAN	17	02:11	7	2000	165	005	142	003	6.9	.10	17.10
JAN	17	02:12	7	0200	000	005	162	002	6.9	.10	17.10
JAN	17	02:13	7	0000	315	006	298	009	6.9	.10	17.10

C. Field Testing

Fabrication and bench testing of two wind averaging and data storage modules was completed in late April 1975. One of the prototype systems (No. 1) was transported to the Jersey Jim site in southwestern Colorado for field testing in early May 1975.

Initial checkout of the system using the LANDSAT field test set (see appendix A3) indicated proper operation. However, data were not being received in Denver via the satellite link. The system was examined to a limited extent at the field site and appeared to be functioning properly. The No. 1 system was left operating at Jersey Jim while the interface was examined in greater detail at WSSI using the No. 2 system. This examination revealed that when the DCP test set was not connected to the DCP, a noise pulse was generated on the interface lines each time the DCP transmitter turned on. This noise pulse simulated the serial data clock from the DCP to the wind averaging system. As a result, the wind averaging circuits turned off the DCP trigger command too early, disabling further data transmission. The interface was redesigned and bench tested on the No. 2 system. After completion of bench testing, the No. 2 system was installed at the Jersey Jim site for an extended period of field testing beginning June 27, 1975. The system operated satisfactorily until field testing was terminated in mid-August when the battery voltage dropped below the level at which the wind averaging electronics would operate.

The No. 1 system was modified to incorporate the interface redesign and installed at WSSI's Fort Collins facility for side-by-side testing with a conventional recording-type wind system. This unit operated from November 1975 through mid-January 1976.

D. Comparison Tests

During November and December 1975 and January 1976, the LANDSAT wind averaging system was operated in side-by-side tests with a Weather-Measure skyvane wind sensor. The wind speed and wind direction outputs from the Weather-Measure sensor were recorded on an Esterline-Angus two-channel chart recorder. These data were reduced manually, providing average values for the 10-minute period immediately preceding the hour. Tables 10, 11, 12, and 13 provide a comparison between wind speed and wind direction values obtained with the two systems for 4 successive days in mid-January 1976. These comparison data are displayed graphically in figures 16, 17, 18, and 19. The cross (x) represents data from the LANDSAT system and the circled dot (⊙) represents data reduced manually from strip-chart records. The shaded regions on the wind speed plots (top half) are for wind speeds in the 0.0 to 2.5 mi/h range. Winds below 2.5 mi/h are considered light and variable and are below the threshold at which accurate wind direction measurements can be obtained. The shaded regions on the wind direction plots (bottom half) identify time periods during which LANDSAT data were not available.

Table 10. - *Comparison wind data - January 16, 1976.*

	Wind Direction (Degrees)			Wind Speed (mph)		
Time	Recording	LANDSAT Averaging System	Difference	Recording Wind Unit	LANDSAT Averaging System	Difference
0100	006	360	-6	5	7	+2
0200	330	331	+1	12	13	+1
0300	321	319	-2	10	11	+1
0400	341	342	+1	5	6	+1
0500	012	360	-12	5	6	+1
0600	262	-		4	-	
0700	181	-		15	-	
0800	152	-		10	-	
0900	162	197	+35	9	9	0
1000	175	197	+22	7	7	0
1100	181	194	+13	4	6	+2
1200	149	169	+20	3	5	+2
1300	145	154	+9	2	2	0
1400	125	129	+4	2	3	+1
1500	059	001	-58	2	2	0
1600	005	360	-5	2	2	0
1700	337	360	+23	2	2	0
1800	134	144	+10	3	2	-1
1900	181	142	-39	3	3	0
2000	162	165	+3	4	5	+1
2100	301	306	+5	15	12	-3
2200	292	294	+2	11	11	0
2300	292	298	+6	7	9	+2
2400	310	315	+5	4	6	+2

Shading indicates periods of light and variable winds.

Table 11. - *Comparison wind data - January 17, 1976.*

	Wind Direction (Degrees)			Wind Speed (mph)		
Time	Recording	LANDSAT Averaging System	Difference	Recording Wind Unit	LANDSAT Averaging System	Difference
0100	153	162	+9	2	2	0
0200	040	360	-40	3	5	+2
0300	118	117	-1	3	2	-1
0400	111	001	-110	2	1	-1
0500	305	301	-4	3	4	+1
0600	253	-		2	-	
0700	045	-		2	-	
0800	277	-		2	-	
0900	259	271	+12	3	3	0
1000	121	110	-11	3	2	-1
1100	287	281	-6	3	2	-1
1200	322	001	+39	2	1	-1
1300	155	001	-154	3	1	-2
1400	210	247	+37	3	3	0
1500	322	001	+39	2	1	-1
1600	038	001	-37	2	2	0
1700	197	238	+41	3	2	-1
1800	202	238	+36	3	3	0
1900	081	-		2	-	
2000	181	207	+26	4	5	+1
2100	151	154	+3	3	4	+1
2200	146	154	+8	4	5	+1
2300	142	145	+3	3	4	+1
2400	163	157	-6	2	2	0

Shading indicates periods of light and variable winds.

Table 12. - *Comparison wind data - January 18, 1976.*

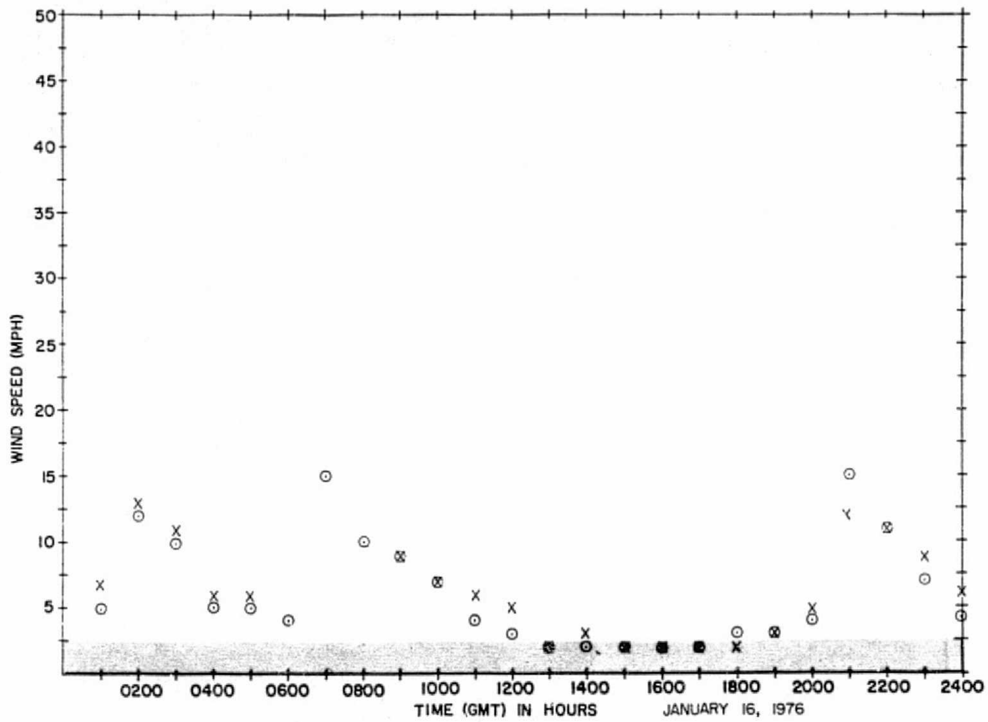
	Wind Direction (Degrees)			Wind Speed (mph)		
Time	Recording	LANDSAT Averaging System	Difference	Recording Wind Unit	LANDSAT Averaging System	Difference
0100	070	248	+178	2	1	-1
0200	303	306	+3	2	3	+1
0300	283	295	+12	2	4	+2
0400	291	315	+24	3	2	-1
0500	299	313	+14	3	4	+1
0600	300	-		2	-	
0700	288	302	+14	2	2	0
0800	301	314	+13	2	2	0
0900	017	360	-17	3	3	0
1000	264	261	-3	2	2	0
1100	269	286	+17	2	2	0
1200	287	318	+31	3	4	+1
1300	219	248	+29	2	1	-1
1400	161	112	-49	2	2	0
1500	193	112	-81	2	1	-1
1600	022	360	-22	2	2	0
1700	283	278	-5	2	1	-1
1800	320	325	+5	3	3	0
1900	146	141	-5	3	3	0
2000	211	157	-54	2	1	-1
2100	010	360	-10	3	4	+1
2200	044	001	-43	2	2	0
2300	187	210	+23	2	2	0
2400	182	210	+28	3	4	+1

Shading indicates periods of light and variable winds.

