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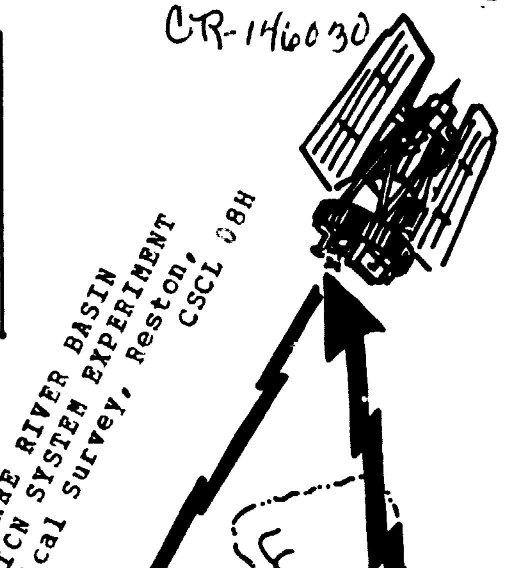
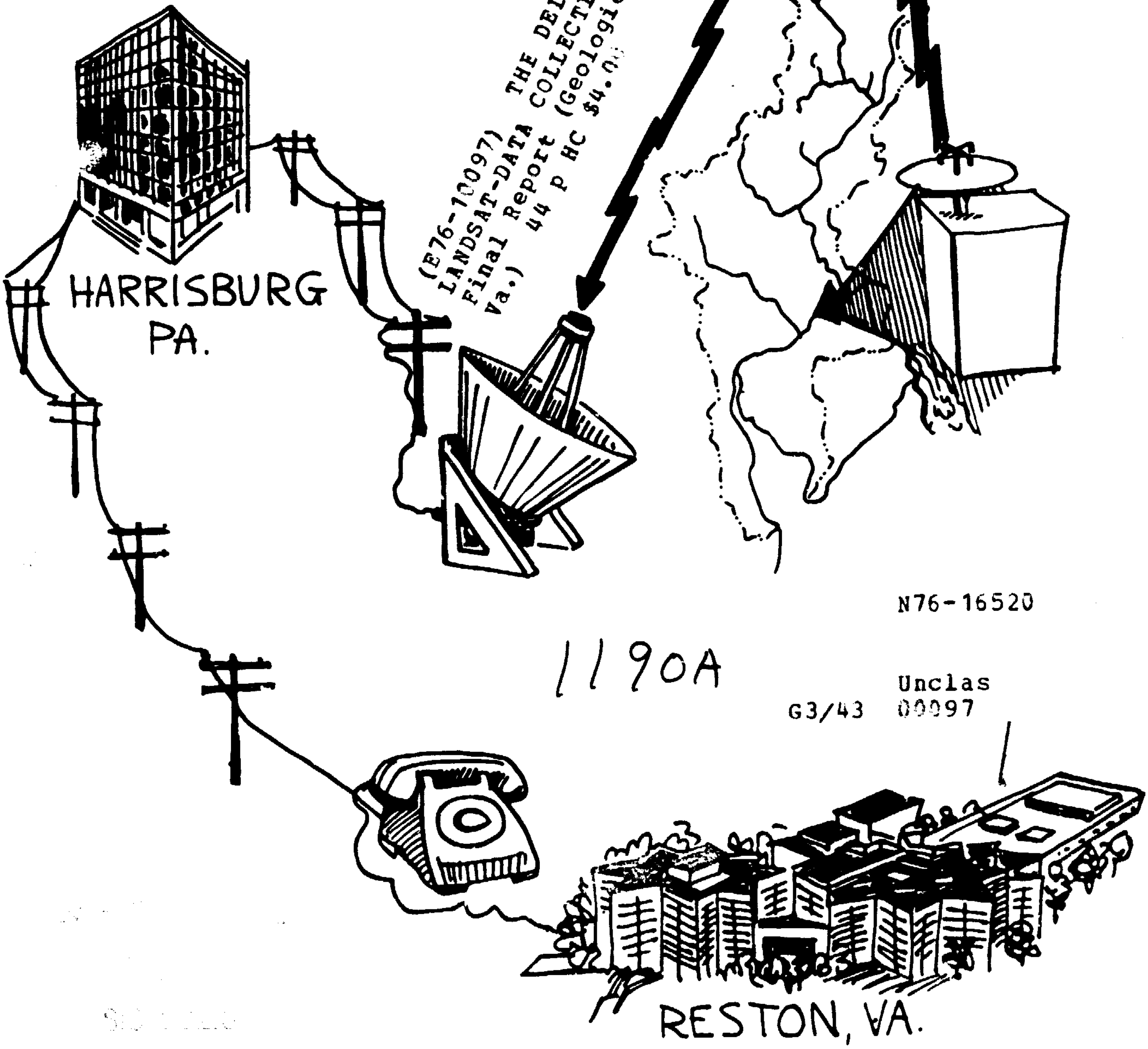
FINAL REPORT
DELAWARE RIVER BASIN
LANDSAT DATA COLLECTION SYSTEM
EXPERIMENT





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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

THE DELAWARE RIVER BASIN

LANDSAT-DATA COLLECTION SYSTEM

EXPERIMENT*

by
Richard W. Paulson

A FINAL REPORT
TO BE SUBMITTED TO THE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

*Approved for publication by the Director, U.S. Geological Survey

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16. Abstract
The Delaware River basin LANDSAT Data Collection System (DCS) experiment was designed as an attempt to integrate an experiment satellite system for relaying resources data with existing Geological Survey systems of hydrologic data collection and computer processing. The integration of these systems was structured as a simulated operational system, and water-resources data were processed daily and provided to water-resources agencies. Although the LANDSAT-DCS is inadequate as a large scale operational data-relay system, the successful use of the experimental system in this simulation demonstrated that space satellite relay of resources data can be accomplished using existing technology.

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Figure 2A. Technical Report Standard Title Page. This page provides the data elements required by DoD Form DD-1473, HEW Form OE-6000 (ERIC), and similar forms.

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INTRODUCTION

The LANDSAT-1 (Earth Resources Technology Satellite [ERTS-1]*) experiment, entitled "Near Real-Time Water Resources Data for River Basin Management" was an evaluation of whether standard U.S. Geological Survey Water Resources Division field instrumentation could be interfaced easily with the LANDSAT Data Collection System (DCS) and the data made to flow smoothly to water-resources management agencies in the Delaware River basin. The test yielded successful results.

LANDSAT Data Collection Platforms (DCP), which are small battery-operated radios, were interfaced with standard Survey instruments in stream-gaging stations, ground-water observation wells, and water-quality monitors in the Delaware River basin. During four to six LANDSAT orbits per day, water resources data were relayed from the Delaware River basin DCP's through the satellite's transponder to National Aeronautics and Space Administration (NASA) data-receive sites in Goldstone, California, and Greenbelt, Maryland. Soon after the completion of each LANDSAT pass over North America, DCS data from the Delaware River basin test site were processed by NASA, through the LANDSAT Operations Control Center (OCC) at the NASA Goddard Space Flight Center (GSFC), and transmitted by dedicated landline teletype to the Survey's district office in Harrisburg, Pa.

At this point in the data flow, the data from the NASA system were entered into the Geological Survey data-handling system. Once a day, after the data were received from the first morning LANDSAT pass over North America, which normally occurred before 11:00 a.m. Eastern Standard Time, the set of DCS data covering the previous 24-hour period was entered into the Geological Survey's telecomputing network for processing. The data were entered as a computer job in the Survey's National Center in Reston, Virginia, via the Survey's District computer terminal in Harrisburg, Pennsylvania. They were entered via a high-speed Remote-Job-Entry batch terminal (which contains a card reader, card punch, and line printer), but it was possible to retrieve part of the completed computer job via a teletypewriter computer terminal in the

*Prior to January 1975 LANDSAT was known as ERTS (Earth Resources Technology Satellite)

Harrisburg, Pennsylvania office. The teletypewriter computer terminal was used because it also could be used as a communications device, to retransmit DCS data summaries to water-resources management agencies that have commercial teletypewriters. This data flow is shown schematically in figure 1. A daily operational goal in processing the data was to release an LANDSAT-DCS water-resources summary to cooperating agencies by mid-afternoon each day. Normally, this objective was met.

