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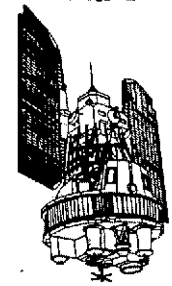

Use of the ERTS-1 Satellite Data Collection System in Monitoring Weather Conditions for Control of Cloud Seeding Operations

DIVISION OF ATMOSPHERIC WATER RESOURCES MANAGEMENT
BUREAU OF RECLAMATION
DEPARTMENT OF INTERIOR

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16. ABSTRACT

Seven ERTS satellite data collection platforms have been utilized by the Bureau of Reclamation in a major winter weather modification program in the Colorado River Basin. The platforms have been operated since the Spring of 1973 and temperature, precipitation, wind speed, wind direction, radiation, streamflow, humidity, and snowpack water equivalent observations are routinely relayed by the ERTS satellite to the Goddard Space Flight Center where they are in turn transmitted to a Denver computer and are accessible within 3 to 8 hours of onsite transmission via teletype terminals.

Presented is a summary of the experience gained from a 22-month experiment to determine the operational utility of the ERTS data collection system in control of cloud seeding operations. The field installations developed for use in the severe weather environment of the San Juan Mountains are described, maintenance experiences are presented, data transmission statistics derived, the cost-effectiveness of the ERTS DCS is evaluated relative to other more traditional data collection systems, and the utility of the ERTS DCS in collection of meteorological and hydrometeorological data is discussed and summarized.

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b. IDENTIFIERS--
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USE OF THE ERTS-1 SATELLITE DATA COLLECTION SYSTEM IN MONITORING WEATHER CONDITIONS FOR CONTROL OF CLOUD SEEDING OPERATIONS

Final Report - July 1974

by Dr. Archie M. Kahan, Chief
Division of Atmospheric Water Resources Management

Prepared for:

Goddard Space Flight Center
Greenbelt, Maryland 20771
Contract No. S-70243-AG
Amendment No. 8, Task No. 41

United States Department of the Interior * Bureau of Reclamation

PREFACE

This final report by the Division of Atmospheric Water Resources Management, Bureau of Reclamation, is submitted to the EROS/ERTS Project Office. It documents the results of 22 months of experimentation with the ERTS-1 satellite data collection system in relaying data from remote, unattended field sites in the severe winter environment of the San Juan Mountains of southwest Colorado. The rugged mountain range is also the primary study area of the Division's 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 research Contract No. S-70243-AG, Amendment No. 8, Task No. 41, was awarded for experimentation and testing to:

1. Interface transmitters with existing hydrometeorological instruments for reliable, accurate operation in remote mountain locations.

2. Develop processing and application procedures by typical data user agencies and groups and prepare preliminary operational and maintenance guidelines for the instrument-transmitter units.

3. Provide the information for cost and effectiveness comparisons between current and ERTS-1 data collection techniques.

4. Provide early field experience and familiarization by western water resource agencies with the ERTS-1 data collection system to help define the eventual justification, scheduling and role of ERTS in water resources management, including weather modification.

These tasks were performed from September 1972 through June 1974. They began with a development stage: designing, fabricating, installing and initiation of operational tests of DCPs at their field locations. The second stage determined the operational utility of the data collection system in relaying meteorological and hydrological data. Emphasis was placed on colocating the ERTS field installations with other pilot project instrumentation. ERTS-relayed data was compared with data recorded at the sites. The initial successes of the operational testing suggested a step forward into a semioperational mode in which several sites were relocated to provide information operationally useful to the pilot project.

Project experience has shown the ERTS field installations to be remarkably reliable, weather resistant, and cost effective units able to relay high quality data in near real time. The availability of quality data in near real time is valuable in decision-making processes of an operational water management program, such as weather modification.

Further research should place emphasis on application of the data collection system for operational use. The data will receive optimum use in operational programs only with a minimum turnaround data transmission time. Other recommendations include:

Development of a system to obtain average wind speed and wind direction data, rather than the instantaneous values currently received.

Development of onsite data storage circuitry to permit recording and transmission of continuous data, rather than data sampled at 12-hour intervals.

Information on the development and operational plans for the ERTS-GOES compatible data collection platforms should be provided to present and potential users of the ERTS Data Collection System to permit long-range planning for data collection by users.

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LIST OF ABBREVIATIONS AND SYMBOLS

CNES - Centre National d' Etudes Spatiales

DAWRM - Division of Atmospheric Water Resources Management

DCP - Data Collection Platform

DCS - Data Collection System

EROS - Earth Resources Observation Systems

ERTS - Earth Resources Technology Satellite

GACS - Ground Acquisition and Command Station

GOES - Geostationary Operational Environmental Satellite

IRLS - Interrogation Recording and Location System

NASA - National Aeronautics and Space Administration

NASCOM - NASA Communication Network

NMC - National Meteorological Center

SMS - Synchronous Meteorological Satellite

WSSI - Western Scientific Services, Inc.

I. SATELLITE DATA COLLECTION SYSTEM CONCEPTS

The function of a satellite data collection system (DCS) is to transmit data from a collection location through a satellite link to another location where the data are stored for operational or post-analysis use. The spaceborne portion of the satellite data collection system is a basic component of such a system and acts as a communications link that would be analogous to a radio repeater in a more traditional ground telemetry system. Satellite data collection systems have received increased emphasis in the last several years as a means of collecting and relaying meteorological and hydrological data. While data collection systems are features increasingly included on meteorological satellites, they received early development on experimental communications satellites and are basically communication systems (Glasstone, 1965).

Two types of satellite communication systems are possible - those carrying radio receivers and transmitters (active satellites) and those acting merely as reflectors of radio waves (passive satellites). Active or repeater satellites carry a transponder. They receive a signal from the ground, amplify it, and retransmit it at a different frequency. Passive satellites act as reflectors and reflect only a small portion of radio power received from the earth. Consequently, sophisticated ground receiving sites are required with passive satellites.

Communications satellites can be further classified by their orbital characteristics. Nonsynchronous, or low altitude, earth satellites may be used for communications coverage over the earth, but a large number of such satellites would be necessary to provide continuous communication between any two ground sites. Active repeater satellites in a high altitude synchronous orbit show promise in overcoming the coverage problem of low altitude satellites. Three geostationary satellites, when properly spaced in an equatorial orbit, could provide continuous communications coverage for nearly the entire earth (see fig. 1).

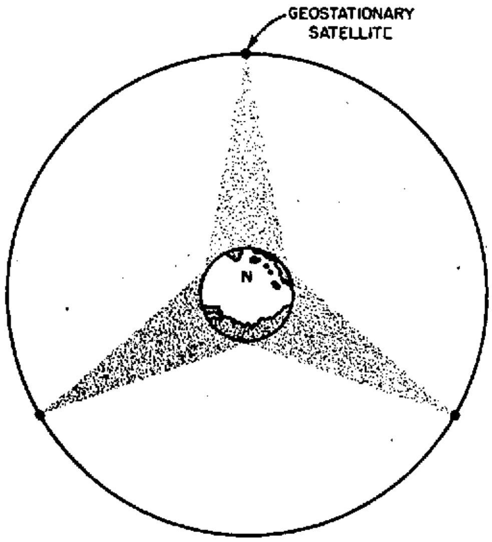

Figure 1. Extent of Earth coverage by means of three geostationary satellites (from Glasstone, 1965).

Only a small section of the polar regions would not receive complete coverage. Since the satellite is stationary with respect to ground transmitting and receiving stations, the antennas at the ground sites need not be as sophisticated as the steerable or omnidirectional antennas required for lower altitude satellites. The problems inherent in using geostationary satellites include the power required to launch them into an orbit 22,300 miles above the earth, attitude stabilization, station-keeping, and the unavoidable 1/2-second delay in communication from one ground station to another.

The history of satellite data collection systems, as opposed to systems designed solely for communication, has been rather brief. Early satellite data collection systems were often combined with navigational experiments to determine the positions of mobile data collection platforms (DCPs) as the stations were interrogated.

In 1959, a proposal was made to develop a satellite data relay and navigation system. The proposal was later accepted, and the Nimbus 3 and 4 satellites were instrumented with a navigational and data relay system called the Interrogation Recording and Location System (IRLS). The objectives of the IRLS system were to collect geophysical, meteorological, and other experimental data from remote unmanned data collection platforms, to determine the location of the platforms, and to track mobile platforms located on balloons, buoys, and ships (Sabatini, 1969). The satellite was programed during orbital passes by an IRLS Ground Acquisition and Command Station (GACS) so that selected stations could be interrogated during successive passes. The IRLS program resulted in the tracking of about 30 stratospheric balloons (Morel and Bandeen, 1973).

The successful balloon experiments on the Nimbus satellites resulted in a larger scale test of the possibilities of global horizontal soundings of the atmosphere by the satellite balloon method. The French Centre National d' Etudes Spatiales (CNES) cooperated with NASA by designing and building the EOLE satellite and 500 instrumented balloons. The satellite was launched in August of 1971 by a Scout rocket provided by NASA. All the balloons were launched in the Southern Hemisphere and were found to distribute at random over the whole hemisphere outside the tropics. Early results of analyses of the EOLE data were presented by Morel and Bandeen in 1973.

The first Earth Resources Technology Satellite (ERTS-1), launched into a polar orbit in July of 1972, was an active low altitude satellite designed to demonstrate that remote sensing from space was a feasible approach to efficient management of the earth's resources (ERTS Project Office, 1972). In addition to the remote sensing equipment aboard the satellite, the satellite also carried the spaceborne portion of a data collection system. The data collection system was designed to relay environmental data from remote, automatic data collection platforms through the satellite to a ground receiving station and data-processing facility.

This report presents the results of a 2-year program by the Bureau of Reclamation in making use of the ERTS-1 data collection system to collect data from remote unattended sites in the San Juan Mountains of Colorado as part of a weather modification project being conducted in the upper Colorado River Basin. Presented is the conceptual design for the ERTS program as it pertains to the Colorado River Basin Pilot project, the history of its conception, design, and execution, a description of the successes and failures of the program, a determination of the operational utility of the ERTS Data Collection System, a comparison of the cost and effectiveness of the ERTS DCS with that of other more traditional methods of collecting data, and recommendations for the future disposition of the ERTS DCS.

II. BACKGROUND: THE COLORADO RIVER BASIN PILOT PROJECT

In the San Juan Mountains of southwestern Colorado, the Bureau of Reclamation, through its contractors, is conducting a major winter orographic cloud seeding operational test called the Colorado River Basin Pilot project. Here, an extensive network of telemetered and recording hydrometeorological instrumentation has been installed to monitor weather conditions for cloud seeding control and to evaluate snowfall increases due to seeding. Snowfall increases of 16 percent are expected in this project, adding half a million acre-feet of valuable water annually to the water-short Colorado River. Decisions for large-scale seeding operations will be based on the results of this project.

The pilot project has been designed under contract by Colorado State University based to a large extent on the University's successful experiments conducted in Colorado. Meteorological instrumentation, including a telemetry network, has been installed under a contract with Western Scientific Services, Inc., of Fort Collins, Colorado. Actual cloud seeding for a 1,300-square-mile target area in the southeastern portion of the 3,300-square-mile San Juan Mountain area of Southwestern Colorado began in December 1970 and is being conducted by EG&G, Inc., from their Durango, Colorado, field office under contract with the Bureau. Colorado State University, the University of Colorado, and Fort Lewis College have developed a comprehensive plan for investigating the ecological aspects of increased snowfall in the San Juan Mountains area and will monitor expected key factors in conjunction with the pilot project.

The pilot project is oriented toward learning definite answers on the technological factors and feasibility considerations involved in producing large quantities of additional streamflow in the Colorado River basin.

Under the planned randomized experiment, seeding will occur on approximately 20 snowfall days out of the estimated 40 snowfall days annually suitable for seeding. Approximately 50 snowfall days in a typical winter are unsuitable for seeding. Increases in mid-October through mid-May precipitation averaging about 16 percent are expected to result in the target area. An average winter precipitation in the study area, above 9,500 feet mean sea level (msl), is about 24 inches water equivalent.

The main objective of the Colorado River Basin Pilot project is to provide sound scientific and engineering evaluations of snowfall increases over a large area by an operation-type application of cloud seeding techniques employed, and of criteria developed through the Climax, Colorado, experiment. The evaluations and analyses of project data will also furnish a more detailed climatology of natural snowfall occurrence over mountainous areas, improved identifications of snowfall increase during different seedable conditions and its distribution over large mountain massifs, and an accounting of costs involved.

The project will afford the first major opportunity and meaningful climate for assessing any social-environmental problems associated with weather modification and appraising technical performance factors.

Instrumentation used for the project includes 33 silver iodide generators; 88 precipitation stations; a number of remote meteorological stations measuring ice nuclei, mountaintop winds, temperatures, and other parameters; 2 snow pillow sites; and 3 stream gage sites. Instruments for the pilot project are located in remote areas and have to operate under as severe a mountain winter environment as is found in the United States. Elevations for instrumentation range from 9,500 to 13,000 feet msl, snow depths of 60 to over 100 inches are common, wind speeds are high, temperatures are often well below 0° C with wide fluctuations, and heavy rime ice and frost are encountered. Data sites in this environment are necessary for cloud seeding projects and are representative of the growing data requirements from western mountain areas. Travel to these sites is expensive, time consuming, and often dangerous. Limited overland access to wilderness areas reduces effectiveness of the data network.

The ability to relay data via satellite would both eliminate the need for extensive multiple telemetry relays, which are subject to frequent downtime, and permit a broader network of instrumentation in limited access areas.

III. ERTS DATA COLLECTION SYSTEM CONCEPTS

The ERTS data collection system consists of the following basic components:

(1) The meteorological, hydrological, and environmental sensors required to collect any data desired at a field location.

(2) The interface electronics or signal conditioning required to interface the sensors to a data collection platform.

(3) A data collection platform to collect data from sensors at a field site and to format and transmit the data to the ERTS satellite. The data collection platform used in the ERTS system is an automatic data relay terminal capable of accepting a total of eight analog inputs, eight 8-bit parallel digital inputs, or eight 8-bit serial digital inputs (General Electric Company, Space Division, 1972).

(4) An active relay device (transponder) aboard the ERTS-1 satellite to relay the data received from a transmitting data collection platform to one of several ground receiving sites (Greenbelt, Maryland; Goldstone, California; and Fairbanks, Alaska). The ERTS-1 satellite carrying the spaceborne portion of the data collection system is in a circular, sun-synchronous, near-polar orbit, at an altitude of 494 nautical miles (table 1).

Table 1*

ERTS-1 ORBIT PARAMETERS

Orbit Parameter	Actual Orbit
Semi-major axis	7285.82 km
Inclination	99.114 deg
Period	103.267 min
Eccentricity	.0006
Time at descending node (equatorial crossing)	9:42 a.m.
Coverage cycle duration	18 days (251 revs)
Distance between adjacent ground tracks (at equator)	159.38 km

The satellite orbits the earth 14 times per day, taking 103 minutes per orbit and viewing the entire earth every 18 days, so that on the 18th day the original ground trace will be repeated at the same

* "ERTS Data User's Handbook," ERTS Project Office, Goddard Space Flight Center, Greenbelt, Maryland, 1972.

local time. Figure 2 shows a typical ground trace for 1 day. Note that only two or three orbits per day (for southbound passes) are within range of a ground receiving site. Consequently, data will be relayed through the DCS two or three times per day during the period when the satellite passes overhead on its southbound passes. Data will also be relayed approximately 12 hours later for two or three orbits of the northbound passes. In Southwestern Colorado, data are relayed during two periods of the day - late morning and late evening.