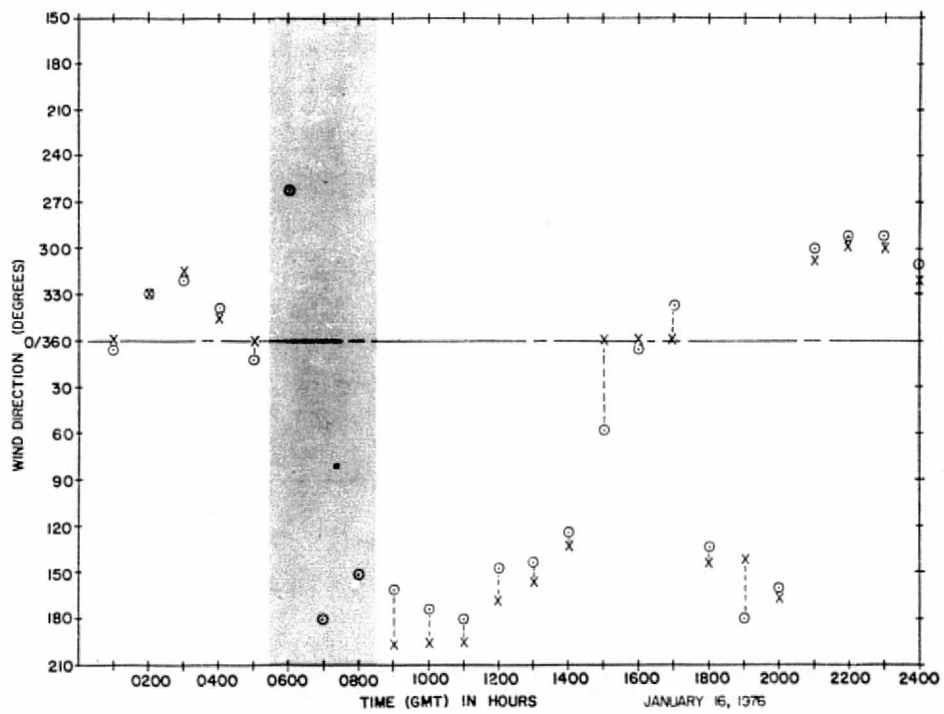
Table 13. - *Comparison wind data - January 19, 1976.*

	Wind Direction (Degrees)			Wind Speed (mph)		
Time	Recording	LANDSAT Averaging System	Difference	Recording Wind Unit	LANDSAT Averaging System	Difference
0100	019	360	-19	28	26	-2
0200	360	360	0	31	29	-2
0300	331	339	+8	24	22	-2
0400	354	360	+6	19	18	-1
0500	360	360	0	18	19	+1
0600	004	-		15	-	
0700	342	342	0	11	12	+1
0800	342	339	-3	7	9	+2
0900	343	345	+2	12	11	-1
1000	357	360	+3	7	8	+1
1100	359	360	+1	10	9	-1
1200	293	295	+2	4	6	+2
1300	326	332	+6	5	5	0
1400	112	108	-4	2	2	0
1500	197	222	+25	2	3	+1
1600	144	138	-6	3	2	-1

Shading indicates periods of light and variable winds.

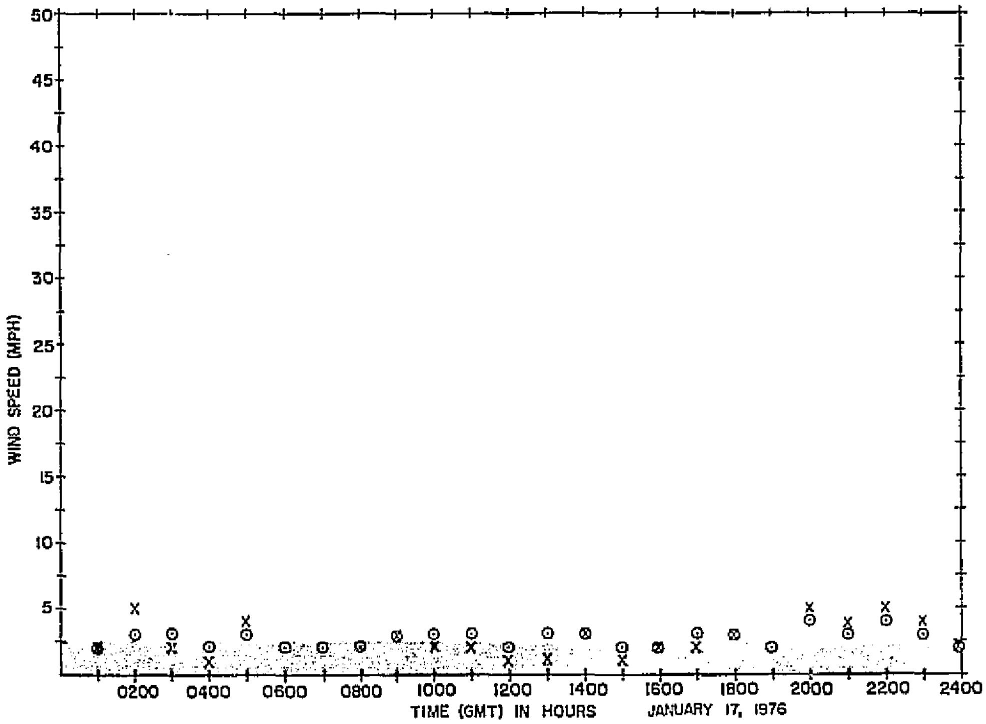


(16a) Averaged wind speed data.

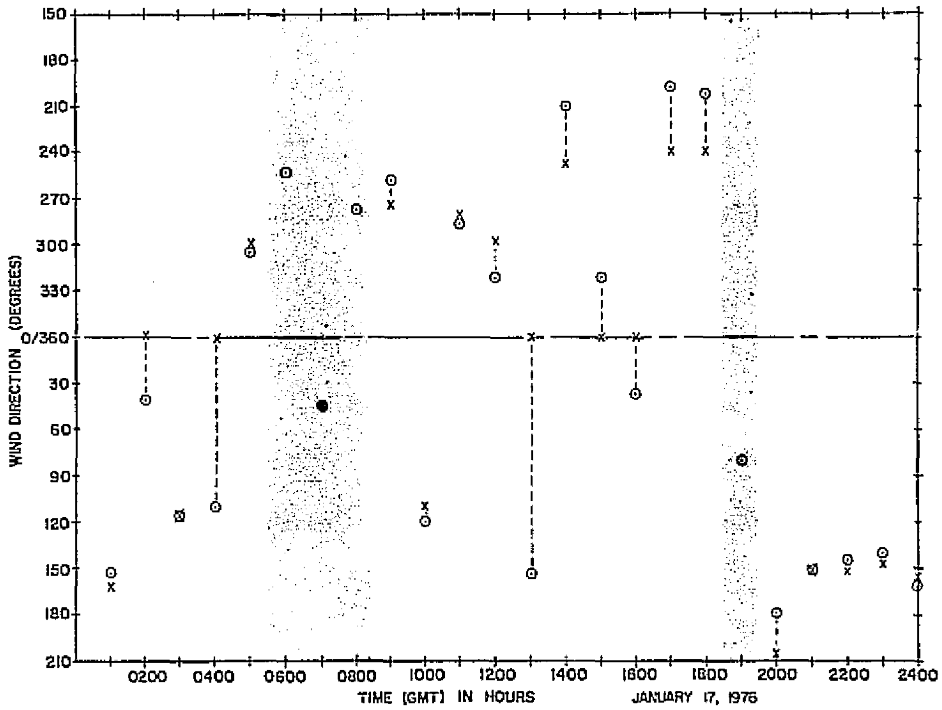


(16b) Averaged wind direction data.

Figure 16. - Averaged wind data comparison - January 16, 1976.
Cross (x) = LANDSAT data point
Circled dot (Θ) = Manually reduced data point

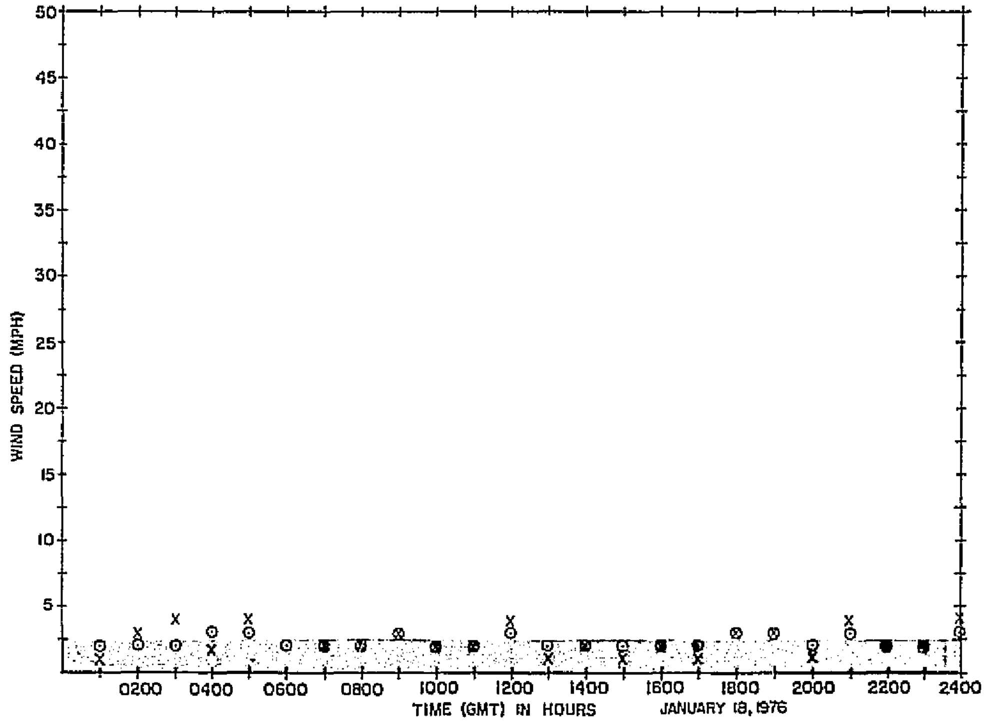


(17a) Averaged wind speed data.