All systems used in the flow of data were standard, Geological Survey tools for collecting and processing water-resources data, except for the NASA-provided DCS communications facilities. They are in or are available to almost all Survey field offices. The flow of data originated at standard Survey instrumentation, passed through the NASA-provided DCS communications system, and was made available in a typical district office. The data were entered into a standard Survey computer terminal, processed at the National Headquarters and returned to the district office. They were made available to several Survey cooperating agencies, which were a small subset of the 500 or more agencies that participate in the Survey's national cooperative program.

Both NASA and the Geological Survey data-handling involved extensive use of teletype and paper-tape recording of the data, which are cumbersome media for large data-processing tasks. The media were adequate for this small simulated operational system, but actual operational systems could be configured to maximize the use of high speed transmission of data to central processing systems. In an operational system, direct high speed transmission of the data from the analog of the NASA Operations Control Center to the Survey's Computer Center would be warranted, rather than low speed transmission of the data to district offices.

BACKGROUND

The U.S. Geological Survey Water Resources Division (WRD) maintains a Hydrological Data Network across the United States in cooperation with State, local, and other Federal agencies. This network includes 18,000 surface water stations, 28,000 observation wells, and 4,900 water-quality stations. Many of the stations are instrumented with continuously operating field recorders, and increasing number are being configured for real-time hydrologic-data transmission. The network is maintained to a great extent through the cooperative program, which collectively is a set of cost-sharing work

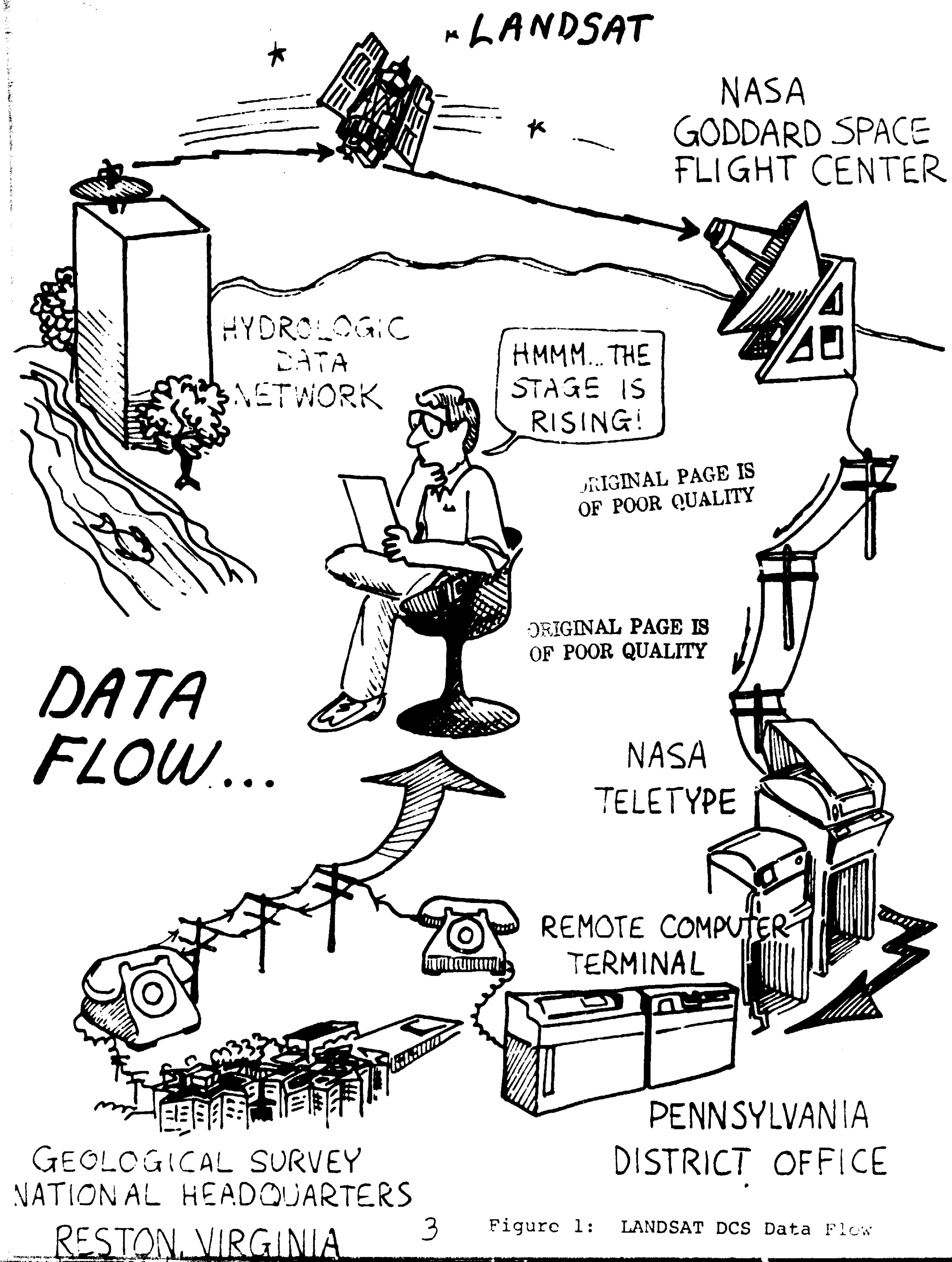

Figure 1: LANDSAT DCS Data Flow

agreements between the Geological Survey and over 500 local and State agencies. These agreements provide for data collection and water-resources investigations by the Survey that cover a diversity of hydrologic topics. A common thread throughout the cooperative program is that the nation's water resources can most efficiently be measured using a standard set of techniques, instruments, and expertise provided by the Survey. The LANDSAT experiment described herein was designed to test a near real-time data collection technology that could become a nationally-used technique for water-resources data collection and dissemination.

The Delaware River basin is an area of approximately 34,000 square kilometers (13,000 square miles) in the northeastern United States (figure 2). The basin includes significant parts of New York, Pennsylvania, New Jersey, and Delaware. The main river in the basin is the Delaware and the major tributaries are the Lehigh and Schuylkill rivers. The lower 157 kilometers (135 miles) of the Delaware River comprises the Delaware estuary and bay. The City of Trenton is at the head of the estuary (head of tide) and the cities of Philadelphia, Pa., Camden, N.J., and Wilmington, Del., are along the estuary. The bulk of the population and industry in the basin are in the vicinity of the Delaware River estuary. Pressure is increasing upon the basin's water resources to meet the needs of the area, which is typical of highly industralized and urbanized areas.

The Delaware River Basin Commission (DRBC) was created as a provision of the Delaware River Basin Compact, Public Law 87-328 enacted in 1961 by the United States and the states of New York, Pennsylvania, New Jersey, and Delaware. The DRBC is required by the Compact to develop and maintain a Comprehensive Plan for the "...conservation, utilization, development, management and control of the water and related resources of the Delaware River Basin..." (Public Law 87-328). The DRBC participates in the cooperative program with the Geological Survey and supports the operation of some hydrologic data stations in the basin.