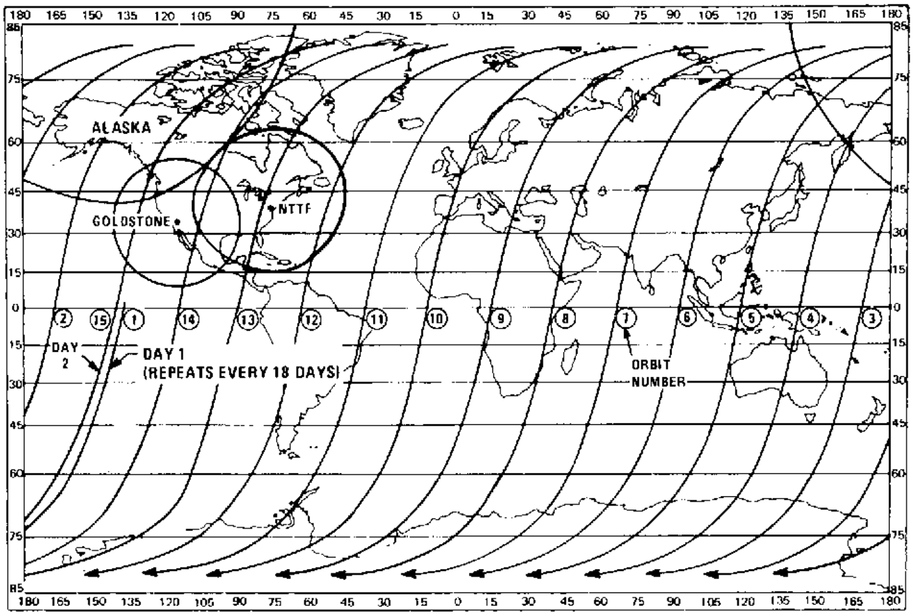

Figure 2. Typical ERTS daily ground trace (only southbound passes shown).*

(5) A ground receiving site to receive the data relayed by the ERTS-1 satellite and direct it to the Goddard Space Flight Center

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* Ibid.

at Greenbelt, Maryland, where it is passed to NASA's Data Processing Facility and sent out to the data users via appropriate ground communication channels.

Users of the data collection system assume responsibility for procuring or developing sensors and signal conditioners, for procuring data collection platforms, and for integrating the components into weather-resistant field installations. The satellite and the communication links between the satellite and the Goddard Space Flight Center are provided and maintained by NASA. The user must assume the responsibility for any communication links between the Goddard Space Flight Center and the field locations where the data is ultimately required by the user.

IV. OBJECTIVES OF ERTS PROGRAM IN THE COLORADO RIVER BASIN PILOT PROJECT

Work was begun at the Bureau of Reclamation in the summer of 1970 to prepare a proposal to be submitted to the EROS/ERTS Program Office to design and execute an experiment that could test the operational utility of the ERTS data collection system under severe environmental conditions for cloud seeding control operations in the Colorado River

Basin Pilot project. The experiment was designed to realize the following four goals:

(1) To interface transmitters with existing hydrometeorological instruments for reliable, accurate operation in remote mountain locations.

(2) To develop processing and application procedures by typical data user agencies and groups and prepare preliminary operational and maintenance guidelines for each type of instrument-transmitter unit.

(3) To provide the information for cost and effectiveness comparisons between current and ERTS-1 data collection techniques.

(4) To provide early field experience and familiarization by western water resource agencies with the ERTS-1 data collection system to help define the eventual justification, scheduling, and role of ERTS in water resources management, including weather modification.

A later version of the original draft proposal was accepted by NASA and was funded through the EROS/ERTS Program. The contract covered the period September 1972 through December 1973, and a 6-month extension allowed work to continue through June 30, 1974. At the time this report is being written, notification has been received that the ERTS Follow-on Proposal submitted in January of 1973 has been tentatively selected, allowing a new phase of experimentation to continue through June 30, 1975. This report is being written to cover the period from September 1972 through June 30, 1974, and will document the results of 22 months of experimentation with the ERTS-1 data collection system.

V. HISTORY OF ERTS WORK

The Bureau of Reclamation's ERTS investigation has gone through three distinct stages during the reporting period. The first stage was to develop seven ERTS field installations and to insure that the proper GSFC-Denver communications links were developed so that the data collection system could be utilized. The second stage was to determine whether the data system would be useful for controlling cloud seeding operations in the Colorado River Basin Pilot project. This stage of the investigation included assessing the quality and quantity of data relayed through the satellite and the characteristics of the data collection system as they affect the data output. The third stage of the program was to begin to use the system in a semioperational mode to collect data for use in making decisions on weather modification operations.

Several organizations aided the Bureau of Reclamation's Division of Atmospheric Water Resources Management (DAWRM) in planning and executing the ERTS program. Two water resource agencies, the Soil Conservation Service and the U.S. Geological Survey, aided by installing and operating special hydrometeorological sensors. Western Scientific Services, Inc. (WSSI), the data collection contractor for the Colorado River Basin Pilot project, handled the developmental and field portions of the ERTS program, and EG&G, Inc., the cloud seeding contractor for the weather modification experiment, used the ERTS data operationally and provided input on the utility of the ERTS data collection system in making cloud seeding decisions.

A. Stage I: Development

Work was begun immediately after the contract was awarded in September 1972, with the goal of designing, fabricating, installing, and beginning operational test of DCPs at their field locations before May 16, 1973, the close of the 1972-73 cloud seeding season. By January of 1973, WSSI had completed the preliminary design for an eight-channel signal conditioner to be used with each of the ERTS field installations. The signal conditioner was designed to meet rigid requirements for dependability, accuracy, immunity to temperature variation effects and power supply variations, low power consumption, and universal adaptability to all proposed installations. The circuit design also included a stable 5 VDC reference source to be used for external transducer excitation when needed. A power supply monitoring system was also designed and operates from two 12V, 20-ampere-hour batteries connected in series to provide a ± 12 VDC supply with center-tap signal grounding. The signal conditioner circuitry was designed to allow the use of a universal printed circuit design. The universal board can be adpated to any one of the seven field sites by mounting the required components and making the appropriate sensor connections at the external connector.

During February and early March, work continued on tests of the signal conditioning printed circuit boards and environmental testing of the components of the field installations. Tripod stands, antennas, sensor-mounting hardware and bracketry, and enclosures for the electronics were fabricated or procured and integrated into a weather-resistant field installation (figs. 3 and 4). Laboratory tests of the ERTS DCS began in March 1973, and upon successful completion of the tests, the first field installation was placed at Wolf Creek Pass on March 21, 1973, and the field tests of the operational utility of the ERTS DCS were begun (fig. 5).

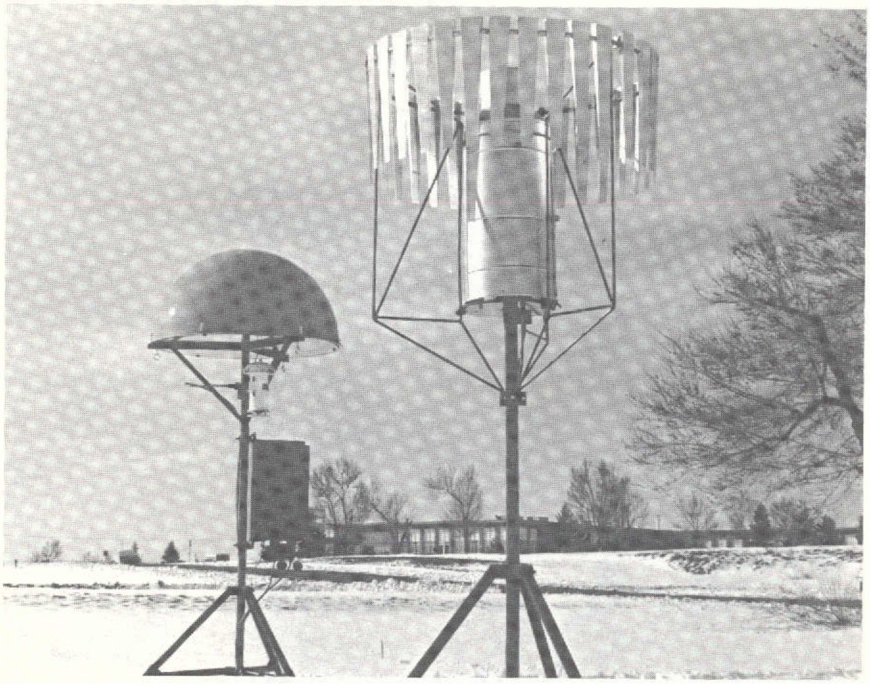

Figure 3. ERTS field installation set up for acceptance test at the Bureau of Reclamation's Engineering and Research Center in Denver, Colorado. ERTS station on left. Precipitation gage with alter shield on right.

Concurrent with developmental work on the field installations, DAWRM began to set up the needed communication links between the Goddard Space Flight Center and the ERTS users. Utilization of the existing and rather extensive weather data handling system of DAWRM's Environmental Network was one of the goals of the program since integration of ERTS data into this computer system would allow many different users to access the ERTS data.

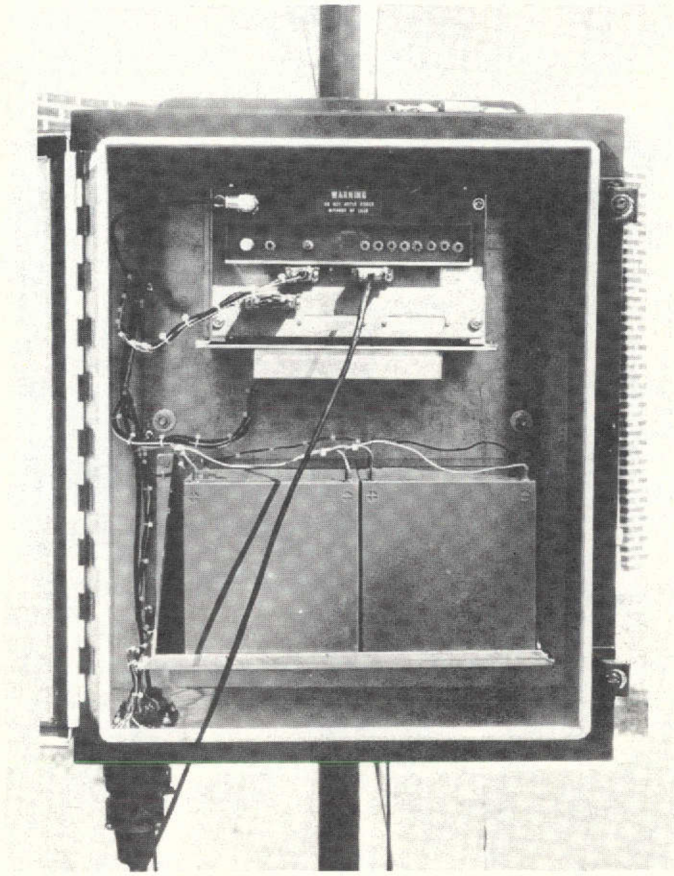

Figure 4. Closeup of ERTS data collection platform, signal conditioning electronics, and power supply in weather-resistant installation.

The Environmental Network, depicted in figure 6, is a computer controlled system for transfer of weather data from the National Meteorological Center (NMC) at Suitland, Maryland, to a time-share computer at Denver, Colorado, where it is processed and stored. The data are then accessible by DAWRM contractors via time-share terminals.

Figure 5. Closeup of Wolf Creek Pass ERTS site.

Arrangements were made whereby ERTS data received at the Goddard Space Flight Center at Greenbelt, Maryland, are relayed to the NMC Computer at Suitland, Maryland, and are then transmitted along with other weather data by an existing high-speed line to DAWRM's time-sharing service (fig. 7).

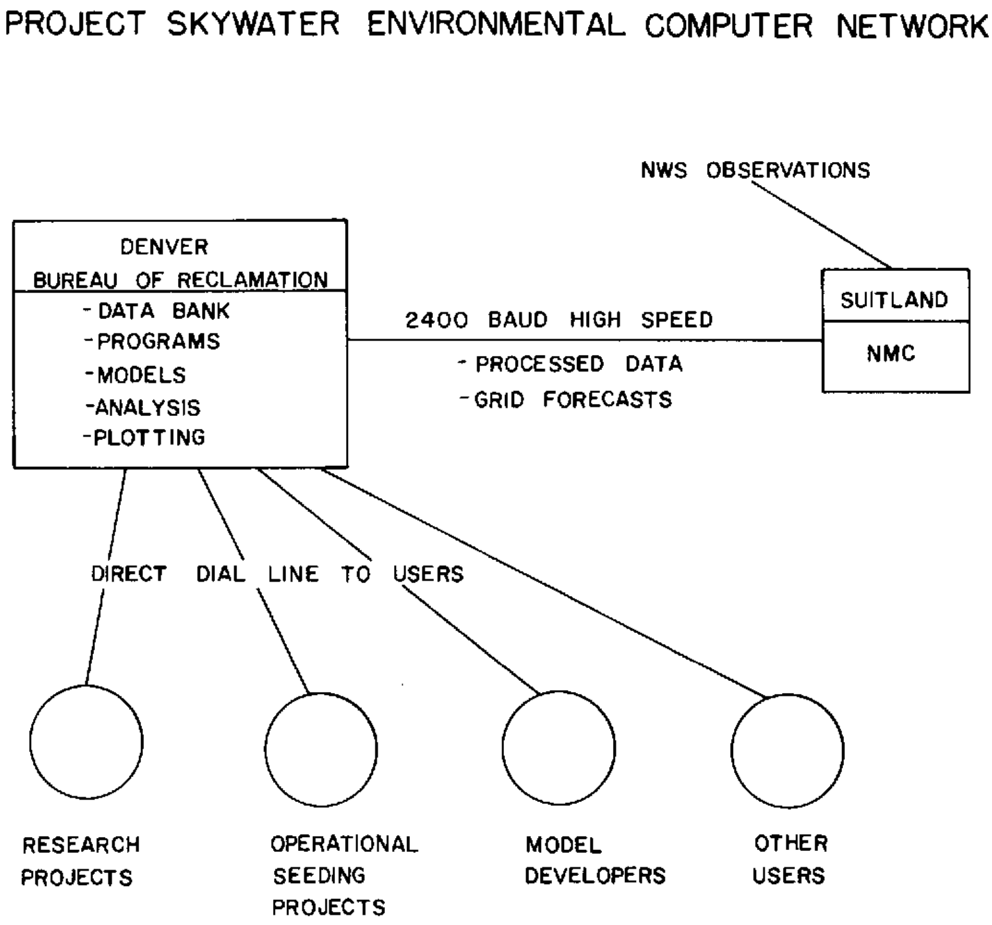

Figure 6. Schematic of DAWRM Environmental Computer Network.