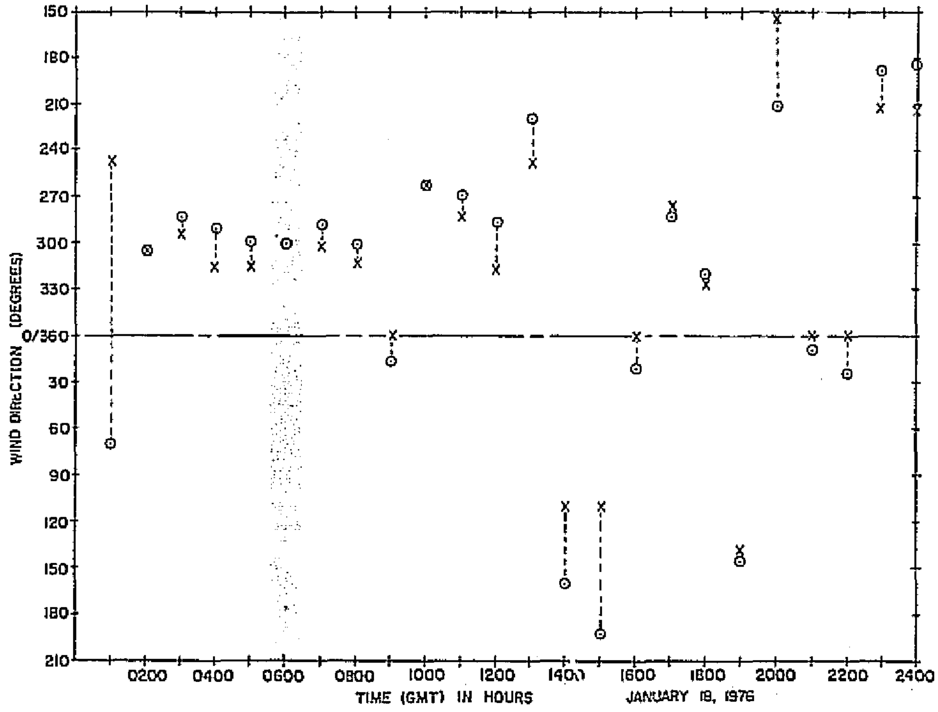


(17b) Averaged wind direction data.

Figure 17. - Averaged wind data comparison - January 17, 1976.
Cross (x) = LANDSAT data point
Circled dot (⊙) = Manually reduced data point

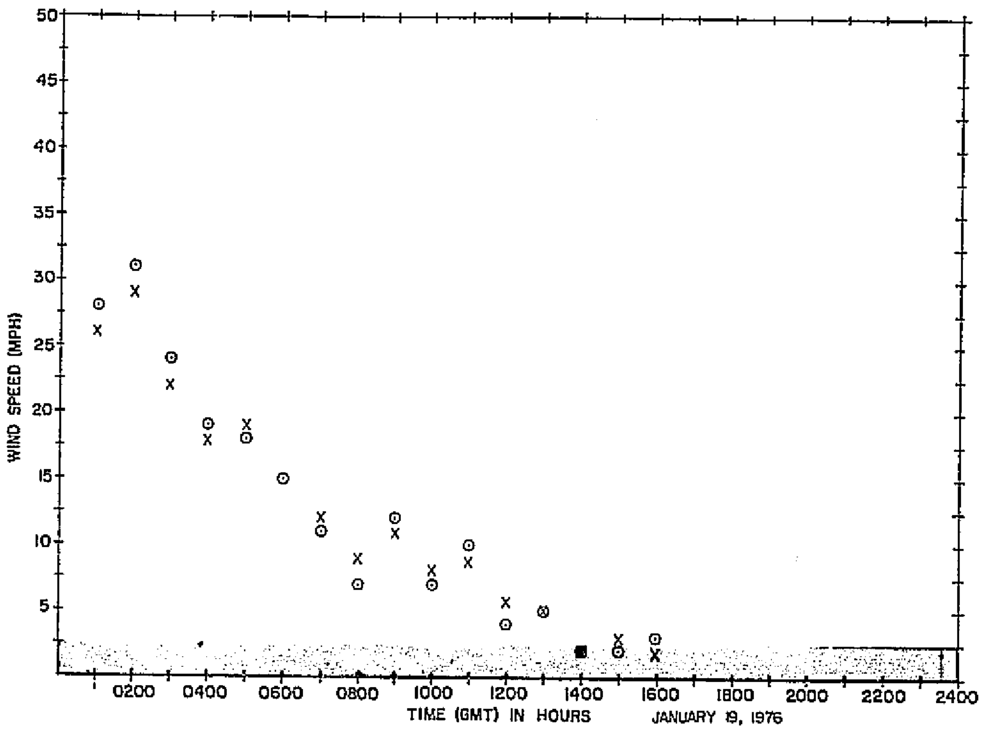


(18a) Averaged wind speed data.

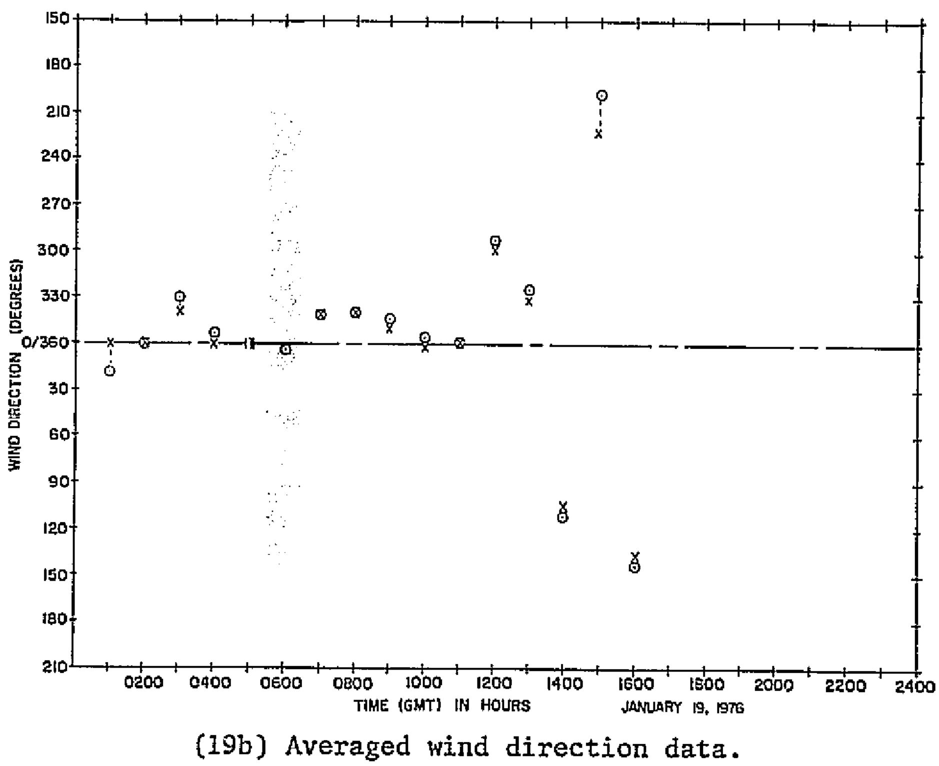


(18b) Averaged wind direction data.

Figure 18. - Averaged wind data comparison - January 18, 1976.
Cross (x) = LANDSAT data point
Circled dot (⊙) = Manually reduced data point



(19a) Averaged wind speed data.



(19b) Averaged wind direction data.

Figure 19. - Averaged wind data comparison - January 19, 1976.
Cross (x) = LANDSAT data point
Circled dot (⊙) = Manually reduced data point

Large differences in wind direction values can occur in the vicinity of 0° and 180° due to loss of resolution in the conversion from an analog voltage to an eight-bit data word. This is caused by the sinusoidal resistance function of the wind direction sensor (see fig. 12). The wind averaging system was originally designed to use a dual wiper wind direction potentiometer with a linear resistance function. The linear resistance function provides 1.4°/bit resolution for 0° to 360°. Resolution obtained with the sinusoidal resistance function is variable with the best resolution (0.9°/bit) occurring at 90° and 270° while the worst (10.14°/bit) occurs at 0° and 180°.

Excluding the periods during which the winds were light and variable and recognizing the coarse resolution in the region of 180° and 360°, the wind direction data are seen to be in close agreement. Most wind direction samples taken at times when the wind speed exceeded 5 mi/h agree within plus 6° to minus 3°. This seems to indicate a slight offset in the alinement of the sensors. A significant difference of minus 19° occurs at 0100 G.m.t. on January 19, 1976 (fig. 19), when the average wind speed was 26 to 28 mi/h. Review of the strip chart data for this period indicates considerable small angle fluctuations around 0° to 360°. Data varying in this manner are difficult to averag manually and can produce a large error in the reduced data.

The wind speed data obtained in the side-by-side comparison tests agree quite well. Except for a single data point at 2100 G.m.t. on January 16, 1976 (fig. 16), the LANDSAT data were within plus or minus 2 mi/h of the conventional type recording system. At the January 16, 2100 G.m.t. data point the difference was minus 3 mi/h.

It is interesting to note that though the system was designed to provide data coverage for two 8-hour blocks of time during a 24-hour period, actual data coverage was typically in excess of 20 hours out of 24.