Other agencies that have a need for real-time water-resources data include the Harrisburg River Forecast Center (RFC) of the National Weather Service, and the City of Philadelphia Water Department. The River Forecast Center in Harrisburg, which is responsible for stage and flow forecasting for major streams and tributaries in many eastern river basins, relies heavily upon USGS river stage data for daily forecasts. A close working relationship exists between the hydrologists of the RFC and the USGS in the operation, maintenance, and analysis of data from the hydrologic network. The RFC in Harrisburg makes daily streamflow and flood forecasts of major streams and tributaries

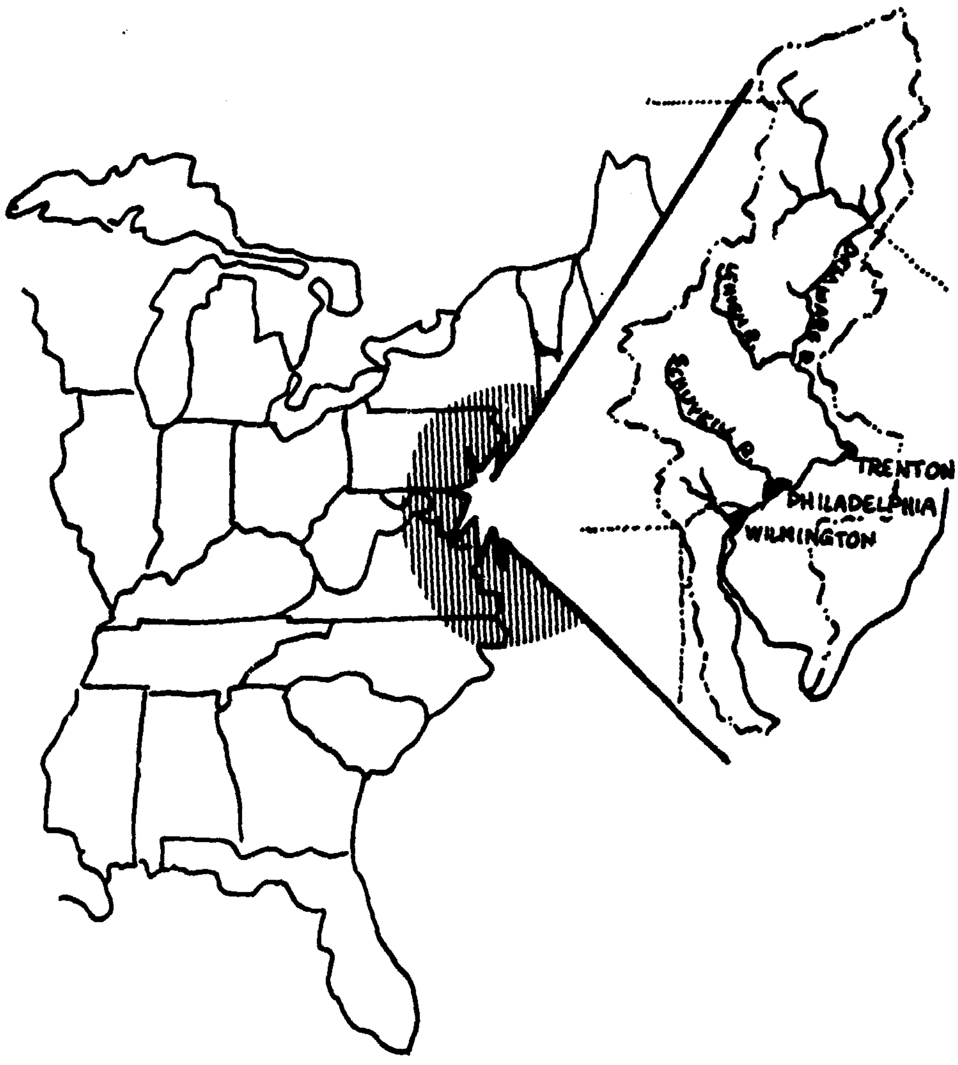

Figure 2: Location Map of the Delaware River Basin

in the Delaware River basin using streamflow data from gaging stations in the basin. The City of Philadelphia Water Department monitors the distribution of water in the Delaware River basin because the Water Department uses the Schuylkill, and Delaware Rivers as water-supply sources, and because the Department operates several water-pollution-control plants along the Delaware River estuary.

The Geological Survey could operate the water-resources instruments of the hydrologic network more efficiently if data were available in real time. A real-time analysis of these data could be used to schedule maintenance visits to the instruments and visits for gathering supplementary hydrologic data. Savings in travel and manpower realized by a more efficient network management could underwrite the added cost of real-time data acquisition.

WATER RESOURCES INSTRUMENTATION

The twenty stations instrumented with DCP's in the Delaware River basin are shown in figure 3 and listed in Table 1. These stations are representative of a larger number of stations the Survey operates in the basin and across the Nation.

There were three types of water-resources instruments interfaced with DCP's in the Delaware River Basin. The first, the digital recording stream stage station, conceptually portrayed in figure 4, is a simple installation where water stage is monitored in a stream-connected stilling well. A float in the well is connected to a shaft encoder on a digital recorder via a metal tape and counterweight. The recorder continuously monitors stream stage and, at regular intervals, the stream stage is punched on a 16-channel paper tape. At each of the five stream gaging stations where DCP's were installed, a Leupold and Stevens digital recorder, equipped with a telemetry module, was interfaced with the DCP's. The telemetry module, which contained a sixteen-bit memory, retained the most recent stream stage that was punched on the paper tape. This sixteen-bit data message, encoded as four binary coded decimals, was available as a parallel digital input to the DCP, which was the radio set used to communicate with LANDSAT. The DCP transmitted the same stream stage in successive data messages until the 16-bit memory was updated, at a 60-minute interval.

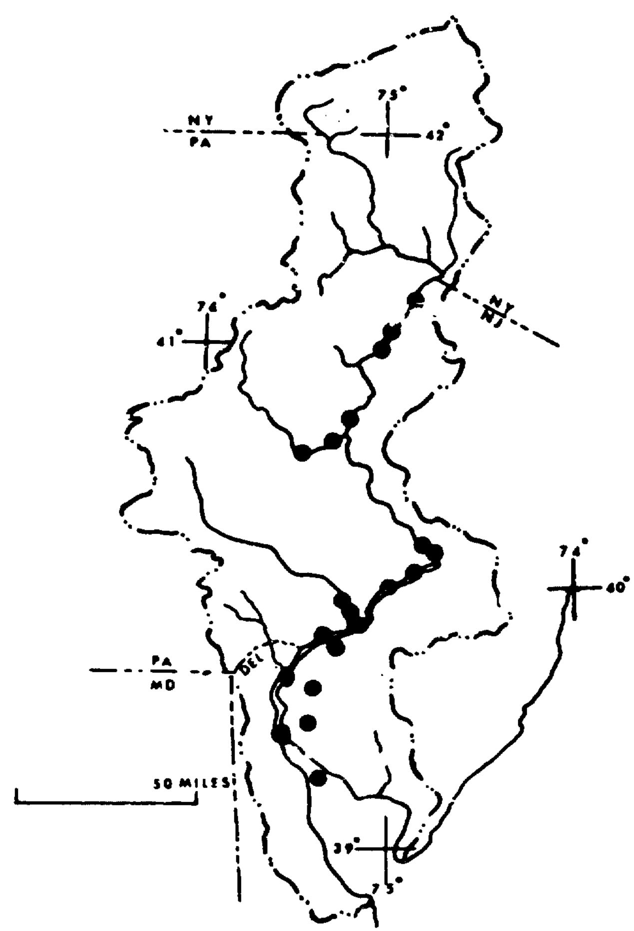

Figure 3: Location Map of USGS Water Resources Stations in the Delaware River Basin That Are Equipped With a LANDSAT Data Collection Platform

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TABLE 1

A Listing of Water Resources Stations In The Delaware River Basin Instrumented With Data Collection Platforms