In the winter of 1972-73, computer software was developed for the Denver computer for each data collection platform so that binary data received from channels of individual platforms are converted to an engineering units listing. Computer programs required an initial input of field calibration data for each channel of every data collection platform and a listing of the platform ID numbers

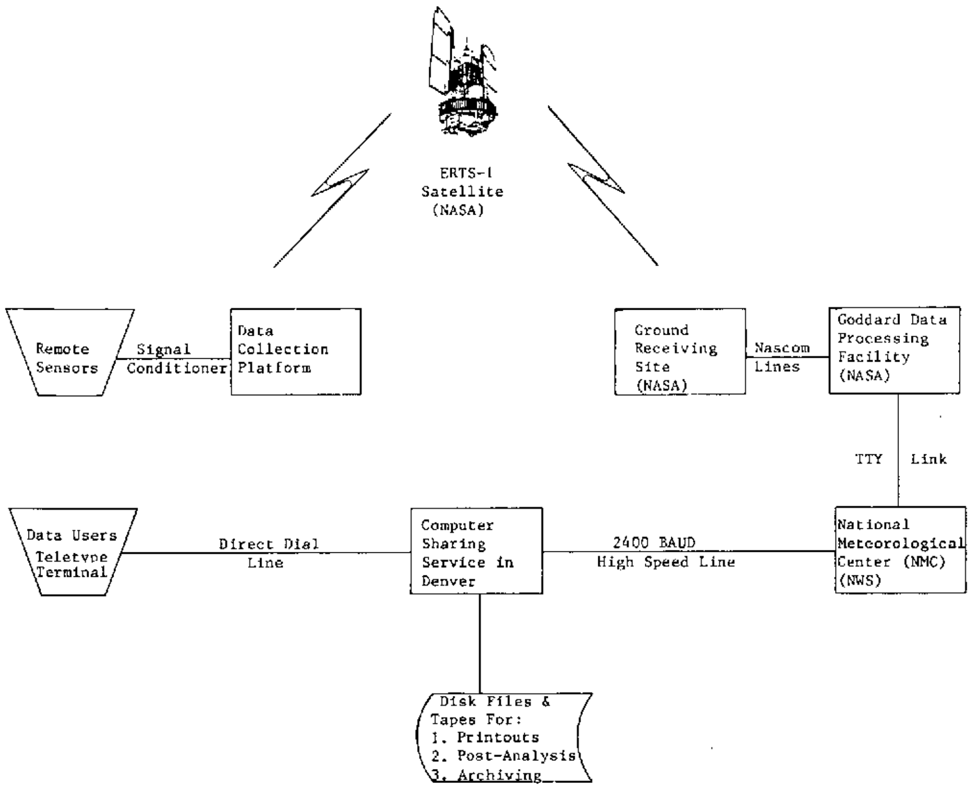

Figure 7. Schematic of ERTS-1 data flow from sensors to users.

for each field site. After the programs are loaded with calibration data, they automatically convert all data received from Suitland into the proper units within specified formats.

A sample of the data formats utilized in these programs is given below in table 2. Listings of the computer programs developed have been presented in previous reports.

Table 2

SAMPLE OF LIME MESA ERTS DATA FOR THE PERIOD

JANUARY 21 - JANUARY 22, 1974

LIMESA 15:11 CSS TUE.01/22/74

100	6347	LIMESA										
110	DATE	HHMM	SS	C	TEM	TVO	TVO	TVO	PCP	TVO	HSV	BAV
120					C	BIT	BIT	BIT	IN	BIT	V	V
130	JAN 21 74	1648	14	7	-9.1	0.0	0.00	0.0	1.79	0.0	2.5	12.7
140	JAN 21 74	1651	44	7	-9.1	0.0	0.00	0.0	1.79	0.0	2.5	12.7
150	JAN 21 74	1658	42	7	-9.1	0.0	0.00	0.0	1.78	0.0	2.5	12.7
160	JAN 22 74	0245	17	7	-13.2	0.0	0.00	0.0	1.86	0.0	2.5	12.7
170	JAN 22 74	0248	50	7	-13.2	0.0	0.00	0.0	1.86	0.0	2.5	12.7
180	JAN 22 74	0421	43	7	-16.1	0.0	0.00	0.0	1.86	0.0	2.5	12.7
190	JAN 22 74	0425	18	7	-15.7	0.0	0.00	0.0	1.86	0.0	2.5	12.7
200	JAN 22 74	0428	54	7	-15.7	0.0	0.00	0.0	1.86	0.0	2.5	12.7
210	JAN 22 74	0432	30	7	-16.1	0.0	0.00	0.0	1.86	0.0	2.5	12.7
220	JAN 22 74	1516	30	7	-18.3	0.0	0.00	0.0	1.86	0.0	2.5	12.6
230	JAN 22 74	1520	14	7	-17.3	0.0	0.00	0.0	1.86	0.0	2.5	12.6

Parameters monitored include temperature (TEM) in degrees Celsius, precipitation accumulation (PCP) in inches of water equivalent, half scale voltage (HSV), and battery voltage (BAV). The time of data transmission is given in Greenwich mean time in hours, minutes (HHMM), and seconds (SS).

B. Stage II: Tests of Operational Utility

The second stage of DAWRM's ERTS program was to determine the operational utility of the data collection system in relay of meteorological and hydrological data from remote unattended sites in the severe weather environment of the San Juan Mountains of Colorado. At the time of contract award, no experience was available concerning operation of ERTS data collection platforms in such an extreme winter environment. In this phase of experimentation, little emphasis was placed on collecting data in near real-time since data quality analyses could be done effectively using historical data. Emphasis was placed on colocating the ERTS field installations with other pilot project instrumentation so that data quality determinations could be easily accomplished by comparing ERTS-relayed data with data recorded onsite. The initial locations for field installation of the ERTS sites were then chosen using criteria of accessibility, and availability of onsite or telemetered data for use in comparison with ERTS-relayed data.

The locations chosen for initial placement of ERTS sites are shown below in figures 8A and 8B. A more detailed description of the ERTS site locations, including latitude, longitude, elevation, and information on the dates of installation and removal of data collection platforms at each location, is given in appendix A. The parameters at the seven initial sites are presented below in table 3. Brief descriptions of hydrometeorological instruments used are listed in Appendix B.

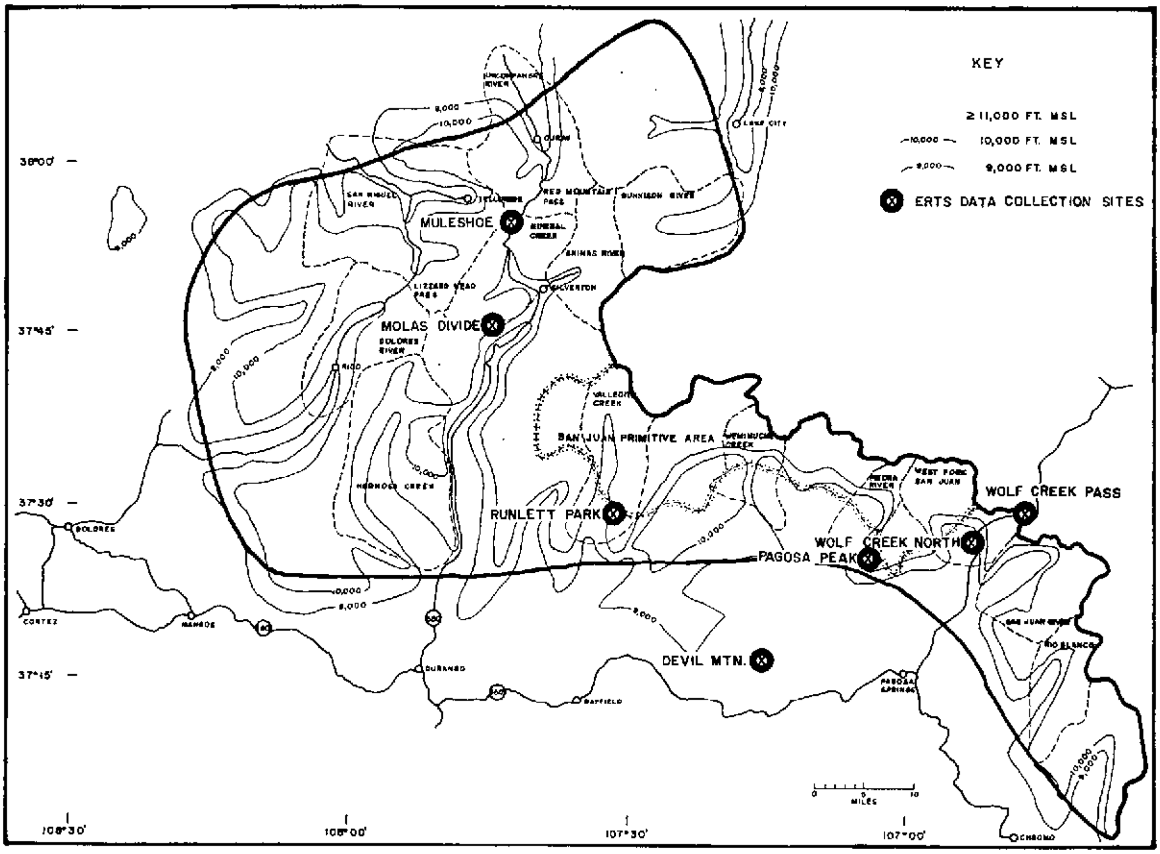

Figure 8A. Location of ERTS sites, 1972-73: Colorado River Basin Pilot project.

All seven ERTS sites were fabricated, installed in the field, and calibrated before the weather modification activities were terminated on May 16, 1973. Most ERTS sites were operated for only 1 to 4 months during the first season of operation and were then removed from the field for storage in Durango, Colorado, over the summer months until the beginning of cloud seeding operations in the fall of 1973. Two

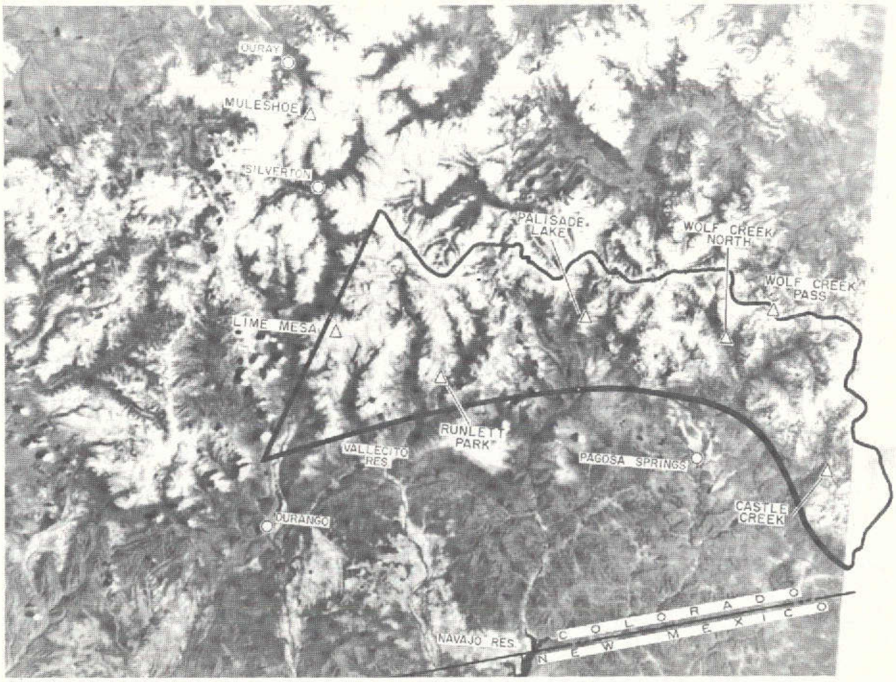

Figure 8B. Denotes locations of ERTS data collection platforms used in the Colorado River Basin Pilot Project during the 1973-74 winter season.

stations, Wolf Creek Pass and Wolf Creek North, were left in the field for the entire summer period as a special experiment to gain experience on battery life expectations and on public response to ERTS installations in high-use portions of the cloud-seeding target area.

Table 3

1972-73 ERTS SITE LOCATIONS AND ENVIRONMENTAL MEASUREMENTS - COLORADO RIVER BASIN PILOT PROJECT

ERTS site name	Lat.N	Long.W	Elev.(ft)	Environmental measurements
Runlett Park	37°29'	107°30'	10,760	Temperature, relative humidity, wind speed and direction
Molas Divide	37°45'	107°42'	10,880	Temperature, precipitation
Wolf Creek Pass	37°29'	106°48'	10,810	Temperature, precipitation
Pagosa Peak	37°26'	107°05'	10,400	Temperature, snow pillow
Muleshoe	37°52'	107°45'	12,800	Temperature, radiation, wind speed and direction
Wolf Creek North	37°27'	106°53'	7,800	Streamflow, water temperature
Devil Mountain	37°16'	107°16'	9,800	Temperature, wind speed and direction

1. Maintenance Experience

Early maintenance experience with the initial field installations was somewhat disappointing since some of the sites required more frequent maintenance than anticipated. Of particular concern was a succession of DCP failures at the Molas Divide site. Replacement of faulty printed circuit cards with printed circuit cards from other DCPs necessitated software changes at the Denver computer and revealed a supply delay in obtaining replacement DCP parts. The problem was traced to a unique site characteristic; the Molas Divide site has frequent lightning storms and large buildups of static electricity. All the problems experienced at this site were consistent with this cause, and a decision to deactivate the site and shift the ERTS instrumentation to another site solved the problem. No other DCP electronic failures have occurred since this initial experience at Molas Divide.

The Pagosa Peak DCP failed to relay data through the ERTS satellite after May 19th when the coaxial cable connecting the DCP to the antenna was severed by a gnawing animal, probably a porcupine, deer, or elk. Several other problems were encountered with sensor tie-in during the installation of other DCPs.

After an initial burn-in period of 2 to 3 weeks, most sites appeared to be operating properly and the data appeared to be of good quality.

2. Data Comparisons

Comparisons have been made between the ERTS-relayed data and data obtained from conventional meteorological instrumentation located next to the ERTS DCPS. Data quality checks such as those shown in figures 9 and 10 indicate that ERTS-relayed data compare very favorably with data recorded onsite. The temperature data comparison shown in figure 9 is between a thermograph located at the Wolf Creek Pass site in a thermoscreen about 65 feet west of the ERTS installation and the temperature sensor mounted with a radiation shield on the ERTS antenna stand. The ERTS precipitation gage has a resolution of 0.10 inch, while the adjacent conventional weighing type precipitation gage located nearby has a resolution of 0.01 inch. The comparison of data shown in figure 10 is quite good but pointed out that a finer resolution was desirable in the ERTS data. Prior to the start of the 1973-74 winter season, the ERTS precipitation sensors were modified to provide approximately 0.04 inch resolution.

The precipitation and temperature parameters provide the best comparisons of quality between ERTS-relayed data and onsite recorded data as the other parameters were generally not recorded onsite. One exception to this is wind data which was recorded at Runlett Park. Wind speed and direction both were recorded on site and transmitted through the ERTS System. The average values from the recorded data did not correlate with the data received through ERTS. The discrepancy has been related to the use of two different types of anemometers located at different heights from the ground surface. This difference has been corrected for continued use under a follow-on experiment.