E. Analog Sensor Channels

Previous meteorological measurements using the LANDSAT DCP have utilized only analog sensor outputs. The wind averaging system discussed earlier provides digital signals to the DCP. To fully utilize the system, three additional meteorological data channels were added to the five digital channels required for the wind data. To operate in this mixed mode (analog/digital), the DCP front panel channel select switches must be set in the following manner:

Channels 1-5, digital

Channels 6-8, analog

Because the DCP timing must be controlled by the wind averaging and data storage module, the DCP program assembly board was modified to accept a transmit trigger command from the wind system. To operate in this mode, the DCP message timer switch must be set to TEST.

The three meteorological sensors selected for use with the modified DCP were: (a) PCRC-11 relative humidity sensor, (b) Belfort No. 552 remote transmitting precipitation gage, and (c) YSI No. 44203 thermolinear thermistor network. These sensors are described in detail in appendix A1. Signal conditioning circuits used with the precipitation and air temperature sensors were identical to those used previously on the CRBPP program. The relative humidity sensor operates with a 1,000-Hz excitation signal and utilizes a peak detector signal conditioning circuit which provides a d-c signal output to the DCP. The precipitation, air temperature, and relative humidity data received through the LANDSAT DCS are instantaneous values, sampled at the time of transmission. An example of the data received during mixed mode (analog/digital) operation of the modified LANDSAT DCP is given in table 9.

VIII. RECOMMENDATIONS

This LANDSAT follow-on investigation has shown that: (1) many different types of environmental sensors can be interfaced to the LANDSAT DCP;

(2) the LANDSAT DCP's are reliable weather-resistant systems; (3) the data received through the LANDSAT system are of high quality; (4) the LANDSAT DCS is a useful tool in providing near-real-time data for activities such as weather forecasting, directing cloud seeding operations, and scheduling maintenance trips into remote areas; (5) the LANDSAT system is cost effective if the program is continued for at least 5 years, with only a similar system which uses a GOES (geostationary satellite) being slightly more effective due to its improved reception frequency; and (6) it is feasible to transmit averaged wind data, stored over a period of several hours, from a remote site. Based upon these findings, several recommendations are presented for utilizing and improving the performance of the LANDSAT DCS.

It is recommended that any future research should place continued emphasis on the application of the LANDSAT DCS for operational use. There are many situations which do not require hourly data and where the receipt of accurate data at approximately 12-hour intervals would be quite satisfactory, e.g., parameters necessary for predicting streamflow. Also, the technology has already been developed for providing a history of averaged wind data from remote sites; these data would be a tremendous asset in preparing operational forecasts. Projects having these data requirements from remote areas should be identified so that the LANDSAT DCS can be used operationally and developed further to expand the system's data collection capabilities.

New technology (referred to in section VI as the Remote Auto-Initiated Network or RAIN concept) acquired through satellite system development work would allow one or more meteorological parameters to be collected at several sites and then transmitted to a single LANDSAT DCP on a "self-timed" basis. In the LANDSAT investigation on the CRBPP, there was one LANDSAT DCP at each of the seven sites operated. The RAIN concept conserves the use of the DCP's, which normally have a higher data channel capacity than would be required, and makes it cost effective to collect data from a large number of sites using a modified LANDSAT/RAIN data collection system. It is recommended that the development of such a LANDSAT/RAIN DCS be pursued and subsequently used with a large instrument network.

Finally, convertible LANDSAT/GOES DCP's are being developed so that an investigator may use either the polar orbiting LANDSAT satellite or the geostationary GOES satellite DCS's. The GOES system allows all data collected to be transmitted and received as often as once per hour, thereby solving the problem some users have with the frequency of the LANDSAT system. Information on the development and operational plans for the LANDSAT/GOES compatible DCP's should be provided to present and potential users of the LANDSAT DCS so that they can develop long-range plans for data collection requirements.

APPENDIXES

APPENDIX A

APPENDIX A1

Parameter	Description of Sensor
Air Temperature	- YSI No. 44203 Thermilinear Thermistor Network. Range minus 30° to plus 50°C. Located on stand approximately 5 metres above the ground with radiation shield.
Precipitation	- Belfort No. 552 Remote Transmitting Gage. Twelve-inch capacity (rain or snow). Gage capacity is reduced to 10 inches because 2 inches of an antifreeze and oil mixture is added to the empty bucket to melt the snow and prevent evaporation. The sensor output is 0 to 5 V and provides 0.04 of an inch water equivalent resolution over the 10-inch range.
Relative Humidity	- PCRC-11 HP Electro-humidity Sensor. Alternating current excited (1,000 Hz). Senses changes in relative humidity by changes in impedance. Range 0 to 100 percent. Accuracy plus or minus 2.5 percent over the 0 to 100 percent range.

Snowpack Water Content - Standard Soil Conservation Service Snow Survey Snow-pillow. Fischer-Porter Hydrostatic measuring type.

Stream Stage - U.S. Geological Survey type, Leopold Stevens water level recorder, modified to provide an electrical output.

Water Temperature - YSI No. 44203 Thermilinear Thermistor Network. Range minus 30° to plus 50°C. Sensor is sealed in a stainless steel housing.

Wind Direction - MRI 1022D wind vane, SIN/COS dual wiper potentiometer, located approximately 8 m above ground.

Wind Speed - MRI 1022S three-cup photo chopper anemometer. Range 0 to 125 mi/h (0-56 m/s). Located with wind vane.

APPENDIX A2

Sensor Calibration Procedures

Prior to the field deployment of the LANDSAT DCPs and hydrometeorological sensors, a calibration was performed in the laboratory on each of the sensors. The LANDSAT FTS (Field Test Set) was used to verify sensor readings. This FTS is discussed in Appendix A3. A DVM (Digital Volt Meter) was used in "set up" procedures prior to final calibration and to insure that the DCP A/D (analog-to-digital) converter was functioning properly. Because of the design of the signal conditioning circuitry (most channels contained fixed-gain amplifiers), these calibrations involved establishing the relationship of digital information being transmitted to sensor readings. The circuit card contained three adjustable electronic controls; one established a 5-V, d-c excitation voltage for all sensors, and the other two were used to scale the temperature sensors. Except for temperature, all channels were prescaled during the design phase. After the laboratory calibrations were completed, the systems were installed in the field with the aid of the LANDSAT FTS and other aids described later. A "quick check" was made in the field to insure no major shift in values had occurred during transport. A description of the method of calibrating and determining the scaling values for each of the parameters both in the laboratory and on site are described in the following paragraphs:

1. Air Temperature - This parameter was measured with a Thermilinear Thermistor network. All three of the controls on the signal conditioning card are adjusted for scaling the temperature channel. The 5-V, d-c bias for sensor excitation is first adjusted with the assistance of a DVM. The DVM is then used to set two potentiometers which control the OFF-SET and SLOPE of the temperature amplifier circuit. When properly set these controls place the slope of the temperature sensor near the "ideal" slope of minus 30° to plus 50°C. However, due to normal variation of manufactured parts, the actual values vary from site to site. To establish the actual curve of the temperature, the temperature sensor was immersed in five or six liquid temperature baths. Temperatures near minus 30°, 0° and plus 50°C were used along with two or three intermediate temperatures for this calibration. Temperatures of the liquid baths were determined with mercury thermometers specified to be accurate to within plus or minus 0.5°C. When the data points were determined, a "best fit" line was established and the slope and intercept values calculated for use in the software at the data receiving central.

A one-point temperature check was made in the field at the time of installation to verify that the calibration had not shifted. This was accomplished by immersing the probe in an ice bath at 0°C.

2. Precipitation - Gages for measuring precipitation were purchased with a 10,000-ohm potentiometer instead of a chart recording device. The 5 V, d.c. generated on the signal conditioning card was used to provide the excitation voltage to the potentiometer. The signal conditioning amplifier was designed with a fixed gain which provided 0 to 5 V, d.c. to the LANDSAT DCP proportional to 0 to 10 inches of precipitation. The calibration was performed using standard calibration weights.

Ten data points equivalent to 0 to 10 inches of precipitation were taken. A "best fit" line was then established for use in data interpretation.

Field checks were made using the standard weights; however, fewer than 10 data points were observed.

3. Water Temperature - The temperature sensor and associated signal conditioners for measuring water temperature were identical to those employed for measuring air temperature, the only difference being the housing in which the linear thermistor was mounted. Calibration procedures used for this sensor were the same as those described in No. 1.

Field calibration checks were made by comparing observed water temperature to that being transmitted by the LANDSAT DCP.

4. Relative Humidity - This parameter is difficult to accurately calibrate without an elaborate humidity chamber. An electro-humidity sensor was used with the LANDSAT DCP. The signal-conditioning circuit was designed to convert the changes in impedance to a 0- to 5-V analog signal in the 30- to 70-percent relative humidity range. Laboratory calibration involved inserting known resistances proportional to the manufacturer's calibration curve into the signal conditioning circuitry and recording the resultant output signal.

Field checks involved checking the output of the LANDSAT DCP against a psychrometer to insure that relative humidity values were comparable.

5. Snowpack Water Content - The snowpillow employed by the SCS (Soil Conservation Service) incorporates a 10,000-ohm potentiometer in the mechanical linkage to the strip chart recorder. The 5-V, d-c excitation voltage developed on the signal conditioning card is applied to the potentiometer at the field site. The "calibration" is then performed by manually setting the water content recorder to predetermined values, recording the resultant output of the LANDSAT DCP, and establishing the slope of the line for data analysis. Normal scaling was for a range of 0 to 5 V, d.c. proportional to 0 to 40 inches of snowpack water content.