USGS Station Number	Water Resources Station Class	Station Name	Latitude (North) Truncated to the minute	Longitude (West) Truncated to the minute	Water Stage	pH	Dissolved Oxygen	Spec. Cond.	Temp.
		Delaware River							
1-4385.	Stream gage	at Montague, N.J.	41°18'	74°47'	X				
1-4402.	"	below Tocks Island Damsite	41°00'	75°05'	X				
1-4635.	"	at Trenton, N.J.	40°13'	74°46'	X				
1-4530.	"	Lehigh River at Bethlehem, Pa.	40°36'	75°22'	X				
1-4745.	"	Schuylkill River at Philadelphia, Pa.	39°58'	75°11'	X				
	Water Quality	Delaware River							
1-4400.9	Monitor	near East Stroudsburg, Pa.	41°02'	75°01'			X	X	X
1-4467.	"	at Easton	40°42'	75°11'		X	X	X	X
1-4635.	"	at Trenton, N.J.	40°13'	74°46'		X	X	X	X
1-4646.	"	at Bristol, Pa.	40°04'	74°51'		X	X	X	X
1-4670.3	"	at Torresdale, Pa.	40°01'	74°59'		X	X	X	X
1-4672.	"	at Ben Franklin Bridge, Phila., Pa.	39°57'	75°08'		X	X	X	X
1-4770.5	"	at Chester, Pa.	39°50'	75°22'		X	X	X	X
1-4821.	"	at Delaware Memorial Bridge, Del.	39°41'	75°31'		X	X	X	X
1-4828.	"	at Reedy Island, Del.	39°30'	75°34'		X	X	X	X
1-4123.5	"	at Ship John Lighthouse	39°34'	75°34'				X	X
1-4547.2	"	Lehigh River at Easton, Pa.	40°41'	75°12'			X	X	X
1-4745.	"	Schuylkill River at Philadelphia, Pa.	39°58'	75°11'		X	X	X	X
	Observation								
N/A	Well	Salem City #1	39°33'	75°27'	X				
N/A	"	Penns Grove #24	39°42'	75°27'	X				
N/A	"	Shell Chemical Company #5	39°50'	75°13'	X				

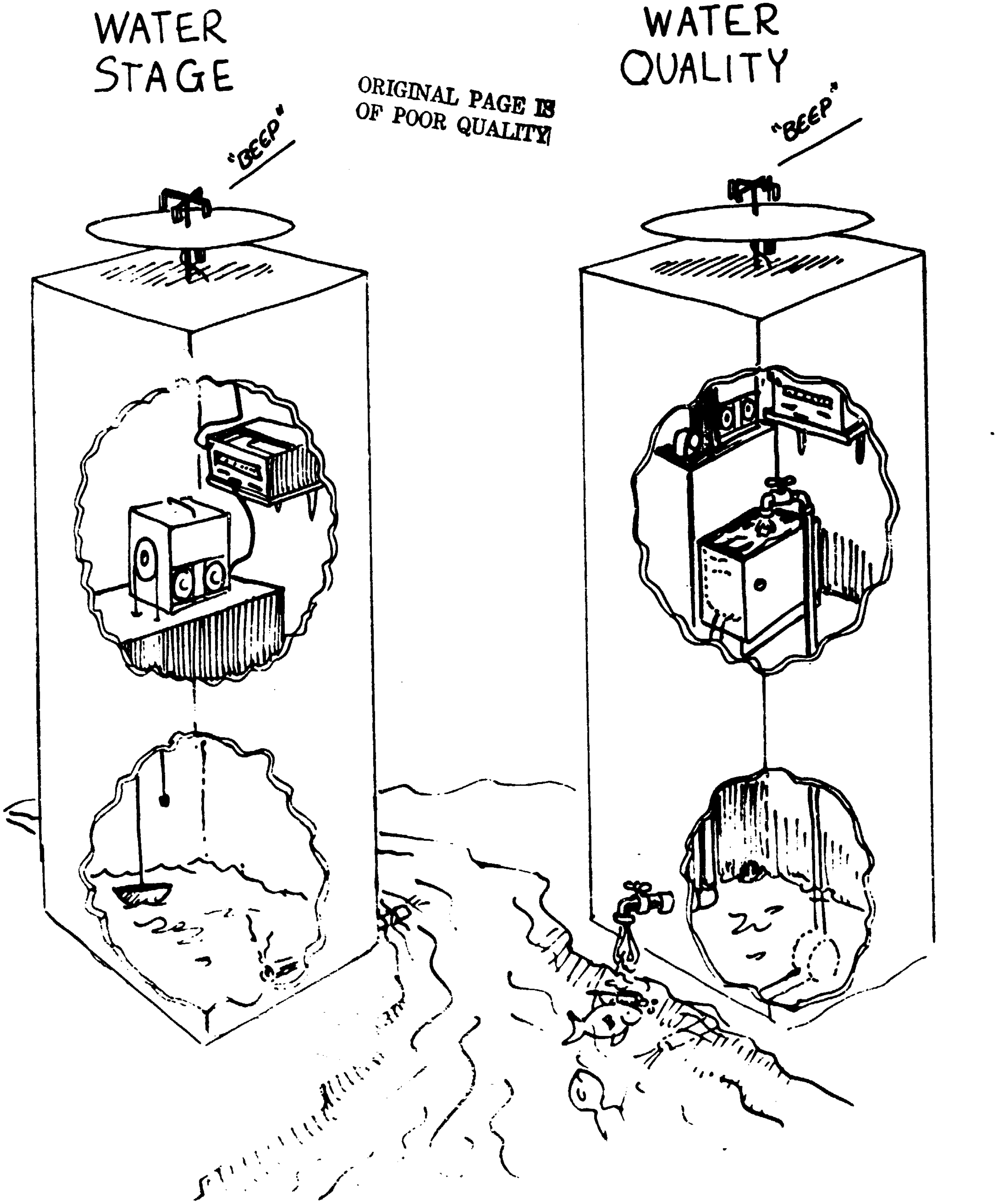

Figure 4: Schematic Drawings of Water-Stage and Water-Quality Monitors Equipped With LANDSAT DCP's

The second recording type of instruments interfaced with DCP's are digital-recording ground-water observation wells, which are conceptually identical to a stream-gaging station except that acquifer water level in a well is monitored rather than stream stage. The three ground-water observation wells instrumented with DCP's also were equipped with Leupold and Stevens digital recorders modified with telemetry modules. The sequence of punching, storing, and transmitting the data was identical to that at the stream-gaging station.

The water-quality monitors, which are the third type of instruments interfaced with DCP's, are electronically and hydraulically more complex than stage stations. A sample of water is continuously pumped from the stream, as schematically shown in figure 4. Water-quality sensors in the sample chamber are continuously bathed with fresh stream water. An alternative approach, to place in-situ sensors in the stream, generally is rejected because of the threat of vandalism, damage to the sensors by debris in the water, and difficulty of sensor maintenance. The sensors in the sample chamber continuously measure the common water-quality parameters of dissolved oxygen concerntration, specific conductance at 25°C, temperature, and pH. Periodically the voltage output of each sensor is punched on a 16-channel tape, which is analogous to the paper tapes upon which stream or ground-water stages are punched.

The values of several water quality parameters are sequentially punched on the paper tape at the recording interval rather than a single stage value.

There were two alternative methods of providing the data to the DCP when it was interfaced with a water-quality monitor. One method was to continuously provide an analog signal from each sensor to the DCP. At the time of DCP transmission the zero-to-five-volt range of each sensor was converted internally within the DCP to an 8-bit serial digital bit string that was included in the DCP data message. A second method was to store the digital data that were punched on the paper tape in a memory unit that accumulated the digital data from the monitor and continuously made available to the DCP, in parallel digital format, the data from the most recent paper-tape punching cycle. The latter method was chosen in the Delaware River Basin study.

The water-resources instrumentation interfaced with the LANDSAT DCS was representative of the large number of instruments that the Water Resources Divion operates. The Water Resources Division does operate other classes of water-resources instruments, such as snow pillows, and tidal discharge stations.

THE LANDSAT DATA COLLECTION SYSTEM

As conceptually shown in figure 5, the LANDSAT Data Collection System is a communications system that consists of three elements; (1) the Data Collection Platform and associated user sensors, (2) the DCS transponder on the polar-orbiting LANDSAT satellite, and (3) the ground receive sites and data-handling systems. Exhaustive descriptions of the DCS system, less the user sensors and user data-handling procedures, are in the ERTS Data Users Handbook (NASA, 1971) and the ERTS DCP Field Installation, Operations, and Maintenance Manual (NASA, 1972).

During the course of LANDSAT experiments, the only element of the system with which the user needed to gain any significant familiarity was the Data Collection Platform. The LANDSAT satellite was beyond this control (and in-depth understanding), and the only concern the user had with the third element, the ground data handling system, was the data output options of that system.