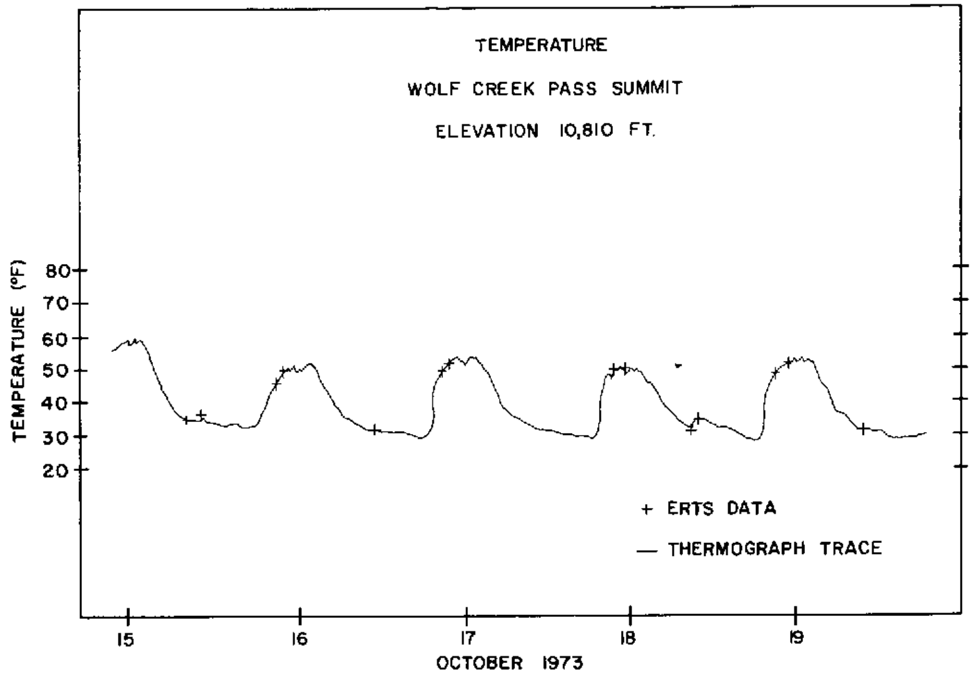

Figure 9. Comparison of ERTS relayed data with onsite temperature data.

3. Battery Life

One of the goals of continued operation of the ERTS stations in the summer network was to monitor the change in battery voltage at each of the two sites to determine the usable battery life. Data from the two sites were continuously checked to see whether a drop in battery voltage affected the quality

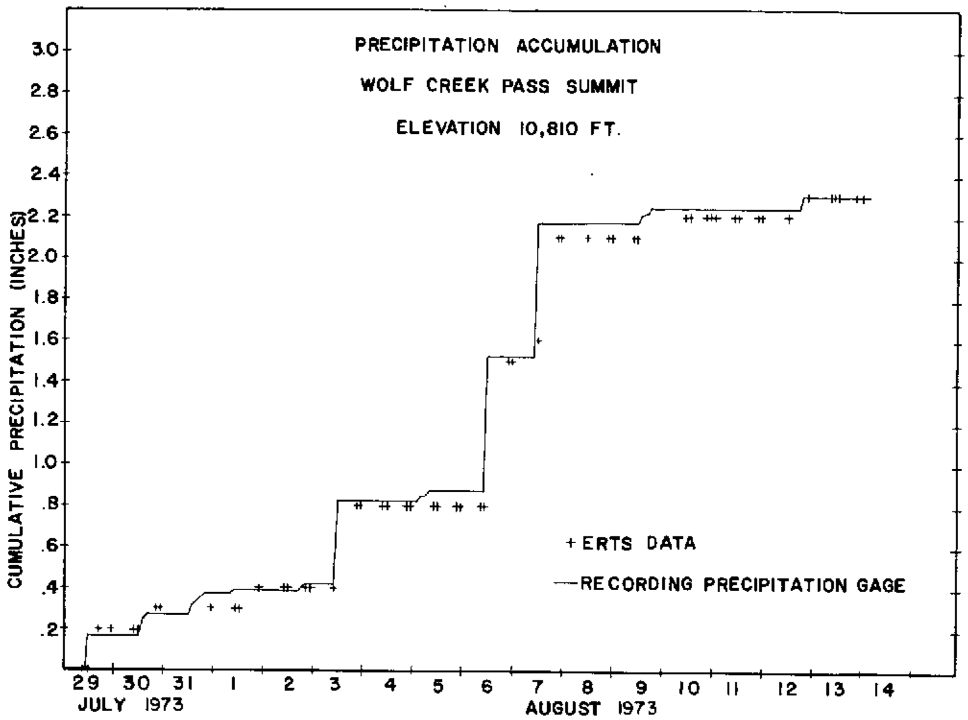

Figure 10. Comparison of ERTS relayed data with onsite precipitation data.

or quantity of data received. The performance of the Wolf Creek Pass battery is plotted in figure 11. No drop in data quality or quantity was noticed during the period of time plotted in the figure. Some difficulty was encountered in calibrating a new temperature sensor on Wolf Creek Pass on November 9, 1973, and batteries were replaced at the next opportunity. Experience at this and at other sites indicates that batteries should be replaced when the battery voltage drops to 12.2 or 12.1 volts and that a fully charged battery

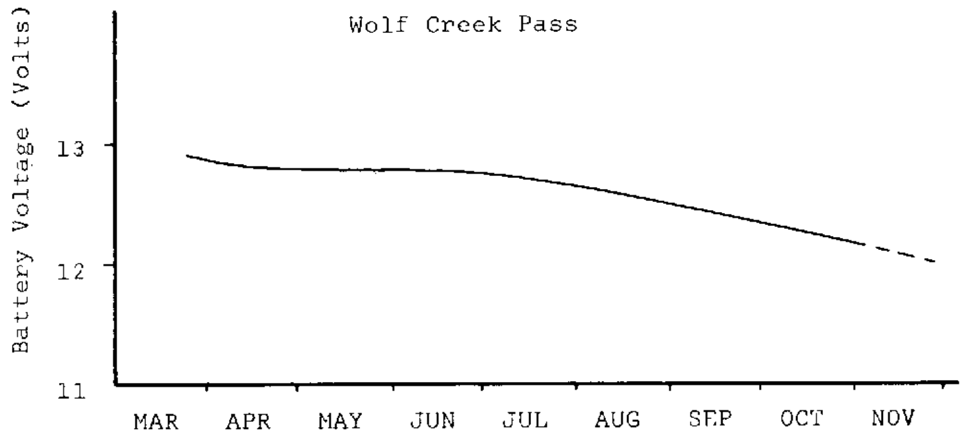

Figure 11. Battery drawdown characteristics, Wolf Creek Pass, 1973.

installed at the beginning of the operational season will last through the entire winter season (October 15 - May 16).

4. Public Reaction to ERTS Sites

The summer ERTS sites were chosen partly on the basis of visibility from high tourist-use areas so that public response to the installations could be measured. The Wolf Creek Pass site is visible from U.S. Highway No. 160 at a point where summer tourists pull over into a parking area at the top of the pass (fig. 12). The Wolf Creek North site is not visible from a main highway but

Figure 12. Wolf Creek Pass ERTS installation as seen from U.S. Highway No. 160.

is located only one-half mile upstream from a popular campground 6 miles southwest of Wolf Creek Pass. To determine the amount of public exposure to the two sites, highway department traffic figures were consulted. A traffic count of vehicles traveling in both directions on Highway No. 160 at Bayfield, Colorado (approximately 20 miles east of Durango), during 1972 was obtained and is shown in table 4.

Table 4

VEHICLE TRAFFIC COUNT
HWY. NO. 160 AT BAYFIELD, COLORADO

Month	Average daily count	Month	Average daily count
January	1492	July	4387
February	1654	August	4152
March	2015	September	3120
April	2179	October	2482
May	2674	November	1897
June	3716	December	1664

Average day of average month: 2619 vehicles

Figures shown in table 4 would be fairly representative of the number of vehicles traveling over Wolf Creek Pass in 1973, although they would probably tend to overestimate traffic on the pass somewhat since local traffic between Durango and Pagosa Springs would be included in the Bayfield count. The Bayfield count indicates that 546,732 vehicles passed the counting point during the months June through October. If the occupants of only one in ten vehicles noticed the Wolf Creek Pass installation in 1973 and if the occupants of only one in ten thousand vehicles walked over to the site, the site would still have received considerable public exposure.

No strong negative public reactions were noted. No vandalism or tampering with the instruments occurred at either site since installation. The ERTS sites also received no damage during the deer and elk hunting seasons in September and October of 1973.

5. Data Throughput

It became apparent early in the investigation that some of the data being relayed via satellite to the NASA facility at Goddard were not being received at the Denver computer. Some data throughput statistics were computed early in the life of the project in order to determine which data links resulted in the rejection of data. The results of this investigation will be reported in the next section.

C. Stage III: Conversion to Semioperational Mode

The second stage of experimentation was designed to determine if the ERTS data collection system could be effectively used in an operational mode. Concurrent with experimentation on the system, data were being received and utilized in near real-time by the cloud seeding contractor within 3 to 8 hours of data transmission. The cloud seeding contractor determined that the ERTS data were occasionally useful in making operational decisions despite the low sampling frequency and the 3- to 8-hour delay in data reception. The ERTS data from the Wolf Creek Pass site were an important input in making the decision when to suspend seeding operations to avoid exceeding the suspension criteria in effect for the Wolf Creek Pass area in the 1972-73 season.

An analysis of the ERTS program was completed by the Bureau of Reclamation and its contractors in August and September of 1973. The strengths and weaknesses of the data collection system were discussed, and decisions were made on the future disposition of the network. The initial successes of the operational testing phase of the program suggested a step forward into a semioperational mode, in which some experimentation would continue with several sites that were colocated with other project instrumentation (especially ground telemetry locations) and other sites would be relocated to provide operationally useful measurements from representative regions within the target area.

Discussions were held with Bureau contractors and other water users to determine the best uses and locations for the limited number of ERTS installations. Decisions on measurements and locations were based mainly on need for near real-time operational measurements. A significant number of installations were committed to the Bureau's seeding contractor for use in monitoring weather conditions for cloud seeding control. A decision was made to instrument these sites with recording precipitation gages and to increase the resolution of the ERTS precipitation measurements. New sites were chosen so that good coverage of the cloud seeding target area would result. Figure 13 shows the new site locations in relation to the target area of the

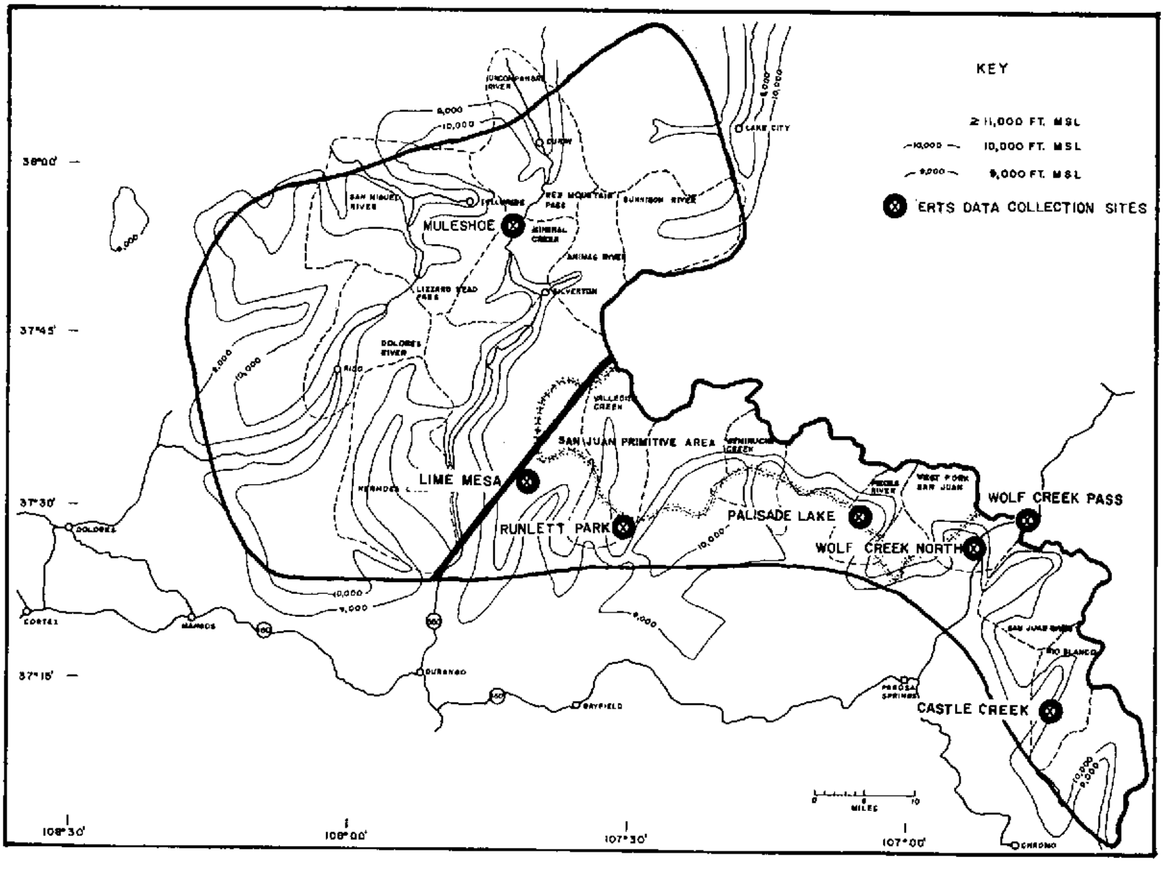

Figure 13. Winter 1973-74 ERTS site locations.

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Colorado River Basin Pilot project. The 1973-74 target area is the southeastern half of the outlined area. Table 5 lists the spring sites and the changes in locations and instrumentation that resulted in the new winter network. New sites are Lime Mesa, Palisade Lake, and Castle Creek. All of the new sites were instrumented with precipitation gages since precipitation measurements were considered to be high priority operational requirements.

Table 5

ERTS Program
Changes in Station Configuration

Spring 1973		Winter 1973-74	
Site	Parameters	Site	Parameters
Muleshoe	Temperature Wind Speed Wind Direction Radiation Battery Voltage	Muleshoe	No Change No Change No Change No Change No Change Add Humidity Add Rime Ice Detector Add Muleshoe Battery
Wolf Creek North	Streamflow Water Temperature Battery Voltage	Wolf Creek North	No Change No Change No Change
Wolf Creek Pass	Temperature Precipitation Battery Voltage	Wolf Creek Pass	Radiation Shield No Change No Change
Molas Divide	Temperature Precipitation Battery Voltage	Lime Mesa	Radiation Shield No Change No Change
Runlett Park	Temperature Wind Speed Wind Direction Relative Humidity Battery Voltage	Runlett Park	No Change No Change No Change No Change No Change
Devil Mountain	Temperature Wind Speed Wind Direction Battery Voltage	Castle Creek	Radiation Shield Omit Omit No Change Add Precipitation
Pagosa Peak	Temperature Snow Pillow Battery Voltage	Palisade Lake	Radiation Shield No Change No Change Add Precipitation

Half-scale voltage is monitored at all sites except Muleshoe.

The Lime Mesa site is a high elevation site on the mountain barrier and is an important indicator of precipitation at the highest elevations in the San Juan Mountains. Because of the remoteness of this site, it was serviced only by helicopter. Servicing was scheduled once per month, with the date of servicing dependent on weather conditions, helicopter availability, and other factors.

The Castle Creek gage provides telemetry coverage of the extreme southeast portion of the target area. The site is accessible to oversnow vehicles during the winter season and generally is serviced by a four-passenger Thiokol snowcat. The servicing run is a 10-mile round trip.

The Palisade Lake gage is installed at the same location as a Soil Conservation Service snow pillow and provides coverage for the mountainous area between Wolf Creek Pass and the West Needle Mountains north of Lime Mesa. Some of the sensors at the Palisade Lake site are also used as input to a ground telemetry transmitter which is also located at this site.

The Muleshoe station is the site of the ground telemetry installation that was designed for collection of meteorological data for use in snow avalanche hazard forecasting. The site is located near the starting zone of several avalanche paths and is safely accessible only by helicopter during the winter months.

Further details on the locations and installation dates of the seven 1973-74 sites are given in appendix A, tables A1-A4. USGS maps of the site locations have been presented in previous reports. ERTS-1 satellite imagery provides another means of locating individual ERTS sites and has been used effectively in this investigation.