6. Stream Stage - A potentiometer was mounted in the stream stage recorder in a manner similar to that for the strip chart recorder for the snowpillow described in No. 5. Field calibration was performed as described for the snowpillow. Scaling for the stream stage was for a range of 0 to 5 V, d.c. proportioned to 0 to 3 feet of water depth in the streambed.

APPENDIX A3

LANDSAT Field Test Set (FTS)

As mentioned in section A2, the primary piece of test equipment which was used in the field to verify performance of the LANDSAT DCP along with the sensors and related signal conditioning circuits was the LANDSAT FTS (Field Test Set). Using the FTS in the NORMAL test mode permits the operator to simulate analog voltages into the DCP and check the transmitted message for each channel. The FTS can also check each channel of the transmitted message with the sensors and signal conditioners connected to the DCP. RF power at the transmitter output is also checked in this mode. In the SELF-TEST mode, the test set generates a preset pattern of digital data which simulates the DCP output. This test verifies correct operation of the FTS.

The only useful parameter that the FTS is not able to check is the actual transmitted power at the antenna. A bad connection between the antenna and the DCP cannot be detected in the field. To eliminate this weakness, a LANDSAT receiver would be required as a part of the FTS so that the actual transmitted message could be received by the FTS and the eight-word message, along with the station ID, decoded, and displayed.

APPENDIX B

LISTING OF COMPUTER PROGRAMS

1. Subroutine ERTS - routine to decode and store data; includes subroutine GDATE which converts Julian date to calendar date.

2. Program WEST1 - program to display the data.

3. Subroutine RCODE - converts averaged wind data to en_ neering units (mi/h and degrees).

I. SUBROUTINE ERTS

```
      SUBROUTINE ERTS
      DIMENSION IMES(8),FNAME(8),FACTR(16,8),FOCT(9),TOCT(9),
     $NSTA(8),A(72),DATAZ(12),KID(8)
      INTEGER FNAME,FNAME1,FNAME2,TOCT,A,B,DATA,C
      DATA NSTA/143,962,241,040,347,202,025,212/
      DATA FNAME/6HCASTLE,6HHIPLEX,6HWLFCRP,6HJERJIM,
     $6HLIMESA,6HWLFCRN,6HUPRSAJ,6HMULSJE/
      DATA(FACTR(1,J),J=1,8)/.308508,1.,1.,1.,.039559,1.,.0196,.056794/
      DATA(FACTR(2,J),J=1,8)/-29.13,0.,0.,0.,-.055566,0.,0.,.626107/
      DATA(FACTR(3,J),J=1,8)/8*1.0/
      DATA(FACTR(4,J),J=1,8)/8*0.0/
      DATA(FACTR(5,J),J=1,8)/.33220,1.0,1.,1.,.039495,1.,.0196,.056794/
      DATA(FACTR(6,J),J=1,8)/-31.66,0.,0.,0.,-.084161,0.,0.,.626107/
      DATA (FACTR(7,J),J=1,8)/5*1.0,.0625,.251,.00355/
      DATA (FACTR(8,J),J=1,8)/6*0.0,-31.23,.0931/
      DATA(FACTR(9,J),J=1,8)/.315243,1.,1.,1.,.039882,1.,.0196,.056923/
      DATA(FACTR(10,J),J=1,8)/-29.88,0.,0.,0.,-.101351,0.,0.,.26538/
      DATA(FACTR(11,J),J=1,8)/.1915,.03846,1.,1.4706,.38040,1.,.0196,
     $.055448/
      DATA(FACTR(12,J),J=1,8)/-30.30,0.,1.923,0.,0.,0.,0.,.6614/
      DATA(FACTR(13,J),J=1,8)/.311356,1.,.039753,1.,.156128,1.,1.,1./
      DATA(FACTR(14,J),J=1,8)/-29.88,0.,-.102859,0.,-1.478044,0.,0.,0./
      DATA(FACTR(15,J),J=1,8)/8*1.0/
      DATA(FACTR(16,J),J=1,8)/8*0.0/
C     READ FIRST LINE
C     OF DATA AND CHECK FOR VALID STATION
 1    READ(5,1000) A
      IF(EOF(5)) 250,2
2     CONTINUE
      PRINT1000,A
      IF(A(1).EQ.1H .AND.A(3).EQ.1H )  GO TO 100
      IF(A(1).EQ.1HN.AND.A(3).EQ.1HN)  GO TO 250
 100  IF(A(2).EQ.1HS) GO TO 1
      IF(A(2).EQ.1HN.AND.A(3).EQ.1H ) GO TO 7
      IF(A(2).EQ.1HG.AND.A(3).EQ.1H ) GO TO 7
      GO TO 1
7      CONTINUE
      DO 19 I=4,72
      IF(A(I).EQ.1H ) GO TO 19
       IF(A(I).LT.1H0.OR.A(I).GT.1H9) PRINT 177,(A(K),K=1,72)
        IF(A(I).GE.1H8.AND.I.GT.21) PRINT177,(A(K),K=1,72)
      IF(A(I).GE.1H8.AND.I.GT.21) GO TO 1
       IF(A(I).LT.1H0.OR.A(I).GT.1H9) GOTO 1
19     CONTINUE
177    FORMAT(1H ,*BAD SXUS*,/,72A1)
      ENCODE(72,1000,KID)A
      DECODE(72,1010,KID) IYR,JUL,ITIME,ISTA,(TOCT(J),J=1,9)
      ENCODE(7,7090,DATA)ITIME
      DECODE(7,7091,DATA)A(1),A(2)
      A(3)=1H.
      ENCODE(5,7092,DATA) A(1),A(3),A(2)
      DECODE(5,7093,DATA) C
7090  FORMAT(I7)
7091  FORMAT(2I2,3X)
7092  FORMAT(I2,A1,I2)
7093  FORMAT(A5)
      IYR=IYR+1970
      DO 10 I=1,8
      IF(ISTA.EQ.NSTA(I)) GO TO 15
10    CONTINUE
      GO TO 1
15    FNAME1=FNAME(I)
      K=(2*I)-1
      KK=K+1
1000  FORMAT(72A1)
1010  FORMAT(4X,I1,1X,I3,I7.7,3X,I3,O3,8O5,O4)
      N=0
      DO 9 I=2,9
```

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```
      N=N+1
      FOCT(I)=TOCT(I)
9     FOCT(I)=FACTR(KK,N)+FOCT(I)*FACTR(K,N)
      CALL GDATE (JUL,AMON,NVDAY,IYR)
      IYR=IYR-1970
      IND=1
      CALL TIME(B)
      REWIND 78
      REWIND 77
      CALL GETIN(IND,6HTAPE77,FNAME1)
      IF(IND.LT.0) GO TO 1
      DO 110 I=1,1000
      K=I
      READ(77,1000)A
      IF(EOF(77)) 111,109
109   WRITE(78,1000)A
110   CONTINUE
111   CONTINUE
      ENCODE(10,1070,DATA)B
      DECODE(10,1071,DATA)B
1070   FORMAT(A10)
1071  FORMAT(A6,4X)
      ENCODE(6,1072,DATA)B
      DECODE(6,1073,DATA)IHR
1072  FORMAT(A6)
1073  FORMAT(1X,I2,3X)
      IF(IHR.GT.17) JUL=JUL-1
      WRITE(78,1025) AMON,NVDAY,C,TOCT(1),(FOCT(K),K=2,9),JUL
     $,B
      IND=1
      CALL PURGIT(IND,FNAME1)
1027  CONTINUE
      REWIND 78
      CALL SAVE(6HTAPE78,FNAME1,0,2HPU)

      GO TO 1
1025  FORMAT(1X,A3,I3,1X,A5,I2,F6.1,F6.1,F6.2,F6.1,F6.2,2F6.1,F6.1,I4,
     $A6)
1026  FORMAT(1X,A3,I3,1X,A5,I2,F6.1,F6.1,F6.2,F6.1,F6.2,2F6.1,F6.1,I4,
     $A6)
250   RETURN
      END
      SUBROUTINE GDATE(JDAY,AMON,NVDAY,IYEAR)
      DIMENSION IEND(13),LENDAY(13),ALPHMO(12)
      DATA (IEND(MO) ,MO=1,13)/0,31,59,90,120,151,181,212,243,273,304,
     $334,365/
      DATA (ALPHMO(K),K=1,12)/3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,3HJUN,3HJUL,
     $3HAUG,3HSEP,3HOCT,3HNOV,3HDEC/
      LENDAY(1)=IEND(1)
      LENDAY(2)=IEND(2)
      LEAP=0
      YEAR=IYEAR
      IYR=IYEAR/4
      YEAR=YEAR/4.0
      YR=IYR
      REM=YEAR-YR
      IF(REM.EQ.0) LEAP=1
      DO 30 K=3,13
      LENDAY(K)=IEND(K)+LEAP
30    CONTINUE
      DO 40 KP=1,13
      IF(JDAY.LE.LENDAY(KP)) GO TO 60
40    CONTINUE
60    AMON=ALPHMO(KP-1)
      NVDAY=JDAY-LENDAY(KP-1)
      RETURN
      END
```

2. PROGRAM WEST1