The LANDSAT DCP was a straightforward communications device to install, power, interface, and maintain (figure 6). The most cumbersome aspect of installing the DCP was mounting the antenna. The 46-inch diameter ground-plant antenna, although lightweight, was cumbersome in size. Efforts were made to make the antenna as unobtrusive as possible at most installations, because of the threat of vandalism. Nevertheless a secure, unobtrusive mounting of the antenna atop typical Geological Survey instrument shelters normally could be achieved by a 2 or 4 man-hour procedure on site. An antenna mounting was achieved at almost every site within the constraint of the 10 foot antenna lead supplied with the DCP.

Power to the DCP was supplied in most instances by four 6-volt dry cell batteries operated in series, or from line power through a 24-volt transformer. One DCP was powered by a 24-volt battery that was charged by a solar panel. These power supplies were all satisfactory, even to providing enough power to the DCP during the winter, when the temperature in the instrument shelter occasionally dropped to 0°F, and battery efficiency declined. A nominal 6-month operational battery life was achieved at all sites where dry cell batteries (the most cost effective power sources) were used.

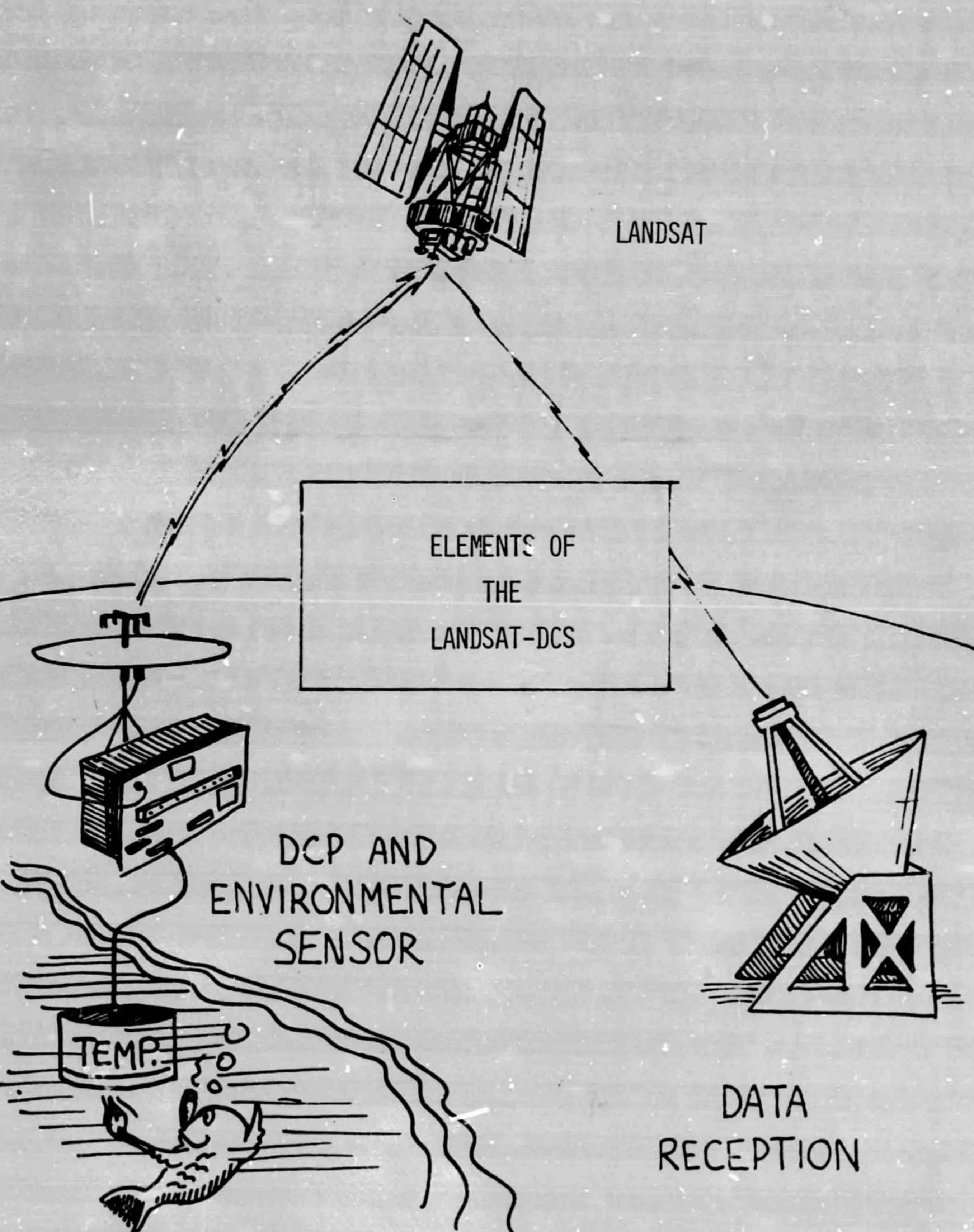

Figure 5: Three Elements of the LANDSAT-DCS

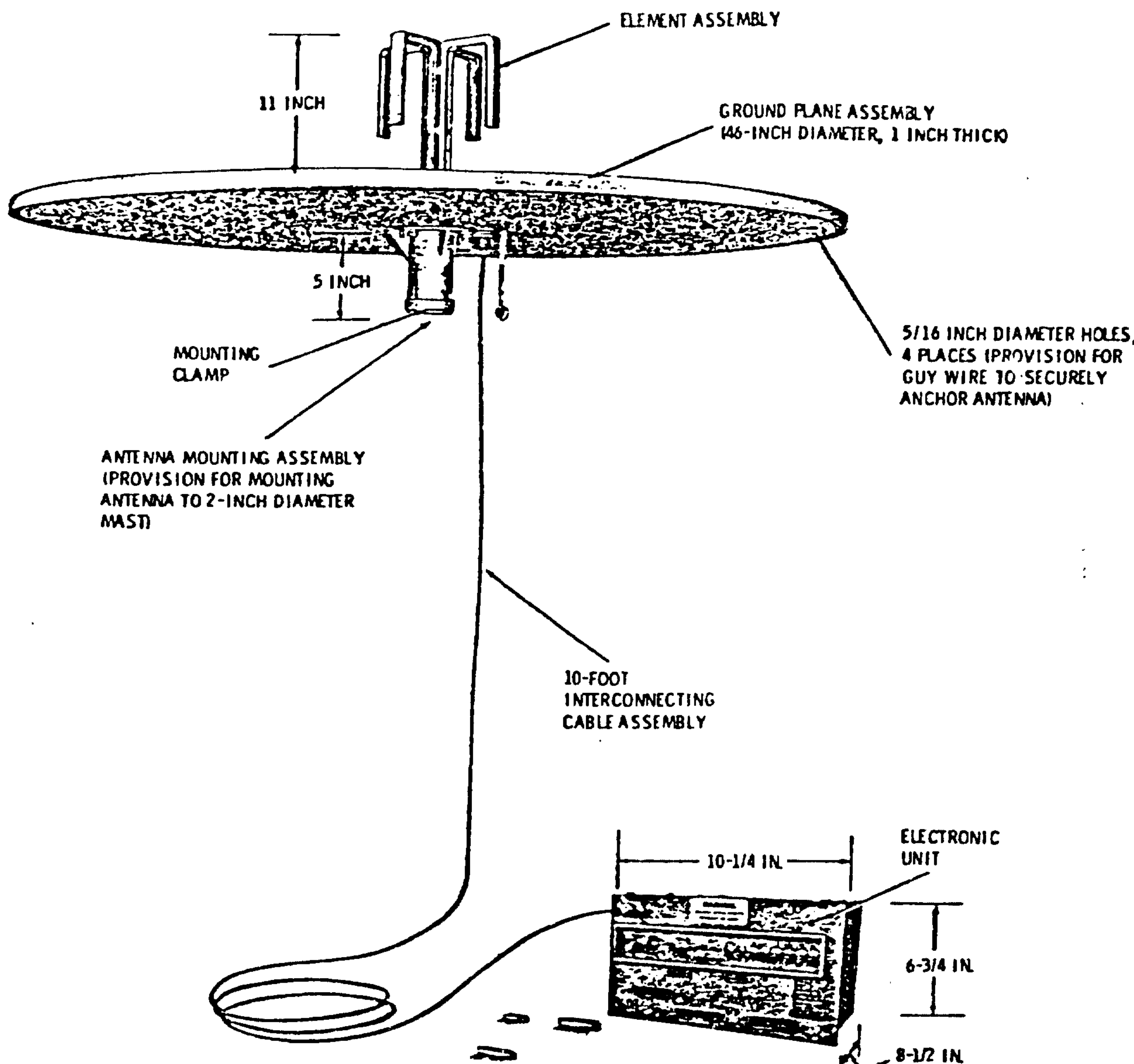

Figure 6: A LANDSAT Data Collection Platform

The interfacing of the DCP with user sensors was accomplished at all sites with no detectable failures within the DCP's. Interface problems were encountered external to the DCP and within the user-supplied instrumentation. These and other problems are addressed in a subsequent section of this report.