Considerable additional experience in the use of the ERTS data collection system was gained during the winter 1973-74 season. As the data set grew, new investigations were preformed, including:

(a) Compilation of maintenance histories for the network of DCPs.

(b) Determination of DCS transmission statistics for each site.

(c) An investigation to determine if calculated data transmission statistics could be correlated with the presence of terrain obstructions near the transmitting data collection platforms.

(d) Investigation of cost-effectiveness of the ERTS DCS versus other traditional data collection methods.

1. Maintenance Experience

Maintenance experience during the semioperational phase of DAWRM's ERTS program showed the field installations to be reliable, trouble-free, weather-resistant units able to operate unattended in remote severe weather environments. No DCP failures occurred during this phase of the project, and only two types of minor maintenance and servicing were required.

The main servicing requirement involved the routine servicing of sensors that were connected to the ERTS DCPs - particularly the precipitation gages. Routine servicing of the weighing-type precipitation gages used in this investigation called for field technicians to visit the sites occasionally to empty the precipitation collector and to recharge the collection bucket with an antifreeze and evaporation retardant solution. The collection buckets have a maximum capacity of 10 inches of water equivalent, and servicing trips were scheduled by monitoring the ERTS-relayed data to determine when the gages were approaching full capacity. This method of scheduling service trips points out a significant advantage of the ERTS data collection system over other more traditional methods of collecting data, since it eliminates unnecessary and costly servicing trips by field technicians. Careful monitoring of the ERTS-relayed data also enables the investigator to determine when a sensor is malfunctioning and to schedule timely maintenance trips. For example, most of the ERTS precipitation sensors malfunctioned during an extremely heavy snowfall cycle in early January 1974, when up to 10 inches of water equivalent (i.e. approximately 100 inches of snow) fell during a 2-week period. Several weeks of ERTS precipitation data were lost during this period since other instrumentation used in verification of seeding effects received first priority servicing.

A maintenance problem which was never completely resolved was encountered during the investigation. Several of the ERTS sites (Devil Mountain, Muleshoe, Runlett Park, and Palisade Lakes) were colocated with ground telemetry sites to facilitate comparisons of ERTS-relayed data with ground telemetry data. Some of these ERTS installations required special interfacing so that individual sensors could be used by both data collection systems. Where sensors were shared, special interfacing was required to achieve a common ground and to provide proper battery power to the sensors. Occasional problems were encountered when RF interference was picked up from the ground telemetry equipment on some of the DCP channels. This interference resulted in a one or two binary bit ambiguity in the ERTS data. This ambiguity was not considered to be significant enough to justify the expense involved in eliminating the problem since a later phase of the investigation called for the ERTS installations to be removed from the ground telemetry sites.

A special problem related to ERTS-ground telemetry interfacing was encountered at Runlett Park where the ERTS batteries failed twice during the winter season. The failures were caused by an unusually severe duty cycle necessitated by sensor sharing between the ERTS and ground telemetry stations. A solar panel was originally installed at this site to alleviate the problem by recharging the ERTS batteries. The solar panel occasionally failed to work, however, when heavy, wet snowfalls covered the solar panel.

Experience in the severe weather environment of the San Juan Mountains has shown the ERTS field installations to be remarkably reliable weather-resistant units able to relay high-quality meteorological and hydrometeorological data from remote unattended sites. The satellite data collection system allows the user to monitor instrument performance and to schedule field maintenance and servicing trips when they are required. While this investigation has shown the satellite data collection system to be a very useful means of relaying data from remote sites, it has also pointed out the continuing need for development of reliable sensors able to operate in severe weather environments.

2. DCS Transmission Statistics

ERTS data received at WSSI in Fort Collins were cataloged and statistics were calculated to define the number of data-relay orbits and the number of messages per satellite orbit for each of the seven field installations. Comprehensive listings of data received at the Goddard Space Flight Center were obtained from NASA, and analyses were performed to determine if the quantity of data received at NASA was different from the quantity received in Fort Collins. Data received at NASA but not in Fort Collins represents a data-throughput problem where data are lost in the communications links between Goddard and the user. Data dropout can occur in various data links including the Goddard to Suitland link, the Suitland to Denver link, and the Denver to time-share terminal link. Figure 14 shows sample

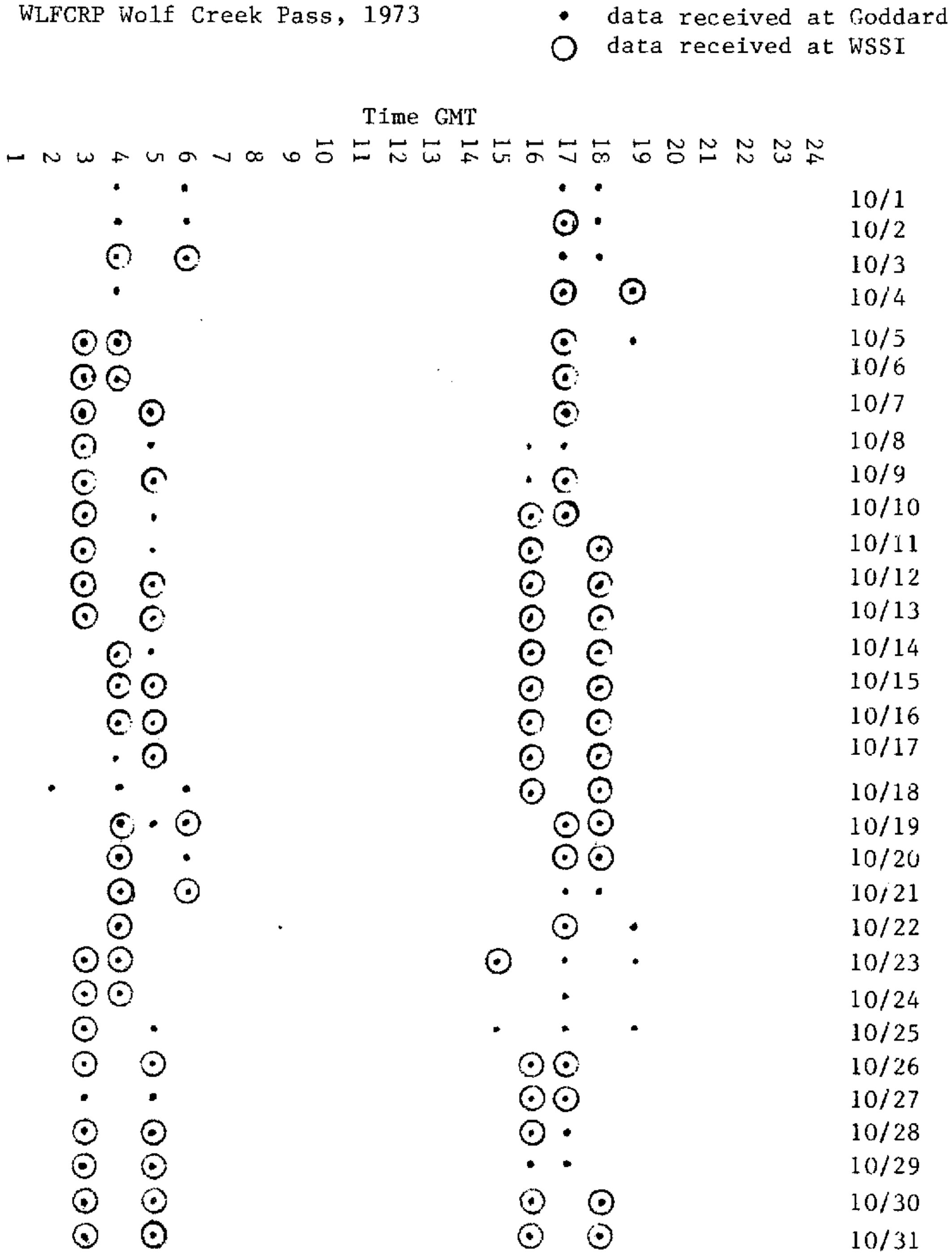


Figure 14. Data received from Wolf Creek Pass, October 1973.

data used in the analysis. In this figure, dots are used to indicate the approximate times of satellite passes in which data were transmitted from the DCP to Goddard. Circles indicate the satellite passes in which data were transferred from the DCP through Goddard to the time-share terminal in Fort Collins. A glance at the figure provides information on the rate of data dropout in the various communications links from Goddard to Fort Collins and also provides information on the number of satellite passes transferring data from the DCP field locations. The number of messages per satellite pass is not shown in the figures but can be ascertained from NASA generated data.

A summary of data throughput from the Wolf Creek Pass site from June through October 1973, is given in table 6. Calculations for the Wolf Creek Pass site for the months June through October give an average throughput efficiency of 75 percent. The average data dropout rate for the Wolf Creek Pass data is then 25 percent. Similar analyses for other ERTS sites for the period November through December 1973, revealed that the data dropout rates at individual sites varied from 22 to 26 percent with an average dropout rate of 24 percent. The significance of this figure is that 24 percent of the data transmitted from DCPs at field locations is received at Goddard but is not available to users who have operational requirements for this data.

Table 6

Data Throughput Efficiency, Wolf Creek Pass

Data Orbits at Fort Collins/Data Orbits at Goddard

Day of Month	June	July	August	Sept.	Oct.	
1	2/4	4/4	3/4	4/5	0/4	
2	3/5	4/4	3/4	3/4	1/4	
3	4/5	2/4	3/4	2/4	2/4	
4	5/5	4/4	4/4	2/4	2/3	
5	0/3	4/4	4/4	3/4	3/4	
6	4/4	5/5	4/4	3/4	3/3	
7	4/4	4/4	3/4	4/4	3/3	
8	3/4	1/4	3/4	4/4	1/4	
9	4/4	3/4	4/4	0/4	3/4	
10	2/4	3/4	2/4	4/4	3/4	
11	2/4	4/4	5/5	4/4	3/4	
12	2/4	4/4	3/5	2/4	4/4	
13	4/4	4/4	4/4	1/3	4/4	
14	4/4	3/3	4/4	4/4	3/4	
15	3/3	2/4	2/4	3/4	4/4	
16	4/4	0/4	4/4	4/4	4/4	
17	4/4	4/4	3/4	3/4	3/4	
18	2/4	3/4	1/4	4/4	2/5	
19	5/5	2/4	2/4	3/4	4/5	
20	5/6	3/4	2/4	4/4	3/4	
21	1/4	*2/0	4/4	3/4	2/4	
22	4/4	3/4	2/4	4/4	2/3	
23	4/4	3/3	2/4	4/4	3/5	
24	4/4	*3/0	4/4	4/4	2/3	
25	4/4	6/6	2/4	4/4	1/5	
26	3/4	4/4	2/4	2/4	4/4	
27	*2/0	5/5	3/4	2/4	2/4	
28	4/4	4/4	2/5	3/4	3/4	
29	2/4	4/4	2/4	*4/0	2/4	
30	2/4	4/4	1/4	3/4	4/4	
31		2/4	2/4		4/4	
Totals	94/120	98/118	89/127	90/116	84/123 =	455/604
Throughput Efficiency	78%	83%	70%	78%	68%	75%

*NASA data not available.
Figures not included in totals.

A further analysis was accomplished using November and December 1973 NASA data to determine the number of satellite passes per day that relayed data from each of the sites to Goddard. The number of data messages per satellite pass was also determined. The results of these analyses are given in table 7. Note that the Wolf Creek North and Palisade Lake sites transmit data approximately every 90 seconds while all other sites transmit data at approximately 180-second intervals. The different transmission frequencies affect the number of data messages per satellite pass and will have a slight effect on the average number of data passes per day.

Table 7

DCS Transmission Statistics

SITE	AVERAGE DATA PASSES PER DAY	STANDARD DEVIATION DATA PASSES PER DAY	COEFFICIENT OF VARIATION	AVERAGE DATA MESSAGES PER PASS	STANDARD DEVIATION DATA MESSAGES PER PASS	COEFFICIENT OF VARIATION
PALADE	4.15	.56	.13	4.67	1.75	.37
WLFCRN	3.10	.86	.28	3.48	1.51	.44
CASTLE	4.11	.32	.08	2.80	.83	.30
RUNPRK	3.68	1.16	.31	3.25	1.18	.36
MULSUE	5.09	.62	.12	2.99	.99	.33
WLFCRP	4.10	.51	.12	3.95	1.48	.37
LIMESA	4.55	.62	.14	3.01	.97	.32

3. Terrain Obstruction - Data Transmission Correlation

Theodolite observations were conducted in later October and early November 1973 to map the terrain and horizon around individual winter sites. These observations (fig. 15) were made to determine what obstacles were present that would interfere with satellite radio communications. It was hoped that if a relationship could be determined between the amount of sky blocked by the terrain and the transmission statistics for individual sites, then a useful formula could be determined to forecast transmission statistics at future sites simply by mapping the horizon at the new site. Once the maps in figure 15 were developed, a gridded overlay was placed on each map and the area of sky blocked by terrain above 20° elevation was determined. The 20° elevation criterion was determined from DCP antenna characteristics (fig. 16). Blocked areas were then weighted using sine and cosine functions depending on their azimuth and elevation. Since the satellite arrives overhead from a north-northeasterly or south-southwesterly direction a terrain obstruction to the NNE of SSW is of little consequence. An obstruction to the ESE or WNW is critical, however, since satellite passes may be barely above 0° elevation in these quadrants. Similarly, high elevation angle passes will get above most obstructions, and the critical passes from the standpoint of transmission statistics are those with low elevation angles. A formula was then developed to assign a weighted terrain obstruction number to each site that could be correlated with individual transmission statistics. Several