```
      PROGRAM WEST1(OUTPUT=65/80,INPUT=65/80,TAPE77)
      INTEGER A,X,B,FNAME,FNAME1,TOCT,ANS,ANAME
      DIMENSIONA(7),B(64),FNAME(8),JUL(530)
      DATA FNAME/6HCASTLE,6HHIPLEX,6HWLFCRP,6HJERJIM,6HLIMESA,
     $6HWLFCRN,6HUPRSAJ,6HMULSUE/
      PRINT 1775
1775  FORMAT(1X,*YOU CAN LIST ANY OF THE FOLLOWING PLATFORMS*,/,
     $,1X,*CASTLE,HIPLEX,WLFCRP,WLFCRN,JERJIM,LIMESA,UPRSAJ,MULSUE*)
1     PRINT 1777
      CRLF=66676767676767676767B
1777  FORMAT(1X,*GIVE THE NAME OF THE PLATFORM YOU WANT LISTED*)
      READ 1176,FNAME1
1176  FORMAT(A6)
      DO 101 IK=1,8
      IND=1
      IF(FNAME1.EQ.FNAME(IK)) GO TO 102
101   CONTINUE
      PRINT 1776,FNAME1
1776  FORMAT(1X,*THE FILE YOU ASKED FOR *,A6,* IS NOT VALID*)
102   CONTINUE
      NUM=7LEP1200B
      IND=1
      CALLGETIN(IND,6HTAPE77,FNAME1,NUM,0)
      PRINT *,IND
      REWIND 77
8     K=IK
30    IPAGE=0
      PRINT 777,CRLF
777    FORMAT(A10)


      GO TO (200,210,220,230,240,250,260,270)K
200   PRINT 500
       GO TO 100
210   PRINT 530
      GO TO 100
220   PRINT 510
      GO TO 100
230   PRINT 525
      GO TO 100
240   PRINT 520
      GO TO 100
250   PRINT 515
      GO TO 100
260   PRINT 505
      GO TO 100
270   PRINT 535
100   CONTINUE
      DO 300 I=1,500
      READ(77,1010) B,JUL(I),X
1010  FORMAT(64A1,I3,A6)
      IF(EOF(77)) 301,90
90      IF(IK.EQ.4.OR.IK.EQ.8) CALL RCODE(B,X)
      IF(IK.EQ.4.OR.IK.EQ.8) GO TO 94
       PRINT1010,B,JUL(I),X
 94   CONTINUE
      IPAGE=IPAGE+1
      IF(IPAGE.GT.50) PRINT 1000
      IF(IPAGE.GT.50) PRINT 777,CRLF
      IF(IPAGE.GT.50) IPAGE=1
300   CONTINUE
301   CONTINUE
1000  FORMAT( ,1X,10(/))
      PRINT 1774
```

PROGRAM WEST1 - CONT'D

```
1774  FORMAT(1X,*DO YOU WANT ANOTHER PLATFORM LISTING\,YES OR NO*)
      READ 1773,IANS
1773  FORMAT(A2)
      IF(IANS.EQ.2HYE) GO TO 1
500   FORMAT(1X,
     $*143 CASTLE CREEK LAT 37.12"N LONG 106.45"W ELV 9100 FT*,/,* *,
     $*DATE   TIME  C  TEMP  TVO    TVO   TVO   PCP   TVO  HSV    BAV *,
     $*JUL TIME*,/,
     $*  GMT   GMT        C    BIT    BIT   BIT   IN.   BIT   V       V*,
     $*  DAY RCVD*)
505   FORMAT(*  025 UPPER SAN JUAN LAT 37.29"N 106.50"W ELV 10200*,/,
     $* DATE   TIME  C  TEMP  TVO    PCP   TVO   SNP   TVO  HSV    BAV*
     $,* JUL TIME*,/,* GMT    GMT        C    BIT     IN.   BIT   FT. *,
     $*  BIT   V       V  DAY RCVD*)
510   FORMAT(*  241 WOLF CREEK PASS LAT 37.29"N LONG 106.53"W ELV 10810*,
     $,*FT*,/,* DATE    TIME  C  TEMP  TVO    TVO   TVO   PCP   TVO*
     $,*  HSV    BAV JUL TIME*,/,*  GMT   GMT        C    BIT    BIT   *
     $,*BIT   FT.    BIT  V        V  DAY RCVD*)
520   FORMAT(*  347 LIME MESA LAT 37.34"N LONG 107.41"W ELV 11700*
     $,*FT*,/,* DATE    TIME  C  TEMP  TVO    TVO   TVO   PCP   TVO*
     $,*  HSV    BAV JUL TIME*,/,*  GMT   GMT        C    BIT    BIT   *
     $,*BIT   FT.    BIT  V        V  DAY RCVD*)
525   FORMAT(*  043 JERSY JIM  LAT 37.34"N  LONG 107.41"W ELV 11700*
     $,*FT*,/,1X,*   DATE TIME          TIME  CURRENT    PREV HR     *,
     $* C U R R E N T  *,/,*XMITTED TO SAT  CON   OF     *,
     $*WIND WIND  WIND WIND    PRECIP RH TEMP  *,/,
     $*         GMT       L/L    DATA  DIR SPEED  DIR SPEED  *,
     $*    (IN)      (C)    *)
515   FORMAT(*  202 WOLF CREEK NORTH LAT 37.27"N LONG 106.53"W ELV 7900*
     $,*FT*,/,*  DATE  TIME  C  TEMP  TVO    TVO   TVO   TVO   TVO*
     $,*  HSV    BAV JUL TIME*,/,*   GMT   GMT        C    BIT    BIT   *
     $,*BIT   BIT   BIT    V       V  DAY RCVD*)
530   FORMAT(*  062 HIGH PLAINS TEST PLATFORM*,
     $/,* DATE    TIME   C  TEMP  TVO    TVO   TVO  TVO   HSV   *
     $,*BAV JUL TIME*,/,*  GMT   GMT        C    BIT    BIT   BIT   BIT*
     $,*  BIT     V        V DAY RCVD*)
535   FORMAT(*  212 MULSHOE LAT 37.52"N LONG 107.45"W ELV 12300 FT*,/,
     $,1X,*DATE TIME    ?    ? TIME?CURRENT   ?PREV HR  ? *,
     $* C U R R E N T? TIME RCVD *,/,*XMITTED TO SAT?CON? OF   ?*,
     $*WIND WIND?WIND WIND? RH TEMP?PRECIP?    AT     *,/,
     $*         GMT     ?LVL? DATA?DIR SPEED?DIR SPEED?*,*
     $*       (C)  (IN)  ? CYBER 74 *)
      END
```

3. SUBROUTINE RCODE