When properly installed, interfaced, and powered, LANDSAT DCP transmitted 401.55 Mhz transmission of 38-millisecond duration approximately once every 180 seconds. The transmitted encoded message of 190 bits contained a 12-bit DCP identification code and 64 bits of user-supplied environmental data, both of which were convolutionally encoded by the DCP. This transmission occurred approximately every 180 seconds on a continuing basis.

Data were received by the DCS receiver on board the satellite several times daily, when the LANDSAT satellite passed within about 1700 miles of the Delaware River basin. After the 401.55 Mhz receiver aboard the spacecraft received the data, they were frequency translated on board, and rebroadcast at 2287.5 Mhz on an S-band transmitter, to the Goddard Space Flight Center in Greenbelt, Maryland, and/or Goldstone, California. The data were successfully relayed only when a DCP and a receive site were mutually visible (in a radio sense) from the satellite at the instant the DCP transmitted a message. The message could have been unsuccessfully relayed even when mutual visibility occurred if two or more DCP's transmitted simultaneously causing interference. The LANDSAT design specification, that at least one transmission was relayed from each DCP every 12 hours, with a probability of success of 0.95, has been more than met by the system. This success, of course, was due in part to a design criteria of 1000 operating DCP's. No more than about 150 DCP's were actually operated during the experiment.

DATA PROCESSING

The Geological Survey's Computer Center Division maintains a national telecomputing network, which consists of an IBM 370/155 computer in the Survey's National Center in Reston, Va., an IBM 360/65 in Washington, D.C. and more than 150 remote terminals across the country. Most Water Resources Division district offices have remote high-speed batch terminals to the system, through which they enter data and computer jobs, and through which they maintain their data files in the National Water Data Storage and Retrieval System (WATSTORE). This is a computer file into which district offices enter their station data for further analysis, retrieval and publication. Although the hardware and software of WATSTORE are maintained in Reston, it is the task of the field offices to enter, verify, update, and generally maintain their own data in the files. Conceptually, a satellite DCS could be used to enter data directly to WATSTORE, if the satellite system were capable of economically collecting data at a sufficiently large rate from a large number of DCP's.

The Geological Survey's Harrisburg, Pa. office has two computer terminals that were used for the ERTS experiment. One is a high-speed batch terminal, a Data 100 model 70-2 shown in figure 7, that uses a 4,800 bits per second (baud) Binary Synchronous Communications (BSC) line for telecommunications. This terminal has a card reader, card punch, and line printer. The second terminal, an ASR-33 teletypewriter terminal that uses a 110 baud asynchronous line is shown in figure 8. This conventional teletypewriter was easily configured to be a remote computer terminal. It produces page copies and can punch or read an 8-level ASCII-encoded paper tape. These two terminals are typical of the classes of terminals found in WRD offices that provide access to a powerful computing system and WRD data files.

Data from LANDSAT DCS were provided by a dedicated-line teletype shown in figure 9. This teletype provided line copy as shown in figure 10, and a 5 channel paper tape. Within about 30-45 minutes after the completion of LANDSAT data-relay pass over North America, DCS data from the Delaware River basin test site were transmitted from the Goddard Space Flight Center's LANDSAT Operations Control Center to Harrisburg. Data on the 5-channel paper tape were punched simultaneously with the listing of the data on the teletypewriter printer.

Salient information on the teletype data listing for each relayed message can be seen in figure 10. Receive site identification, Greenwich Mean Time of data reception, DCP identification, message quality, user data, and the check sum were provided. Only message quality data of level 7 (highest level) were forwarded to the user. Five or ten percent of the data were sufficiently degraded during transmission for NASA to suspect that the data were spurious, and NASA's operating criterion was to not provide degraded data to the user.

The 64 bits of user data were octally encoded into 8 "data words" of 8 bits. Each data word was encoded as 3 octal characters each. Table 2 shows the bit equivalent of the 8 octal characters 0 through 7.

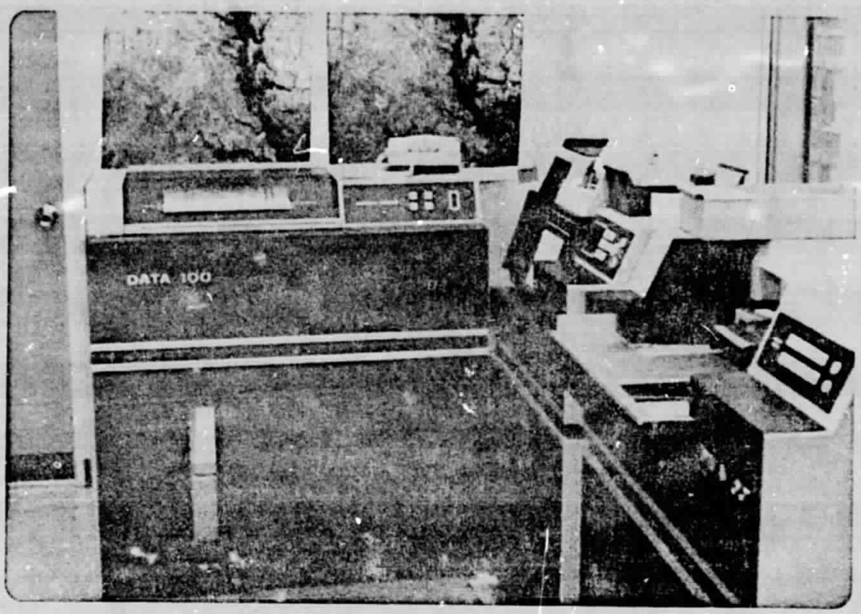

Figure 7: Data 100 Model 70-2 Batch Terminal

Figure 8: ASR-33 Teletypewriter Terminal

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Figure 9: NASA Supplied Teletype

●02A
PP GZAA
DE GERS 0120
23/0227Z

REF ERTS DCS
ATT R PAULSON USGS HARISBG PHONE 717 782 3420

S	Y	DDDHHMM	SS	PID	C	D1	D2	D3	D4	D5	D6	D7	D8	CS
N	3	2350156	45	6030	7	377	377	173	357	377	257	377	216	4
N	3	2350159	49	6030	7	377	377	173	357	377	257	377	216	4
N	3	2350202	52	6030	7	377	377	173	357	377	257	377	216	4
N	3	2350205	56	6030	7	377	377	173	357	377	257	377	216	4
N	3	2350158	55	6046	7	73	35	377	377	377	377	377	377	7
N	3	2350201	49	6046	7	73	35	377	377	377	377	377	377	7
N	3	2350204	44	6046	7	73	35	377	377	377	377	377	377	7
N	3	2350207	38	6046	7	73	35	377	377	377	377	377	377	7
N	3	2350157	13	6067	7	377	377	177	370	207	370	177	207	5
N	3	2350200	17	6067	7	377	377	177	370	207	370	177	207	5
N	3	2350203	21	6067	7	377	377	337	374	315	374	337	315	1
N	3	2350206	25	6067	7	377	377	237	370	211	370	237	211	5
N	3	2350157	46	6114	7	377	377	374	252	373	156	257	251	7
N	3	2350200	53	6114	7	377	377	374	252	373	156	257	251	7
N	3	2350204	00	6114	7	377	377	374	252	372	336	257	251	6
N	3	2350207	07	6114	7	377	377	371	272	372	336	252	251	0
N	3	2350157	27	6115	7	237	77	377	377	377	377	377	377	7
N	3	2350200	31	6115	7	237	77	377	377	377	377	377	377	7
N	3	2350203	35	6115	7	237	77	377	377	377	377	377	377	7
N	3	2350206	40	6115	7	237	77	377	377	377	377	377	377	7