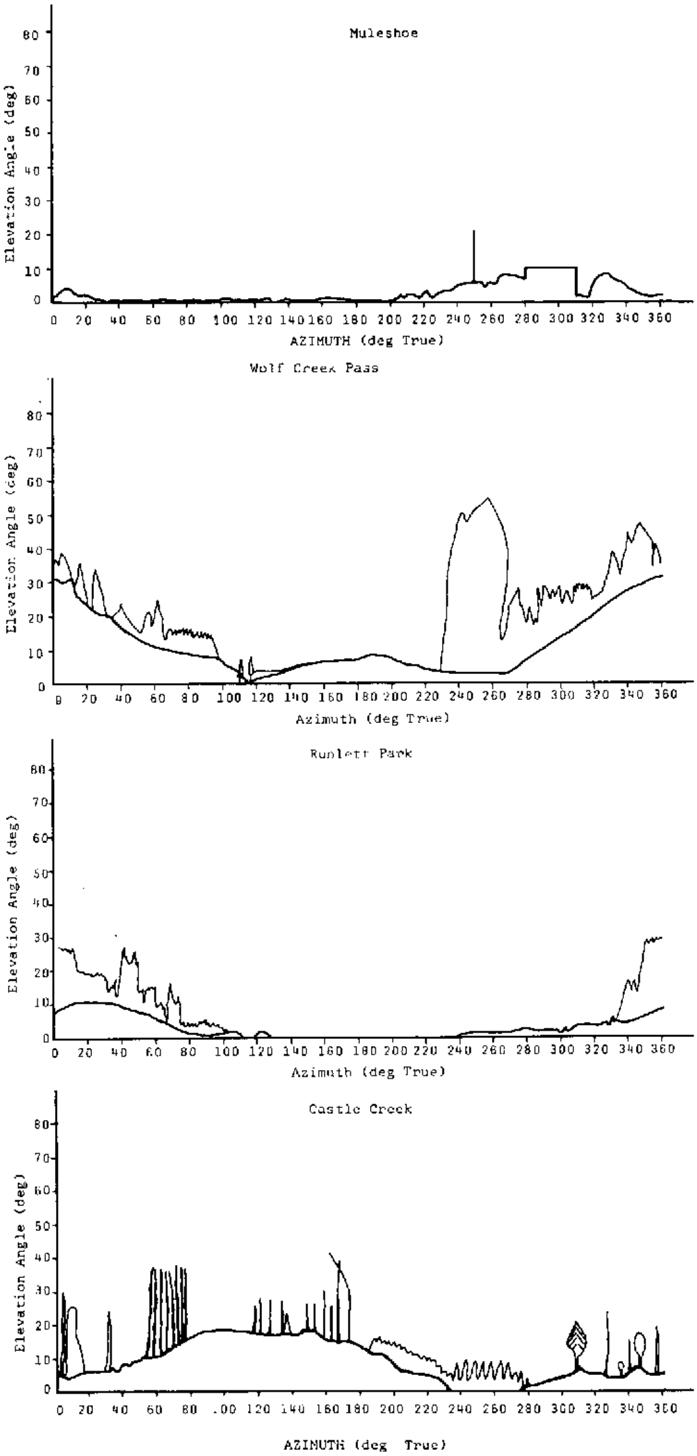
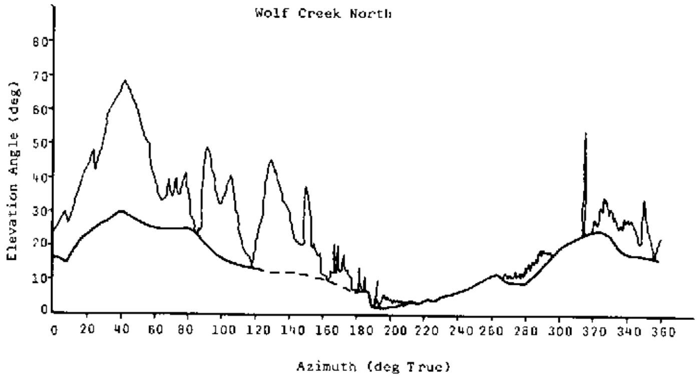
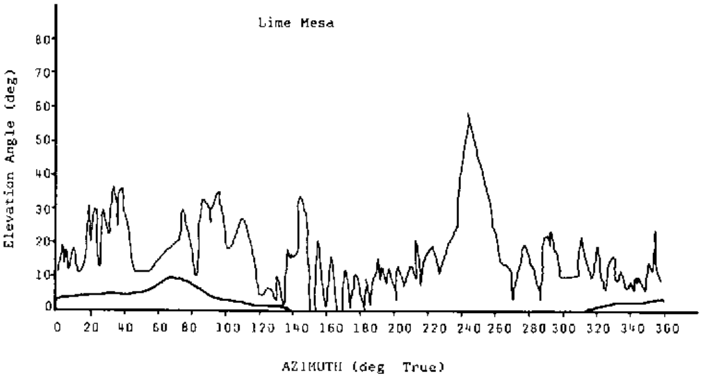


Figure 15. Terrain configuration around individual ERTS sites. The heavy lines outline the position of the solid horizon. The thin lines outline trees and other "soft" obstacles. Dashed lines are used for estimates of the horizon when it is not clearly visible from the ERTS site due to intervening trees, etc.





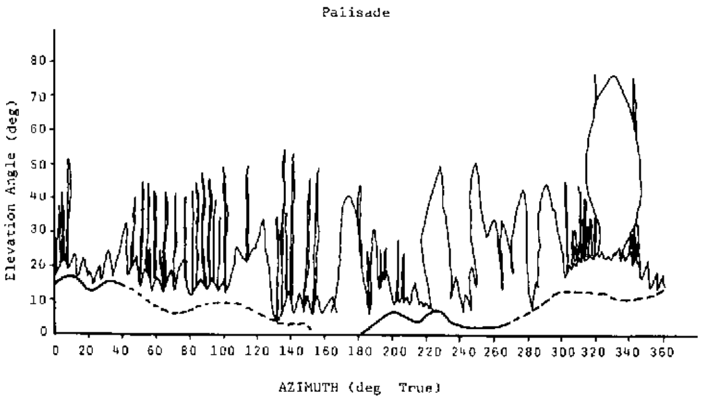


Figure 15 - continued

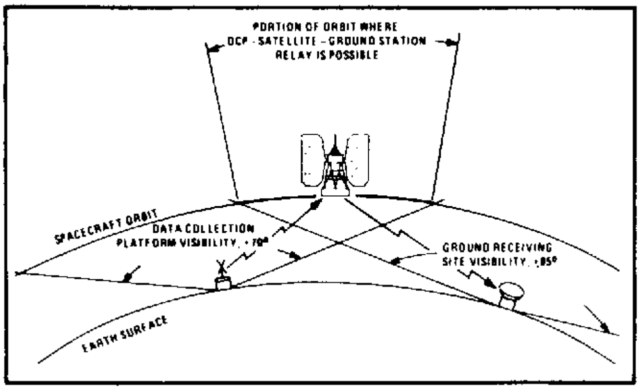


Figure 16. DCS data relay geometry (from ERTS Project Office, 1972).

attempts at correlation were made including attempts to correlate transmission statistics with terrain obstruction numbers determined for the "hard" horizon and for the blockage by "soft" objects. The analysis did not produce meaningful results, and no further attempts at correlation were made. Recommendations for further work along these lines call for a more refined analysis taking account of specific orbit characteristics of the ERTS-1 satellite and the actual transmission frequency for each site.

4. Cost-effectiveness Comparison of Alternative Data Collection systems

The purpose of this portion of the report is to analyze the cost-effectiveness of the Earth Resources Technology Satellite (ERTS) data collection system in relation to manual data collection and remote ground-telemetry systems. Each of the three is currently being used in collecting data useful to weather modification efforts. However, the outputs of the three systems differ in terms of the types of data collected, the frequency with which data are collected and received, the resolution and accuracy of the data, and the ease with which the data can be manipulated. Differences also arise with respect to the costs of installing, operating, and maintaining the systems. The problem which is addressed is that of determining which of the three systems appears to be most effective in delivering a fairly standard output for the least cost outlay.

The approach used here is the cost-effectiveness method of analysis. Basically, cost-effectiveness analysis allows one to assess the relative advantages and disadvantages of a particular course of action in either or both of two ways. On the one hand, if a particular level of cost is defined, the analysis seeks to identify the alternative which will yield the greatest effectiveness (output) for the cost outlay. On the other hand, if a comparable level of effectiveness is defined, the analysis then seeks to identify the least-cost alternative. Basically, the analysis is one of identifying trade-offs between similar, but not identical objectives and costs.

As the three systems are currently being operated, substantial differences may be noted in the respective outputs. The ERTS system, briefly, consists of ground-based meteorological and hydrological sensors interfaced with data collection platforms. These platforms sample readings from the sensors every 180 seconds. The data are broadcast via onsite transmitters to the ERTS-1 satellite and are then relayed to a ground receiving station. The orbit of the satellite generally allows for two relay periods each day and thus, while the frequency of the sample is once every 3 minutes, the frequency of effective sampling 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 to Denver is near real time. The ERTS system has the capability to handle eight separate types of data or the same type of data from eight sensors for each data collection platform. The degree of ease of data manipulation under the ERTS system is rated high since the data are received by the user in a digital format.

The manual data collection system consists of data collection stations gathering both meteorological and hydrometeorological data in analog format. Data are collected automatically and continuously and are stored at the site. On the average, meteorological data are retrieved manually every 2 weeks while hydrometeorological data are retrieved, again manually, on the average of once per month. The frequency of effective sampling is one observation per hour. The ease of manipulating data collected from the manned system is low since the data must be reduced to a digital format. It is also to be noted that while the data collected from the ERTS system are almost immediately available for use, and thus, are operational on a near real time basis, those collected from the manual system are available once every 2 weeks (for meteorological data) and once per month (for hydrometeorological data). Thus, data from the manual system tend to be more useful from an analytical perspective but less useful from an operational perspective than those collected from the ERTS system. With appropriate modification the ERTS system can also be adapted to comparable analytical use.

The ground telemetry system, like the ERTS system, is a remote sensory system. The meteorological and hydrological sensors are interfaced with data collection platforms which transmit data via radio links through various ground-based repeating stations to the master station. Again, both meteorological and hydrometeorological data are recorded. The frequency of the samples is programmable so that data can be collected as frequently as desired, subject to station power capabilities. The power capabilities are such that a maximum of three observations per hour can currently be obtained. On the average, data are collected once every 3 hours with data reception and frequency of the effective sample occurring at this same rate. Like the ERTS system, the ground telemetry system is more useful in providing operational data on a near real time basis than is the manual data collection system. It also is functional as an analytical device, as is the manual system. Ease of data manipulation under the ground telemetry system is rated high. The outputs of the three systems in terms of data collected, sample frequency, effective sample frequency, frequency of reception, resolution and accuracy of data, and ease of manipulating data are summarized in table 8. Resolution and accuracy figures are based on a standard weighing-type rain gage (meteorological sensor) and a snow pillow (hydro-met sensor).

Table 8

Summary of Output from ERTS, Manual and Ground Telemetry Data Collection Systems

Collection System	Information	Frequency of Sample	Effective Frequency	Frequency of Reception	Accuracy	Resolution	Ease of Manipulation
ERTS	Met.	180 sec.	12-hourly	12-hourly	± .05"	.04"	high
	Hydro-Met.	180 sec.	12-hourly	12-hourly	± .50"	.30"	high
Manual	Met.	Continuous	hourly	bi-weekly	± .05"	.01"	low
	Hydro-Met.	Continuous	hourly	monthly	± .50"	.30"	low
Ground Telemetry	Met.	Programmable	Programmable	Programmable	± .05"	.01"	high
	Hydro-Met.	Programmable	Programmable	Programmable	± .50"	.30"	high

Because of the differences in the type of data which the three systems currently collect, i.e., ERTS has the capability of using eight data collection channels, the manual system currently collects only one type, and the ground telemetry system has the capacity for multiple-data inputs, a straightforward comparison of the three is not possible. Hence, it was necessary to devise some acceptable strategy which would allow a meaningful comparative analysis of the three. The strategy selected is discussed immediately below.

Since the scales of current operation and the number of data parameters collected by the three systems differ, making direct comparisons of either their outputs of costs meaningless, it is necessary to extrapolate the number of output parameters and the scale of operation to a common level.

At present the ERTS system has seven data collection sites each with the capability of measuring eight data parameters, though in practice not all eight are typically utilized. The number of channels used varies from site to site. The manual system has 68 precipitation gages, 6 hygrothermographs, and 4 wind data systems, while the ground telemetry system has 20 sites each with the capability of collecting 8 data parameters. In addition, each ground telemetry site has eight supervisory control channels.

If the manual system is taken as the base system, then the hypothetical operation of the ERTS system would have to be scheduled up to 68 sites, as would the ground telemetry system. If the enlarged ERTS and ground telemetry systems are assumed to gather only one type of data (comparable to the manual system), the analysis would be both misleading and infeasible. It would be misleading because of the excess capacity represented by each of the ERTS and ground telemetry sites; the eight-channel capability of both systems would be uneconomically utilized. Furthermore, such a comparison would require prorating the costs of collecting each data parameter, an exercise which in this report is not feasible. Alternatively, it could be assumed that 68 sites are utilized for each of the three alternatives and that each of the three alternatives collects eight data parameters. This option, however, is not particularly realistic either, since eight data parameters generally are not gathered at all 68 sites.

The alternative strategy selected for analysis is to utilize the ERTS system as the basis for comparison. The scale of operation of the manual system is hypothetically reduced from 68 sites to 7 sites and the ground telemetry from 20 sites to 7. With respect to the number of data parameters assumed to be collected, if only one data parameter is collected, the same problems of excess capacity and prorating costs exist as cited previously. Similarly, if eight data parameters are required of each system at each site, then the problem of having an unrealistic analysis again arises.

On balance, the most useful approach appears to be a comparison of the ERTS system with its seven sites and variable number of collected data parameters with equivalent manned and ground telemetry systems. Thus, the analysis assumes three systems, having seven sites each collecting the same data parameters, and then proceeds to an examination of comparative costs. Problems of prorating system costs to each data parameter collected, those of excess capacity, and those of unrealistic situations are thus avoided.

Since only the ERTS system actually exists in the form specified, it is necessary to estimate the costs of comparable manned and ground telemetry systems. These estimates are calculated for the hardware, software, and labor costs of installing, operating, and maintaining each system. The results of the cost calculations are summarized in table 9.

Table 9

Estimates of Annual Costs for ERTS, Manned and Ground Telemetry Systems

System	Installation				First Year Operation and Maintenance				Subsequent Years Operation and Maintenance			
	Hardware	Software	Labor	Total	Hardware	Software	Labor	Total	Hardware	Software	Labor	Total
ERTS	$38,892	$3,047	$26,131	$ 68,070	$2,402	$2,548	$23,245	$28,195	$2,402	$2,548	$29,814	$34,764
Modified ERTS	52,892	3,047	26,131	82,070	2,402	2,548	23,245	28,195	2,402	2,548	29,814	34,764
Manned	21,486	4,876	14,022	40,384	2,340	609	45,956	48,905	2,340	609	52,293	55,242
Ground Telemetry	76,288	6,095	53,526	135,849	2,767	1,707	32,361	36,835	2,767	1,707	39,000	43,544

While the estimation of installation costs is straightforward, several assumptions are required in order to arrive at the operation and maintenance cost estimates. It is assumed that for each system: (1) service would be from WSSI's Fort Collins office on a monthly basis; (2) two personnel equipped with a four-wheel drive vehicle and two snowmobiles would be required; (3) the Muleshoe and Lime Mesa sites would be serviced via helicopter; and (4) the period of operation is 9 months per year.

Furthermore, it is assumed that for both the ERTS and ground telemetry system: (1) service trips would be 5 days consisting of 1 day en route from Fort Collins to the project area, 3 days servicing and maintaining the equipment, and 1 day returning to Fort Collins; (2) if a given remote station fails between scheduled maintenance trips, repairs would be delayed until the next scheduled service trip; and (3) the seven sites would be divided into two groups to be serviced every other month. In addition, the ground telemetry system is anticipated to require one repair trip to a repeater site and three repair trips to the master station each year. The ground telemetry system requires a heated office facility to house the master station, whereas the ERTS and manned systems simply require storage facilities during the 3 months that the systems are not in use.

Finally, it is assumed that for the manned system: (1) each of the seven sites would be serviced each month; (2) service trips would require 10 days consisting of 2 travel days, 6 workdays and 2 weekend days; and (3) equipment repairs would be made by the field crew as problems developed.

First year cost is the sum of the installation costs and the costs of operation and maintenance for that year. Included in the operation and maintenance costs are the costs of storing some equipment when not in use. Since this equipment must be reinstalled the following year, the operation and maintenance costs for the second year and all subsequent years reflect this cost along with routine operation and maintenance costs and removal costs.

A cost estimate is also calculated for a modified ERTS system which would record hourly data parameter measurements. The hypothetical modified ERTS system is included in the analysis to allow a comparative analysis of similar analytic systems. Cost estimates for the modified system differ from the existing ERTS system only in the addition of cassette tape recorders at each of the seven sites, therefore increasing the hardware installation costs.