```
      SUBROUTINE RCODE(B,X)
      INTEGER B,C,X
      DIMENSION B(64),C(5),KT(64),
     $IXX(5)
      ENCODE(64,1000,KT) B
      DECODE(64,1010,KT) DATE,ITIME,IMIN,ICON,AN,W,WS,W1,WS1,PCPN,TEMP,
     $RH
      WS=WS*.407
      WS1=WS1*.407
 1000 FORMAT(64A1)
 1010 FORMAT(1X,A6,1X,I2,A3,I2,F6.1,F6.1,F6.2,2F6.2,3F6.1)
      IAN1=AN/16.0
      IAN2=AN
      IAN2=(IAN2.AND.7B)
      IDEL=IAN1-IAN2
      IF(IDEL.LT.0)IDEL=IDEL+8
      NTIME=ITIME-IDEL
      NTIME=NTIME*100
      IF(NTIME.LT.0)NTIME=NTIME+2400
      IF(W.GE.128)GOTO2000
      IF(W.GE.64)GOTO2010
      WD=90+57.2958*ASIN((64-W)/64)
      GO TO 3000
 2000 W=W-128
      IF(W.GE.64)GOTO2020
      WD=180+57.2958*ACOS((63-W)/64)
      GO TO 3000
 2020 WD=270+57.2958*ASIN((W-63)/64)
      GO TO 3000
 2010 WD=ACOS((W-64)/64)
 3000 CONTINUE
      IF(W1.GE.128) GO TO 2500
      IF(W1.GE.64)GOTO2510
      WD1=90+57.2958*ASIN((64-W1)/64)
      GOTO4000
 2500 W1=W1-128
      IF(W1.GE.64)GOTO3020
      WD1=180+57.2958*ACOS((63-W)/64)
      GO TO 4000
 3020 WD1=270+57.2958*ASIN((W1-63)/64)
      GOTO4000
 2510 WD1=ACOS((W1-64)/64)
 4000 CONTINUE
      ENCODE(5,1099,KN)ITIME,IMIN
      DECODE(5,1098,KN)C
      C(3)=1H:
      DO 1097 I=1,5
 1097 IF(C(I).EQ.1H )C(I)=1H0
 1099 FORMAT(I2,A3)
 1098 FORMAT(5A1)
 1055  FORMAT(I3)
 1056 FORMAT(3A1)
      IWD1=WD
      IWS=WS
      IWS1=WS1
      IWD2=WD1
      PRINT 1040, DATE,C,ICON,NTIME,IWD1,IWS,IWD2,IWS1,PCPN,RH,
     $TEMP
 1040 FORMAT(1X,A6,2X,5A1,I4,4X,I4.4,1X,
     $4(2X,I3.3),F9.2,F5.2,1X,F6.1,1X)
      RETURN
      END
```

APPENDIX C

RELATIVE HUMIDITY SENSOR TECHNOLOGY

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Investigation of

Relative Humidity Sensor Technology

Accurate relative humidity measurements at remote, battery-operated installations are difficult to obtain. Most relative humidity sensors in use today have a nonlinear response and require some type of linearizing electronics. These units, which include the linearizing circuits, usually consume excessive power and are not suitable for remote applications. Digitizing the sensor output prior to linearization results in poor resolution over certain portions of the sensors operating range. Also, many sensors require an a-c excitation signal and are sensitive to changes in the frequency of this signal. This appendix presents the results of a small-scale investigation of the current status of relative humidity sensor technology.

Various meteorological instrument and sensor manufacturers around the country were contacted, and descriptions and specifications of relative humidity measurement equipment were obtained from these firms. Typical sensors available from these manufacturers are described below:

General Eastern Corporation - Model 400C

Sensor: Sulfonated polystryene ion-exchange sensor produces large changes in electrical resistance with changes in relative humidity.

Price: $795.00 (includes linearizing electronics and meter readout of relative humidity and temperature).

Hygrometrix, Inc. - Model 8501

Sensor: Assembly of hygromechanical crystallite structures (sensing element) and a piezoresistive silicon strain gages on a common substrate. The sensing element responds to changes in relative humidity, actuating the strain gages to yield changes in electrical resistance proportional to the changes in electrical resistance proportional to the changes in relative humidity.

Price: $525.00 (includes linearizing electronics with 0- to 5-V, d-c output).

Phys-Chemical Research Corporation - Model PCRC-11

Sensor: Chemically treated styrene copolymer - surface resistivity varies with changes in relative humidity.

Price: $50.00 (probe with sensor only)

Thunder Scientific - Model BR-101

Sensor: Crystal ladder network mounted in a TO-5 transistor-type package.

Price: $100.00 (sensor only)

Yellow Springs Instrument Company - Model YS19101

Sensor: Bifilar electrodes wound on a wick covering a hollow bobbin. The wick is impregnated with lithium chloride, a hygroscopic salt which becomes increasingly conductive as it absorbs moisture. When a voltage is applied to the electrodes, heat is generated as the wick conducts current between the electrodes. Moisture evaporates from the wick until a heat-moisture equilibrium is reached. This equilibrium temperature, related to the dewpoint temperature, is sensed with thermilinear thermistors mounted inside the hollow bobbin.

Price: $70.00

A short period of comparison testing was conducted using the following sensors:

Hygrometrix - Model M8501

Phys-Chemical Research Corporation - Model PCRC-11

Sling Psychrometer

Hair hygrometer

The Hygrometrix unit included the linearizing electronics and was obtained from the manufacturer for evaluation. The PCRC-11 had been used previously with the LANDSAT DCP's. This unit did not include any linearizing electronics. The sling psychrometer and hair hygrometer were used as the reference sensors.

There was extreme variability in the relative humidity measurements obtained with the various sensors. All sensors were installed in a ventilated thermal screen and can, therefore, be considered to have been measuring the same relative humidity. The variations in actual measured values can realistically be attributed to such factors as response time of the sensor and temperature dependence of the sensor's sensitivity. Also, this testing consisted of a small number of samples, and the results should not be considered anything more than a general look at the relative characteristics of several typical relative humidity sensors.