NO MESSAGES 6116

N	3	2350158	41	6124	7	376	175	314	150	351	353	177	275	3
N	3	2350201	41	6124	7	376	175	314	150	351	353	177	275	3
N	3	2350156	50	6215	7	373	31	377	377	377	377	377	377	6
N	3	2350202	53	6215	7	373	31	377	377	377	377	377	377	6
N	3	2350205	55	6215	7	373	31	377	377	377	377	377	377	6
N	3	2350200	12	6223	7	137	1	377	377	377	377	377	377	1
N	3	2350203	27	6223	7	137	1	377	377	377	377	377	377	1
N	3	2350206	43	6223	7	137	1	377	377	377	377	377	377	1

NO MESSAGES 6227

N	3	2350158	54	6275	7	377	377	372	253	277	253	372	277	5
N	3	2350201	46	6275	7	377	377	372	253	277	253	372	277	5
N	3	2350204	38	6275	7	377	377	372	253	277	253	372	277	5
N	3	2350201	28	6277	7	157	377	377	377	377	377	377	377	3
N	3	2350204	25	6277	7	157	377	377	377	377	377	377	377	3
N	3	2350158	17	6306	7	377	377	377	377	377	377	377	377	7
N	3	2350201	04	6306	7	377	377	377	377	377	377	377	377	7
N	3	2350203	52	6306	7	377	377	377	377	377	377	377	377	7
N	3	2350206	39	6306	7	377	377	377	377	377	377	377	377	7

Figure 10: Format of NASA teletype data

TABLE 2

Octal character	3 bit equivalent
0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111

The NASA convention was to construct a 9-bit string by concatenating a dummy zero bit to the 8 bits of data in a data word. Thus, for example, the 8-bit string 01010011 was padded with a leading zero to become the 9-bit string 001 010 011, which was subdivided into 3 groups of 3 bits each, and octally encoded as 123. This merely was a simple scheme for compacting binary information for data communication and handling. The 64 bits of environmental data supplied by the user to the DCP was retrieved by the user by expanding and decoding the 8 octal data words under D1 through D8.

The "Checksum" (CS) value was used to check the validity of each of the teletype transmitted messages. This was necessary because teletype data are vulnerable to significant interference, resulting in spurious data transmission. The algorithm used was to octally sum all the octal characters beginning with the "7" in the "C" field (message confidence) in figure 10 and continuing through field "D8". The units value of the sum was entered by NASA in the "checksum" field "CS". This allowed the user to validate the data by testing the same algorithm NASA used prior to transmitting the data. The "checksum" algorithm could fail, but it did increase the probability of detecting spurious data.

Unfortunately, the format and level of the paper tape punched by the NASA-supplied teletype was incompatible with the ASR-33 teletypewriter that was used as a computer terminal to the Survey's computer. It was necessary to translate the 5-level tape data to another computer-compatible medium. This was most easily done with an IBM 047 tape-to-card punch, which translated each line of data from the tape to a card. The use of paper tapes and computer cards, and much of the manual data handling would be cumbersome and inefficient for an operational data handling system, but the procedure was satisfactory as an operational test.

Normally, one LANDSAT data-processing computer job was run daily. Nominally, the computer job processed data that were received during a 24-hour period ending in midmorning. As will be discussed in a later section of this report, in more detail, the LANDSAT mutual visibility periods for the Delaware River basin test site always fell in the periods 0800-1300 and 3000-2400 local time. A normal job included data from the latter half of a morning visibility period, the data from the evening period, and the first good mutual visibility period of the following morning. This permitted a 24-hour block of data which included at least one pass of fresh data, to be processed, and also permitted the data job to be processed and disseminated by midafternoon.

One of the advantages of having remote terminal access to a large computing machine like the IBM 370/155 in Reston is the opportunity for remote terminal users to write, compile, test, and store software online in the system. A user-written program to process LANDSAT-DCS data from the Delaware River basin was written and maintained by project personnel in Harrisburg, and stored online in the Reston computer. The only non-data cards required for daily processing of the data were a small number of Job Control Language (JCL) cards that provided the computer with information about the system resources required to execute the job.

Among the tasks performed by the computer program was the association of DCP ID with water-resources station, conversion of Greenwich Mean Time to local time, testing the checksum validation algorithm, conversion of the raw data to engineering units, the removal of duplicate data, and formatting of data summaries.

There are several job queues available to the user for processing batch jobs through the Geological Survey's computers. Queue priorities range from A through F, where A is the fastest and most expensive priority, and F is the slowest and least expensive. LANDSAT daily data processing jobs normally were run on an A or B priority, which cost less than $10 per job, with an average waiting time of about 30 minutes.

Once a computer job has been executed, the Survey system automatically places a job output on a queue to return the job to the originating remote terminal. The output is printed automatically if that terminal is still connected to the system. Before permitting the LANDSAT-DCS computer job to be returned over the batch terminal, the high-speed terminal was disconnected from the system, and the teletypewriter terminal

EROS-NASA

USGS DELAWARE RIVER BASIN-DATA COLLECTION SYSTEM EXPERIMENT

WATER RESOURCES SUMMARY

MARCH 16, 1973

WATER QUALITY STATIONS

TIME	S.C. UMHOS	D.O. MG/L	TEMP F/C	PH
DELAWARE RIVER AT REEDY ISLAND				
19: 11 0EST, MARCH 15,1973	4800	9.5	46/ 8.0	6.9
19:30:37EST, MARCH 15,1973	4960	7.4	46/ 8.0	6.9
21:10:33EST, MARCH 15,1973	4900	9.3	45/ 7.0	6.3
22:53:40EST, MARCH 15,1973	5400	10.2	45/ 7.0	7.0
22:59:51EST, MARCH 15,1973	5640	7.6	46/ 8.0	7.0
9:41:30EST, MARCH 16,1973	5080	10.0	46/ 8.0	7.0
DELAWARE RIVER AT CHESTER				
19:32:33EST, MARCH 15,1973	332	5.2	55/13.0	6.5
19:38:50EST, MARCH 15,1973	332	5.1	55/13.0	6.5
21:10:19EST, MARCH 15,1973	336	5.0	54/12.0	6.5
22:54:40EST, MARCH 15,1973	336	5.0	54/12.0	6.5
9:39:39EST, MARCH 16,1973	336	4.9	54/12.0	6.5
DELAWARE RIVER AT PIER 11,PHILA.				
21:13:12EST, MARCH 15,1973	205	12.6	47/ 8.5	6.9
9:42:31EST, MARCH 16,1973	199	13.1	47/ 8.0	6.9
DELAWARE RIVER AT BRISTOL				
19:33: 0EST, MARCH 15,1973	164	10.4	48/ 9.0	7.0
21: 8:44EST, MARCH 15,1973	165	10.5	48/ 9.0	7.2
9:41:40EST, MARCH 16,1973	165	10.4	48/ 9.0	7.0