The three systems differ in several important aspects. The ERTS and ground telemetry systems are initially more costly than the manned system, with the ground telemetry system being fully three times more costly and the ERTS system being nearly twice as expensive to install. The converse is true for operation and maintenance of the three systems. ERTS operation and maintenance costs are approximately 60 percent of those of the manned system, while these costs for the ground telemetry system are roughly 75 percent of those of the manned system. In general, the more technologically sophisticated systems are more costly to install but require less operation and maintenance expenditures.

One other cost problem which must be considered is the difficulty of equating a dollar invested today in the data collection systems with a dollar invested 5 or 10 years in the future. In order to equate the three types of investments, the cost stream for each alternative has been discounted back to the present, using two discount rates, one of 6 percent and the other 12 percent. (These alternatives might be considered roughly equivalent to a public rate and a private rate of discount.)

Total dollar costs for each alternative have been computed both before and after applying these discount rates. The costs have been computed assuming a project life of 5 and 10 years for each alternative. Table 10 summarizes the undiscounted costs, and table 11 summarizes the discounted present value of costs for the three alternatives.

Table 10

TOTAL UNDISCOUNTED COSTS FOR ERTS, MANNED AND GROUND TELEMETRY DATA COLLECTION SYSTEMS

System	Total undiscounted cost	
	5 years	10 years
ERTS (Modified)	$235,321 ($249,321)	$409,141 ($413,141)
Manned	$310,257	$586,467
Ground telemetry	$346,860	$564,580

Table 11

Total Discounted Costs for ERTS, Manned and Ground Telemetry Data Collection Systems

System	(6 Percent Discount Rate)										Total Discounted Cost	
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	5 Yr. Total	10 Yr. Total
ERTS (Modified)	$ 96,265 ($110,265)	$32,796 (")	$30,936 (")	$29,188 (")	$27,536 (")	$25,976 (")	$24,505 (")	$23,122 (")	$21,811 (")	$20,573 (")	$216,721 ($230,721)	$332,708 ($346,708)
Manned	$ 89,289	$52,110	$49,160	$46,381	$43,757	$41,277	$38,940	$36,741	$34,659	$32,698	$280,697	$465,012
Ground Telemetry	$172,684	$41,075	$38,750	$36,560	$34,487	$32,536	$30,694	$28,957	$27,320	$25,769	$323,556	$468,832

System	(12 Percent Discount Rate)										Total Discounted Cost	
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	5 Yr. Total	10 Yr. Total
ERTS (Modified)	$ 96,265 (110,265)	$31,040 (")	$27,714 (")	$24,745 (")	$22,092 (")	$19,725 (")	$17,611 (")	$15,724 (")	$14,041 (")	$12,536 (")	$201,856 ($215,856)	$281,493 ($295,493)
Manned	$ 89,289	$49,326	$44,039	$39,321	$35,106	$31,344	$27,986	$24,986	$22,312	$19,920	$257,081	$383,629
Ground Telemetry	$172,684	$38,880	$34,713	$30,995	$27,672	$24,707	$22,059	$19,695	$17,587	$15,702	$304,944	$404,694

Table 10 indicates that, in terms of total undiscounted costs, with project life assumed to be 5 years in each case, the ground telemetry system is the most expensive alternative, while the ERTS system, in both the existing form and with the modification to accommodate continuous data collection, is the least costly. Assuming a 10-year project life, the ERTS system is again less costly than either of the remaining alternatives, but the ground telemetry system is shown to be less costly than is the manned system.

An examination of the total discounted costs indicates that, for both assumed discount rates and for both the 5- and 10-year assumed economic life of the alternatives, the ERTS system and its modification are less costly than the other alternatives. The manned system is slightly less expensive than the ground telemetry system in both cases simply because of the greater capital expenditure required for the latter. It is quite likely that the relative merits of the manned system and the ground telemetry system would be reversed if an inflation factor were included in the discounting procedure. Since the annual operating and maintenance costs for the manned system exceed those of the ground telemetry system, inflation will have a greater effect on increasing the costs of the manned system. The position of the ERTS system relative to the others would not, however, change.

The analysis of costs indicates decisively that, under the assumptions made regarding the estimates of operation and maintenance costs for the three systems and the requirements imposed on the systems with respect to the number of sites and the data collected, the ERTS system is less costly than the other two. Thus, it may be argued that, in terms of the specified data parameters, the ERTS system is the most cost-effective. The modified ERTS has both the operational advantage of providing data on a near real-time basis and also the analytical capability of the manned system and the ground telemetry system at lower cost than either. For ease of manipulating data, both the ERTS and the ground telemetry systems are rated high.

There are, however, other factors which comprise effectiveness which are not considered in the analysis and which must be considered by policymakers in the decision as to which system is the most effective. In the present case these factors include the frequency of the sample and the effective sample, the frequency of data reception, the resolution and the accuracy of the data. The policymaker must ultimately decide the relative desirability of more frequent versus less frequent sampling and data reception, greater as opposed to lesser accuracy in the data, and more or less detail in the resolution of the data. Additionally, the policymaker must have information at his disposal on whether the cost of placing a satellite into orbit will continue to be financed using public monies or whether, in future years, it must be borne by the data collection system users. Information must also be available on the anticipated usable lifetime of the satellite data collection system as presently configured and the availability and suitability of backup satellite systems should the satellite suddenly fail.

The question, couched in terms of trade-offs, becomes one of whether the apparent cost advantages of the ERTS system in both its present and modified forms, are great enough to offset possibly lesser accuracy and resolution of the data and less frequent data reception than are enjoyed in total or in part by the alternative systems.

The modified ERTS system does offer advantages over the existing ERTS system in that data are sampled and recorded hourly, thus giving the system both operational and analytical capabilities. However, the frequency of reception, the accuracy, and the resolution of the data have not changed.

Additional considerations, admittedly beyond the scope of this analysis, include the costs of displaced labor should the manned system be replaced by the more sophisticated satellite system and the increasingly important environmental quality impacts of additional data collection sites. These cost considerations, while difficult to quantify, are nonetheless important social issues which must be accommodated.

VI. GENERAL SUMMARY AND CONCLUSIONS

The ERTS data collection system provides a user with the capability of collecting, transmitting, and disseminating up to eight channels of data from remote unattended sites. Data are collected and transmitted every 90 or 180 seconds from individual data collection platforms and are relayed to a ground receiving site whenever the transmitting platform and the ground receiving site are within mutual view of the orbiting

ERTS-1 satellite. Once data are received, they are processed, and distributed to the user.

The data collection system, as designed for the ERTS satellite, has been tested by the Bureau of Reclamation's Division of Atmospheric Water Resources Management to determine whether it has operational utility as a means of collecting meteorological and hydrometeorological data for control of cloud seeding operations in the Colorado River Basin Pilot project - a major wintertime orographic weather modification project designed to enhance natural precipitation in the Colorado River Basin. Experiments conducted by the Bureau of Reclamation were designed to realize the following four goals:

(1) To interface transmitters with existing hydrometeorological instruments for reliable, accurate operation in remote mountain locations.

(2) To develop processing and application procedures by typical data user agencies and groups and prepare preliminary operational and maintenance guidelines for each type of instrument-transmitter unit.

(3) To provide the information for cost and effectiveness comparisons between current and ERTS-1 data collection techniques.

(4) To provide early field experience and familiarization by western water resource agencies with the ERTS-1 data collection system to help define the eventual justification, scheduling, and role of ERTS in water resources management, including weather modification.

Several organizations have aided DAWRM in planning and executing the ERTS program. Two western water resource agencies, the Soil Conservation Service and the U.S. Geological Survey, aided by installing and operating special hydrometeorological sensors. Western Scientific Services, Inc., the data collection contractor for the Colorado River Basin Pilot project, handled the developmental and field portions of the ERTS program, and EG&G, Inc., the cloud seeding contractor for the weather modification experiment, used the ERTS data operationally and provided input on the utility of the ERTS data collection system in making cloud seeding decisions. Other western water resource agencies and private contractors were introduced to the ERTS program as utilized by the Bureau of Reclamation at the biannual meeting of the Weather Modification Association in Huntington Beach, California when a talk was presented entitled, "A Satellite Data Collection System to Monitor Weather Conditions for Cloud Seeding Control."

The first stage of project operations called for developing and testing signal conditioning circuitry and designing and fabricating a weather-resistant field installation for the ERTS data collection platforms.

The first data collection platform was installed in the field in March 1973, and environmental testing was begun at the field locations in the severe winter weather environment of the San Juan Mountains of southwestern Colorado. Data flow from the NASA facility at Goddard Space Flight Center was structured so that data were transferred to the users via the National Meteorological Center at Suitland, Maryland and the Bureau of Reclamation's Environmental Computer Network.

The near real-time DCS platform data transfer to time-share computer has proven to be a working reality. During the 1973-74 winter season, seven ERTS stations located in remote areas of the San Juan Mountains were automatically monitored and displayed with a system delay of 3 to 8 from time of data transmission to time of data accessibility on the computer.

The types of data transmitted routinely from the ERTS field sites included air temperature, relative humidity, wind speed and direction, precipitation, water equivalent of snowpack, rime ice detection, solar radiation, stream stage, stream temperature, and battery voltage. At some sites, one or more of these parameters were also recorded by instruments that are part of the data collection network for the Colorado River Basin Pilot project. In these cases, the data relayed from the field by ERTS satellite were compared with data recorded onsite and were determined to be of high quality. The accuracy of the data received was generally limited by the accuracy of the sensors and was not affected by ERTS design considerations. However, the resolution of the data was in some instances compromised when transmitted through the ERTS satellite because of the fixed number of binary bits available to represent data within sensor design ranges. Binary data relayed from the platforms were changed to engineering units listings by software developed by DAWRM for the Denver computer. Input for the computer programs called for sensor calibration data and platform numbers for the individual field sites. Binary data were routinely and automatically converted to engineering units listings after calibration data were entered into the computer.

The DCS platforms, as deployed in this investigation, have proven themselves to be reliable weather-resistant systems for winter mountain environments in the southwestern Colorado mountains. Maintenance experience showed the data collection platforms to be extremely reliable data collection devices. Few maintenance problems were encountered through the lifetime of the project although some short-lived problems were encountered when the ERTS installations were first put in the field. These initial difficulties were attributed to the location of one of the sites in a lightning-prone area and included some minor initial difficulties with sensor tie-in. Colocation of the ERTS sites with ground telemetry site locations produced some special interfacing and maintenance difficulties, including an occasional one or two binary bit ambiguity in the ERTS transmitted data apparently caused by RF interference. This was not judged to be significant enough to justify special maintenance trips.

One advantage of the ERTS system over manual data collection systems is the capability of monitoring transmitted data in near real time to detect when maintenance or servicing is required so that timely servicing trips can be scheduled with little or no loss of data.

Characteristics of the quantity and frequency of data relayed through the DCS were a function of the radio visibility of the specific sites. The average number of ERTS-1 satellite orbits relaying one or more transmissions from the sites varied from 3.1 orbits per day at Wolf Creek North to 5.09 orbits per day at Muleshoe. Standard deviations were .86 and .62, respectively. Each orbit may relay one or more messages. The average number of messages per orbit varies from 2.80 at Castle Creek to 4.67 at Palisade Lakes with standard deviations of .83 and 1.75, respectively. The messages received from a transmitting DCP were generally identical during a given orbit since the parameters generally measured were relatively invariant during the short time that the satellite was within view. Thus, useful data were transmitted from a site an average of three to five times a day. The three to five orbits fell into two periods of the day - one in a 3-1/2-hour period centered at 0930 MST and the other in a 3-1/2-hour period centered at about 2130 MST. The orbital characteristics of the ERTS-1 satellite thus determine the frequency of data reception through the DCS.

The DCS platform system has proven itself as a valuable tool in providing additional and more rapidly acquired data for weather forecasting, cloud seeding operations, streamflow forecasting, and evaluation purposes. Data have been used by DAWRM's cloud seeding contractor for near real-time monitoring of meteorological and hydrological data for control of cloud seeding operations and verification of weather forecasts. Despite some inadequacy in the sampling frequency of some of the parameters monitored through the ERTS system (especially temperature, wind speed, and wind direction) early experimentation determined that the ERTS DCS was a useful aid in making operational decisions for control of cloud seeding operations. The Wolf Creek Pass site, for example, provided data important in making the decision when to suspend seeding operations in the spring of 1973 so as to insure that suspension criteria (for above normal snowpack) were not exceeded.

An analysis of the operational testing phase of the ERTS program in August and September 1973 resulted in a decision to make immediate use of the ERTS DCS as a semioperational tool on the pilot project. New sites were chosen for some of the instruments so that better coverage of the cloud seeding target area would result, and a decision was made to instrument the new sites with recording precipitation gages since precipitation data were deemed to be operationally important. The ERTS project, in addition to its usefulness and success in collection of data from remote instrumented sites, has drawn additional attention to the pilot project as a national cooperative scientific effort in weather modification and water resources development.

A cost-effectiveness analysis of the ERTS DCS relative to manual and remote ground telemetry data collection systems was completed using experience gained in costing similar types of existing networks in the Colorado River Basin Pilot project. The approach taken was to specify a comparable level of effectiveness for the three systems and then to seek the least-cost alternative. Costs were determined using the seven-station ERTS network as the standard, but adding an electronics modification so that storage of hourly data at each of the ERTS sites was possible. Results of the analysis indicate the ERTS and ground telemetry systems are initially more costly than the manned system, with the ground telemetry system being fully three times more costly and the ERTS system being nearly twice as expensive to install. The converse is true for operation and maintenance of the three systems. ERTS operation and maintenance costs are approximately 60 percent of those of the manned system, while these costs for the ground telemetry system are roughly 75 percent of those of the manned system.

It can be concluded from this cost-effectiveness analysis that the more technologically sophisticated systems are more costly to install but require less operation and maintenance expenditure. Under the assumptions made regarding the estimates of operation and maintenance costs for the three systems and the requirements imposed on the systems with respect to the number of sites and the data collected, the analysis of costs indicated decisively that the ERTS system is less costly than the other two and is, therefore, the most cost effective. The question then becomes one of whether the apparent cost advantages of the ERTS system are great enough to offset less assurance of continued data transmission and less frequent data reception than are enjoyed in total or in part by the alternative systems.

VII. RECOMMENDATIONS

This investigation has shown that: (1) the DCS platforms are reliable weather resistant systems; (2) the transmitted data are of high quality; (3) the ERTS system is a useful tool in providing near real-time data for activities such as weather forecasting, directing cloud seeding operations, and forecasting streamflow; and (4) the system is cost effective if the program is continued for at least 5 years. Based upon these findings, several recommendations are presented for improving the performance of the satellite data collection system.

It is recommended first that this investigation be continued in conjunction with the Colorado River Basin Pilot project. However, primary emphasis should be away from the demonstration and testing of the ERTS data collection system and toward its use as an operational tool. Efforts should be made to improve the turnaround time in getting the data back to the field. No ERTS data sites should duplicate existing ground-link data sites. During the period of this investigation, the seeding contractor on the Colorado River Basin Pilot project also received meteorological data from Runlett Park via a ground-based telemetry network; therefore, all ERTS equipment should be moved from this site to a new location. Other changes should be made in the configuration of the network if justified based on operational needs for real-time meteorological data.

An important step toward making the ERTS data collection system an operational tool is the development of a system for obtaining wind speed and wind direction averaging, as these values would be much more useful than the instantaneous values received thus far. It is therefore recommended that a reliable system for averaging wind speed and wind direction data be adopted or developed and tested.