A test example which is indicative of the problems associated with relative humidity measurements occurred when three PCRC-11 sensors were tested simultaneously within 12 inches of each other inside the thermal screen. Over a 30-day period, simultaneous readings for the three indentical sensors ranged from within 2 percent to as much as 18 percent difference.

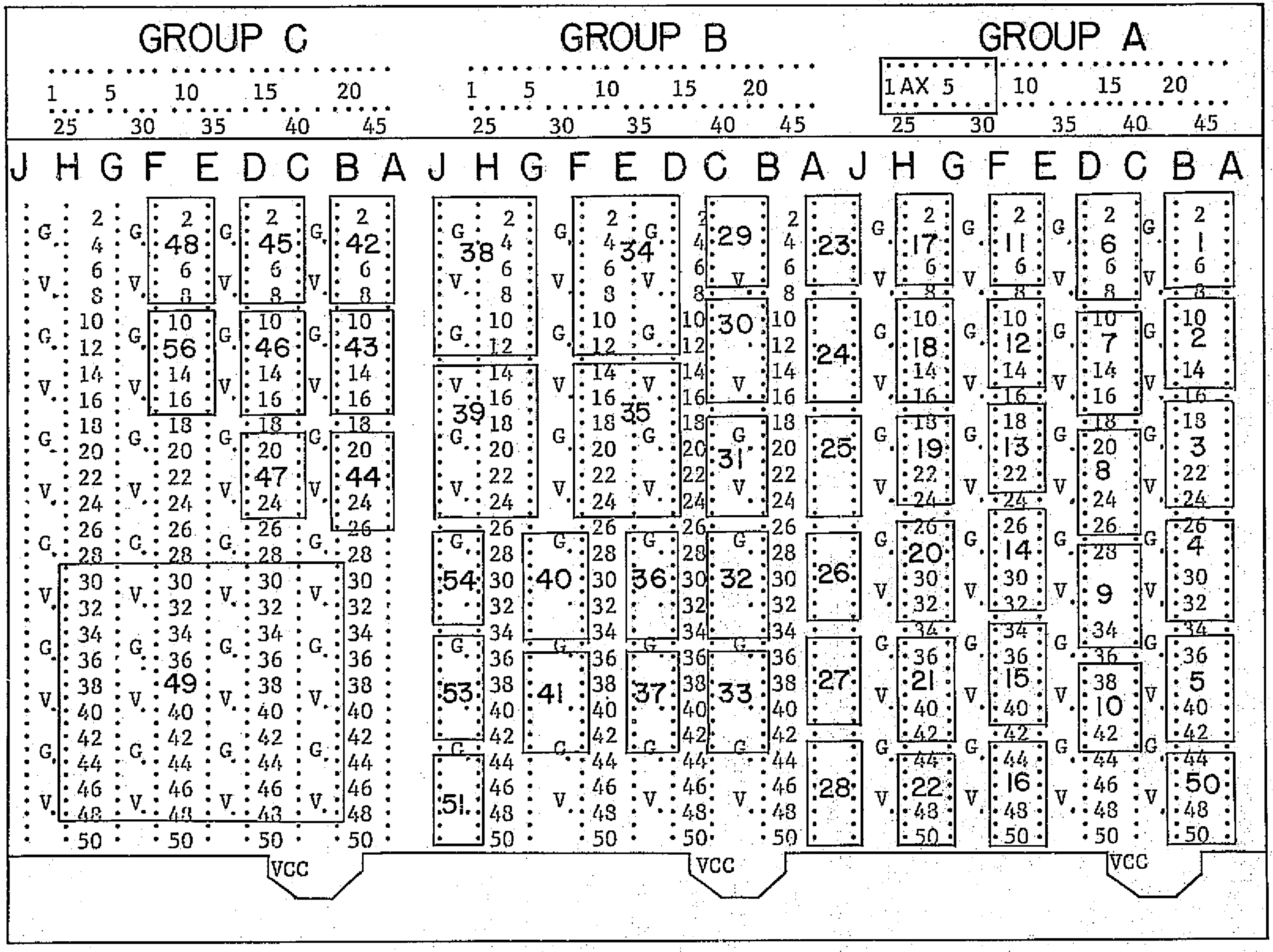
The Hygrometrix Model M8501 compared favorably with the PCRC-11 for use in remote, battery-operated systems. The power requirements of the linearizing electronics is less than 3 watts. Applying power to the linearizing electronics only during measurement periods would reduce power consumption to a level compatible with battery operation.

Measurements of relative humidity remain a problem in the field of meteorological data collection. More extensive investigations and evaluations pertaining to sensor technology will require an extended test period with access to specialized test and calibration instrumentation.

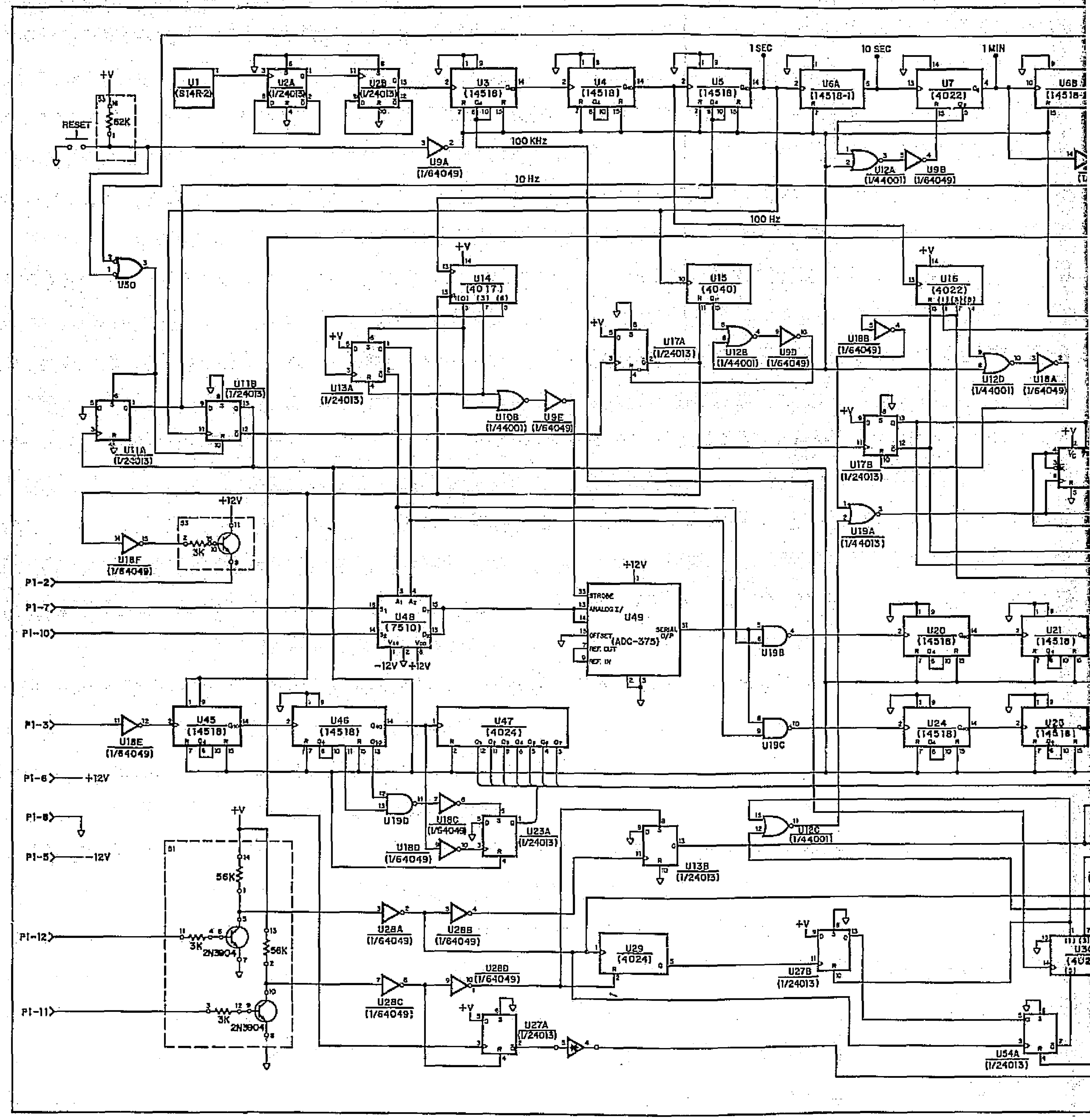
APPENDIX D

D1. Wire Wrap Board Layout for LANDSAT Wind Averaging System

D2. Detailed Circuit Diagram of LANDSAT Wind Averaging System



D1. - Wire wrap board layout for LANDSAT wind averaging system.



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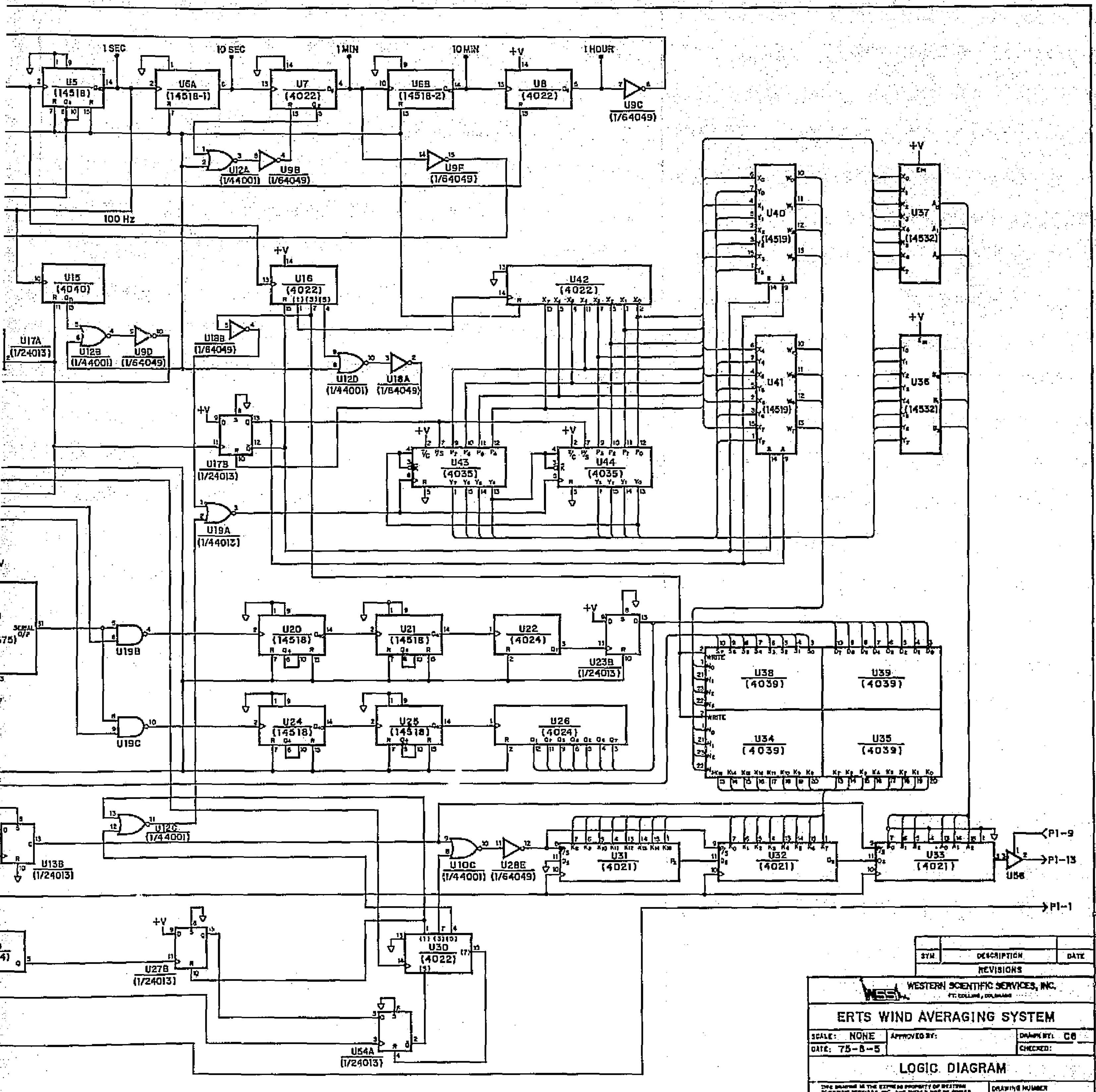

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GLOSSARY

Cloud Seeding	- Any technique carried out with the intent of adding to a cloud certain particles that will alter the natural development of that cloud.
Geostationary	- Of, relating to, or being an artificial satellite that travels about the equator and at the same speed as the earth rotates so that the satellite seems to remain in the same place.
Hydrometeorology	- A branch of meteorology that deals with water in the atmosphere, especially as precipitation.
Meteorburst Communications	- A VHF communications technique that utilizes free electrons in ionized meteor trails in the upper atmosphere to reflect and/or reradiate radio waves.
Null Hypothesis	- A statistical hypothesis to be tested and accepted or rejected in favor of an alternative; specifically, the hypothesis that an observed difference (as between the means of two samples) is due to chance alone and not due to a systematic cause.

Orographic	- Of or relating to mountains; especially: associated with or induced by the presence of mountains, e.g., clouds and precipitation caused by the lifting of an air mass as it moves up and over a mountain range.
Precipitation Gage	Any device that measures the amount of precipitation; - specifically for this project, one that measures the weight of the water (as rain or snow); the bucket inside the gage requires periodic recharging with new antifreeze-type solution.
River Basin	- The entire tract of country drained by a river and its tributaries.
Runoff	- The water, derived from precipitation, that ultimately reaches stream channels.
Satellites	- A manmade object or vehicle intended to orbit the earth.

Snow Bridging - Basically the same as snowcapping; snow accumulates inside a precipitation gage during periods of heavy snowfall faster than it can melt into the antifreeze solution. Consequently, the snow will eventually build out through the gage orifice, preventing the measurement of any additional precipitation.

Snowcapping - A covering cap of snow, especially a cap of snow over the orifice of a precipitation gage due to an abnormally heavy precipitation rate.

Snow Course - An established line, usually several hundred feet, traversing representative terrain in a mountainous region of appreciable snow accumulation. Samples of the snowpack are periodically taken and averaged to obtain measurements of snow depth and its water equivalent.

Snowpillow - An instrument installed in the field which measures the cumulative equivalent water content of the snowpack by weight.

Streamflow - The water flowing in a stream channel.

Stream Gage	- A device installed in a stream channel which measures the stream stage.
Synchronous	- A satellite moving from west to east with a 24-hour circular orbital period is said to have a synchronous orbit or to be a synchronous satellite. In the special case in which the orbital plane of the synchronous satellite is the same as the Earth's equatorial plane, the satellite is referred to as geostationary.
Telemeter	- Electrical apparatus for measuring quantities (as air temperature, precipitation, wind speed and direction), transmitting the result especially by radio to a distant station, and there recording the quantity measured.
Telemetry	- The measurement of quantities at a distance.
Thermograph	- An instrument which measures temperature by utilizing the variation of the physical properties of substances according to their thermal states and records the data onsite.

Transducer	- A device which converts variations in a physical parameter to changes of an electrical nature.
Weather Modification	- In general, any effort to alter artificially the natural phenomena of the atmosphere, e.g., increasing precipitation.

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