The data sampling frequency of the ERTS DCS is of concern to users desiring synoptic data and/or data sampled at a higher frequency than once every 12 hours. Special onsite data storage circuitry is possible to allow for storage of data between satellite passes for transmission at an accelerated rate when the satellite is within mutual line of site communication path of both the transmitting site and a ground receiving station. Information on the development of such circuits would be helpful to other investigators, and DAWRM recommends that a means of dissemination of such information be provided by EROS.

Finally, convertible ERTS-GOES data collection platforms are being developed so that an investigator may use either the polar orbiting ERTS satellite or the SMS/GOES satellite data collection systems. The first SMS/GOES satellite was launched during May 1974 and is presently positioned over 75 degrees west longitude. This satellite has a geostationary equatorial orbit. A second SMS/GOES satellite is scheduled to be launched during February 1975 and will be positioned over 130 degrees west longitude. These geostationary satellites will solve the problem some users have with the frequency of data sampling with the ERTS system. Information on the development and operational plans for the ERTS-GOES compatible data collection platforms should be provided to present and potential users of the ERTS DCS so that long range plans for data collection can be made by users.

APPENDIX A

ERTS SITE LOCATIONS AND DATES OF OPERATION

Table A1

ERTS FIELD LOCATIONS

Station	Computer ID	WSSI ID	Latitude	Longitude	Elev.(ft)	County
Devil Mountain	DVLMTN	N/A	37°16'N	107°16'W	9,800	Archuleta
Molas Divide	MOLASS	HH1	37°45'N	107°42'W	10,880	San Juan
Pagosa Peak	PAGOSA	N/A	37°26'N	107°05'W	10,400	Mineral
Palisade Lake	PALADE	JL4	37°30'N	107°09'W	9,500	Hinsdale
Wolf Creek North	WLFCRN	KN1	37°27'N	106°53'W	7,800	Mineral
Castle Creek	CASTLE	NP3	37°12'N	106°45'W	9,100	Archuleta
Runlett Park	RUNPRK	KI1	37°29'N	107°30'W	10,760	LaPlata
Muleshoe	MULSUE	FG6	37°52'N	107°45'W	12,800	San Juan
Wolf Creek Pass	WLFCRP	JO1	37°29'N	106°48'W	10,810	Mineral
Lime Mesa	LIMESA	JH1	37°34'N	107°41'W	11,700	LaPlata

Table A2

PLATFORM LOCATIONS - SPRING 1973 THROUGH JUNE 30, 1974

Platform	Site	Dates
6025	Muleshoe	4-13-73 to 4-13-73
	Pagosa	4-26-73 to 5-19-73
	Palisade	9-25-73 to 6-5-74
6040	Wolf Creek North	4-27-73 to present
6143	Muleshoe	4-13-73 to 4-19-73
	Devil Mountain	5-3-73 to 6-28-73
	Castle Creek	12-10-73 to 5-24-74
6202	Molas Divide	4-12-73 to 4-25-73
	Runlett Park	5-2-73 to 5-29-73
	Runlett Park	11-7-73 to 6-6-74
6212	Muleshoe	4-20-73 to 5-25-73
	Muleshoe	11-6-73 to 5-23-74
6241	Wolf Creek Pass	3-23-73 to present
6347	Molas Divide	4-25-73 to 5-4-73
	Spare	5-4-73 to 9-27-73
	Lime Mesa	9-27-73 to 5-16-74
6062	Spare	9-27-73 to present
*6141	Spare	3-5-73 to 5-4-73
	Molas Divide	5-4-73 to 5-16-73

* Platform number 6141 was a nonassigned platform number inadvertently used for a short period of time after an incorrect address card was received on a replacement platform.

Table A3

USGS MAPS OF ERTS SITES

Site	Quadrangle
Wolf Creek Pass	15' Wolf Creek Pass 1957
Wolf Creek North	15' Wolf Creek Pass 1957
Palisade Lake	7-1/2' San Cristobal 4SW 1973*, Oakbrush Ridge 1964
Castle Creek	15' Wolf Creek Pass 1957
Muleshoe	7-1/2' Ironton, Telluride, Ophir, Silverton 1955
Runlett Park	7-1/2' Vallecito Reservoir, Granite Peak 1964
Lime Mesa	7-1/2' Needle Mountains SW 1974*

* Advance proofs

Table A4

FOREST SERVICE AERIAL PHOTOGRAPHS OF ERTS SITES

Site	Photo Number
Wolf Creek Pass	ENP 3 139
Wolf Creek North	ENP 5 91
Palisade Lake	EOU 25 245
Castle Creek	ENP 3 46
Muleshoe	ENP 11 44
Runlett Park	ENP 8 170
Lime Mesa	Unknown

APPENDIX B

BRIEF DESCRIPTIONS OF HYDROMETEOROLOGICAL

INSTRUMENTS USED ON THE ERTS DCS PLATFORMS

APPENDIX B

Parameter	Description of sensor
Air temperature	YSI No. 44203 Thermilinear Thermistor Network. Range -30°C to +50°C Located on stand approximately 5 meters above the ground with radiation shield.
Precipitation	Belfort No. 552 Remote Transmitting Gage. Twelve-inch capacity (rain or snow). Gage capacity is reduced to ten inches because two inches of an antifreeze and oil mixture is added to the empty bucket to melt the snow and prevent evaporation. The sensor output is 0-5 volts and provides 0.04 inch water equivalent resolution over the 10 inch range.

Relative humidity	PCRC-11 HP Electro-humidity Sensor. AC Excited (1,000 Hz) Senses changes in relative humidity by changes in impedance. Range 0-100 percent. Accuracy ±2.5 percent over the 0-100 percent range.
Rime ice	WSSI Special. Senses change in DC resistance across sensor surface. Indicates only absence or presence of rime ice.
Snowpack water content	Standard Soil Conservation Service Snow Survey Snow Pillow. Fischer-Porter Hydrostatic measuring type.
Solar radiation	SOL-A-METER MK 1-G100. Pranometer (sun and sky radiation). Spectral response 0.35 to 1.15 microns. Located on top of building at Muleshoe site.

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 -30°C to +50°C. Sensor is sealed in a stainless steel housing.
Wind direction	WSSI WD-0-108 Wind vane, dual potentiometer, located approximately 8 meters above ground.
Wind speed	Electra Speed No. 406. Three cup DC generating anemometer. Range 0-100 mph (0-45 m/sec). Located with wind vane.

APPENDIX C

LISTING OF COMPUTER PROGRAMS

1. Subroutine ERTS (routine to decode and store the data)

2. Program WESTSC (program to display the data)

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      SUBROUTINE ERTS
      DIMENSION IMES(8),FNAME(8),FACTR(16,8),FOCT(9),TOCT(9),
     $NSTA(8),A(80),DATAZ(12),KID(8)
      INTEGER FNAME,FNAME1,FNAME2,TOCT,A,B,DATA,C
      DATA NSTA/143,062,241,040,347,202,025,212/
      DATA FNAME/6HCASTLE,6HHIPLEX,6HWLFCRP,6HWLFCRN,
     $6HLIMESA,6HJERJIM,6HUPRSAJ,6HMULSUE/
      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)/.333264,1.,1.,1.,.01245,1.,.0196,.55308/
      DATA(FACTR(8,J),J=1,8)/-32.87,0.,0.,0.,-.025,0.,0.,.67224/
      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.,0.,.6614/
      DATA(FACTR(13,J),J=1,8)/.311356,1.,.039753,1.,.312816,1.,1.,1./
      DATA(FACTR(14,J),J=1,8)/-29.88,0.,-.102859,0.,-.807673,0.,0.,0./
      DATA(FACTR(15,J),J=1,8)/.193381,.345956,.383168,1.378951,.006765,
     $.39,.057902,.056740/
      DATA(FACTR(16,J),J=1,8)/-29.77681,8.898140,.620505,2.489109,0.,0.,
     $.092645,.6940/
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=4,80
      IF(A(I).EQ.1H ) GO TO 19
       IF(A(I).LT.1H0.OR.A(I).GT.1H9) PRINT 177,(A(K),K=1,80)
        IF(A(I).GE.1H8.AND.I.GT.21) PRINT177,(A(K),K=1,80)
      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*,/,80A1)
      ENCODE(80,1000,KID)A
      DECODE(80,1010,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(80A1)
 1010 FORMAT(4X,I1,1X,I3,I7,3X,I3,03,705,04)
      N=0
      DO 9 I=2,9
      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)
      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
      IF(FNAME1.EQ.6HMULSUE)WRITE(78,1026)AMON,NVDAY,C,TOCT(1),
     $(FOCT(K),K=2,9),JUL,B
      IF(FNAME1.EQ.6HMULSUE) GO TO 1027
      WRITE(78,1025) AMON,NVDAY,C,TOCT(1),(FOCT(K),K=2,9),JUL
     $,B
      IND=1
      CALL PURGIT(6HTAPE77,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,F5.1,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
```

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```
      PROGRAM WESTSC(INPUT=/80,OUTPUT,TAPE77,TAPE78)
      INTEGER A,B,FNAME,FNAME2,TOCT,ANS,ANAME
      DIMENSION A(7) ,B(64),JUL(500),FNAME(8)
      DATA FNAME/6HCASTLE,6HUPRSAJ,6HWLFCRP,6HWLFCRN,6HLIMESA,
     $6HJERJIM,6HHIPLEX,6HMULSUE/
1     PRINT 101
101   FORMAT(1X,*PRINT THE NAME OF THE FILE YOU WANT LISTED*,
     $/,*CASTLE FOR CASTLE CREEK*,
     $/,*UPRSAJ FOR UPPER SAN JUAN*,
     $/,*WLFCRP FOR WOLF CREEK PASS*,
     $/,*WLFCRN FOR WOLF CREEK NORTH*,
     $/,*LIMESA FOR LIME MESA*,
     $/,*JERJIM FOR JERSY JIM*,
     $/,*HIPLEX FOR HIGH PLAINS TEST PLATFORM*,
     $/,*MULSUE FOR MULSHOE*)
111   READ 109,ANAME
109   FORMAT(A6)
      PRINT 10
10    FORMAT(1X,*PRINT THE JULIAN DATE YOU WANT THE FILE LISTED FROM*)
      READ *,JULDAY
      DO 7 I=1,8
      IF(ANAME.EQ.FNAME(I)) GO TO 8
7      CONTINUE
      PRINT 102
102   FORMAT(1X,*THE STATION YOU ASKED FOR IS NOT VALID TRY AGAIN*)
      GO TO 1
8     K=I
30    IPAGE=0
      PRINT 777
777    FORMAT(1X,*-----*,61X,*-----*,5(/))
      GO TO (200,210,220,230,240,250,260,270)K
200   PRINT 500
      GO TO 100
210   PRINT 505
      GO TO 100
220   PRINT 510
      GO TO 100
230   PRINT 515
      GO TO 100
240   PRINT 520
      GO TO 100
250   PRINT 525
      GO TO 100
260   PRINT 530
      GO TO 100
270   PRINT 535
100   CONTINUE
      FNAME2=ANAME
      IND=1
      CALL GETIN(IND,6HTAPE77,FNAME2,7HER1200B)
      IF(IND.LT.0) PRINT 1005
1005  FORMAT(1X,*THE DATA FILE IS NOT PRESENT*)
      IF(IND.LT.0) GO TO 301
      DO 300 I=1,500
      READ(77,1010) B,JUL(I),X
1010  FORMAT(64A1,I3,A6)
      IF(EOF(77)) 301,90
90    IF(JUL(I).GE.JULDAY) PRINT1010,B,JUL(I),X
      IF(JUL(I).GE.JULDAY) IPAGE=IPAGE+1
      IF(IPAGE.GT.50) PRINT 1000
      IF(IPAGE.GT.50) PRINT 777
      IF(IPAGE.GT.50) IPAGE=1
300   CONTINUE
301   CONTINUE
```

```
      PRINT 1000
 1001 FORMAT(1X,*PRINT THE NAME OF THE FILE YOU WANT LISTED*)
 1000  FORMAT(1X,15(/))
      PRINT 103
 103  FORMAT(1X,*DO YOU WANT ANOTHER STATION \ ANSWER YES OR NO*)
      READ 104 ,ANS
      IF(ANS.EQ.2HYE) PRINT 1001
      IF(ANS.EQ.2HYE) GO TO 111
 104  FORMAT(A2)
 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    PCP   TVO   TVO   TVO  *
     $,*HSV    BAV JUL TIME*,/,*  GMT   GMT        C    BIT    IN.   BIT*
     $,*   BIT   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*)
 515  FORMAT(*  040 WOLF CREEK NORTH LAT 37.27"N LONG 106.53"W ELV 7800*
     $,*FT*,/,* DATE    TIME  C  TEMP  TVO    TVO   TVO   STF   TVO  HSV*
     $,*    BAV JUL TIME*,/,*  GMT   GMT        C    BIT    BIT   BIT   *
     $,*IN.   BIT    V      V  DAY RCVD*)
 525  FORMAT(*  202 JERSY JIM  LAT 37.34"N  LONG 107.41"W ELV 11700*
     $,*FT*,/,*  DATE  TIME  C  TEMP  TVO    TVO   TVO   TVO   TVC*
     $,*  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   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 12800 FT*,/,
     $* DATE    TIME   C  TEMP  TVO  TVO   TVO   TVO   TVO  HSV    BAV*
     $,*  JUL TIME*,/,*  GMT   GMT        C    BIT  BIT   BIT   BI*
     $,*T   BIT    V      V   DAY RCVD*)
      END
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APPENDIX D

PUBLICATIONS AND PRESENTATIONS

APPENDIX D

PUBLICATIONS AND PRESENTATIONS

Foehner, Olin H., Monitor Weather Conditions for Cloud Seeding Control, ERTS Investigation Number 642. Presentation of paper to Discipline Panel Review, ERTS Investigations, Goddard Space Flight Center, Greenbelt, Maryland. October 24, 1973

Hartzell, Curtis L., A Satellite Data Collection System to Monitor Weather Conditions for Cloud Seeding Control. Oral presentation at biannual meeting of the Weather Modification Association, Huntington Beach, California. March 22, 1974. Abstract: Brief description of Bureau of Reclamation ERTS program, listing the objectives of the investigation and providing preliminary results of tests of the operational utility of the data collection system.

Whiteman, C. David, Satellite Data Collection Systems. Report to the Bureau of Reclamation by Western Scientific Services, Inc. October 10, 1973.

GLOSSARY

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 the orbital plane of the synchronous satellite is the same as the Earth's equatorial plane, the satellite is referred to as geostationary.

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.

Satellites - A man-made object or vehicle intended to orbit the earth.

Attitude stabilization - Maintenance of a spacecraft in the desired position about the pitch, roll, and yaw axes.

Station-keeping - Periodic corrections needed in order to maintain a satellite in the proper position.

Snow pillow - An instrument which measures accumulation of snow by weight.

BIBLIOGRAPHY

ERTS Project Office, 1972: ERTS Data User's Handbook. Greenbelt, Maryland: Goddard Space Flight Center.

General Electric Co. Space Division, 1972: Earth Resources Technology Satellite Data Collection Platform Field Installation, Operation and Maintenance Manual. Valley Forge Pennsylvania: Valley Forge Space Center.

Glasstone, S., 1965: Sourcebook on the Space Sciences. Princeton: D. Van Nostrand Co., Inc., 937 pp.

Morel, P., and W. Bandeen, 1973: The EOLE Experiment: Early Results and Current Objectives. Bull. Amer. Meteor. Soc., 54, No. 4, 298-306.

Sabatini, R. R., ed., 1969. The NIMBUS III Users Guide. Greenbelt, Maryland. Goddard Space Flight Center, NIMBUS Project.

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