SURFACE WATER STATIONS

TIME	GAGE HEIGHT FEET	DISCHARGE CFS
DELAWARE RIVER AT MONTAGUE		
19:32: 4EST, MARCH 15,1973	7.76	9030
21:10:17EST, MARCH 15,1973	7.78	9100
21:17: 3EST, MARCH 15,1973	7.79	9130
22:51:49EST, MARCH 15,1973	7.83	9420
9:42:11EST, MARCH 16,1973	7.20	8480
9:48:58EST, MARCH 16,1973	7.21	8510
DELAWARE RIVER AT TRENTON		
21:12:14EST, MARCH 15,1973	10.41	14500
9:44: 0EST, MARCH 16,1973	10.37	14200
LEHIGH RIVER AT BETHLEHEM		
21:15:12EST, MARCH 15,1973	3.54	1960
9:43:11EST, MARCH 16,1973	3.67	2140
SCHUYLKILL RIVER AT PHILA.		
19:32:11EST, MARCH 15,1973	6.37	2270
21:10:10EST, MARCH 15,1973	6.38	2310
22:54:37EST, MARCH 15,1973	6.38	2310
9:42: 0EST, MARCH 16,1973	6.61	2450

GROUND WATER STATIONS

TIME	WELL DEPTH FEET
SALEM CITY NUMBER 1	
19:31:49EST, MARCH 15,1973	23.36
21:11:10EST, MARCH 15,1973	23.35
22:54: 4EST, MARCH 15,1973	23.33
23: 0: 8EST, MARCH 15,1973	23.32
9:43:47EST, MARCH 16,1973	23.37
PENNS GROVE NUMBER 24	
19: 11:28EST, MARCH 15,1973	13.43
19:33:25EST, MARCH 15,1973	13.42
21:14:29EST, MARCH 15,1973	13.42
21:17:39EST, MARCH 15,1973	13.43
22:52:54EST, MARCH 15,1973	13.44
9:39: 3EST, MARCH 16,1973	13.43
SHELL CHEM. CO. NUMBER 5	
19:32:16EST, MARCH 15,1973	36.40
21: 8:55EST, MARCH 15,1973	36.44
22:54:19EST, MARCH 15,1973	36.22
9:41:17EST, MARCH 16,1973	36.08

EROS-NASA

USGS SUSQUEHANNA RIVER BASIN DATA COLLECTION SYSTEM EXPERIMENT

WATER RESOURCES SUMMARY

MARCH 16, 1973

SURFACE WATER STATIONS

TIME	GAGE HEIGHT FEET	DISCHARGE CFS
JUNIATA RIVER AT NEWPORT,PA.		
19:31:20EST, MARCH 15,1973	5.37	5240
21:10: 5EST, MARCH 15,1973	5.37	5240
22:55: 1EST, MARCH 15,1973	5.36	5220
9:42:15EST, MARCH 16,1973	5.41	5310
W. BR. SUSQUEHANNA AT LEWISBURG,PA		
19:31:29EST, MARCH 15,1973	6.53	19700
21: 9:58EST, MARCH 15,1973	6.97	21100
22:54:53EST, MARCH 15,1973	7.10	22300
9:42: 8EST, MARCH 16,1973	8.49	30300

THESE DATA WERE RELAYED BY THE ERTS OBSERVATORY AND ARE PROVISIONAL. THE SYMBOLS -- INDICATE DATA WERE SUSPECT AND WERE DELETED. THIS SUMMARY WAS PREPARED BY THE SPECIAL PROJECTS SECTION IN HARRISBURG USING REMOTE TERMINAL ACCESS TO THE GEOLOGICAL SURVEYS 360/65 COMPUTER IN WASHINGTON, D.C. CALL 717-782-3420 FOR FURTHER INFORMATION.

END OF SUMMARY

Figure 11: Daily Water-Resources Summary

connected. System software then was used to extract a portion of the job, which was retrieved by the low-speed teletypewriter terminal. The basis for this shuffling of the computer peripherals and software was to permit a computer-generated LANDSAT-DCS water-resources summary to be retrieved on a teletype readable record, 8-level punched-paper tape, which was punched as the job was retrieved from the computer. Later, when the ASR-33 was disconnected from the computer and reconfigured as a conventional teletype, the tape was read into the ASR and the data summary was sent via commercial Telex lines to other agencies.

Figure 11 is an example of a part of one daily DCS summary.

An objective in the data-handling scheme was to minimize manual manipulation of the data and maximize the use of the telecomputing system. This was done to gain experience with these data-handling techniques, techniques that would be needed if operational data-collection systems were used by the Geological Survey.

PERFORMANCE CHARACTERISTICS OF THE INTEGRATED USGS-NASA WATER RESOURCES DATA SYSTEM

No system, especially an experimental system, ever works flawlessly.

For the sake of brevity, no discussion is made here of the performance characteristics of the instruments in the Geological Survey's Hydrologic Data Network. Suffice it to say that the digital-recording stream gages and ground-water observation wells provide, on the average, greater than 95 percent of the potential data record, while water-quality monitors frequently provide in excess of 75 percent of the potential record. The discussion contained herein will follow the flow of data from DCP interfaces through the NASA and USGS systems to the users, specifically highlighting problem areas.

The normal run-of-the-mill human errors occurred early in the program. At times DCP switches were set improperly, cables were poorly placed, and power to the DCP not applied. At one location, power to the DCP was provided from a transformer that converted 110 volts AC line power to 24 volts DC. However, the line power outlet was controlled by the light switch inside the instrument shelter. The technician would enter the shelter, turn on the light (and power) check out the DCP, then turn out the lights (and power), and leave. Then, after no data were relayed by ERTS, he would visit the station again, and would find the DCP in apparent working order. Finally after a few iterations the "power off" problem was discovered. These human errors were not stratified by grade level but the frequency of this type of error tended to decrease with operational experience.

Persistent but minor problems were encountered with the interface with the Leupold and Stevens digital stage recorder. At about 20 percent of the stations equipped with these vender-supplied interfaces, there were occasional problems with a spurious bit being set on the interface. Normally the 16-bit memory interface in the digital recorder is cleared and updated during the mechanical paper-tape punch cycle, when stage data are punched on site on a machine-readable paper tape. The format of the data in the memory and paper tape is that of 4 binary coded decimals. Each decimal is coded by four bits. In the four-bit switches that are used to encode a decimal there are sixteen possible bit combinations, 10 of which (0 through 9) are valid and six are invalid. There were occasional invalid bit combinations in the interfaces that occasionally failed. After discussions with the vendor, it was discovered that there was a design defect in the mechanical clearing and setting of the bit switches, which the vendor will correct in future models. Fortunately the invalid bit combinations occurred infrequently and sporadically, and one could normally review and correct the data in almost all instances.

Another minor problem was encountered with the Leupold and Stevens interface. During the normal punch cycle, when stream stage is being punched on a paper tape, there was a brief period of about a second when the 16-bit memory interface was cleared of its previous value in preparation for storing the current stage. If the DCP transmitted during this brief period, a stream stage of 0.00 would be encoded in the DCP data messages. As a result, there were transmitted occasional spurious stream stages of 0.00 feet.

There were few failures in the NASA system, and none that could be localized to the DCP or spacecraft systems by this investigation.

A computer analysis of DCS data indicated that there might be defective timers in several DCP's, because data messages were being provided from these DCP's spaced a few seconds apart rather than the nominal 180 seconds. After discussing this discrepancy with NASA personnel at the Goddard Space Flight Center the problem was traced by NASA to a defective clock at a receive site, which was erroneously time tagging some messages. The problem was quickly solved and has not been detected again.

Occasionally DCS data from LANDSAT, which were slated for teletype transmission to Harrisburg, were lost or delayed. The disruption normally was caused by human error at Goddard. These disruptions were infrequent and far below the expect rate for such an ad hoc processing system.

The teletype transmission line between Harrisburg and the Goddard Center was vulnerable to line noise and interference, which is characteristic of an asynchronous communications system. Data on the teletype were occasionally garbled or shifted. This was not generally serious, because two to four redundant transmissions from each DCP were found on most LANDSAT passes. If one transmission was garbled, the rest generally were not. When data were garbled, and invalid characters were entered in the data field, or when data fields were shifted, the "checksum" algorithm or other automatic data checking algoriths were employed to screen the data.

On some occasions, the teletype, which operated unattended throughout the 24 hour cycle, ran out of paper or tape, or the media jammed. Loss of data due to running out of paper or tape was most common over a weekend. The paper-tape reserve was insufficient to last over a 3-day weekend.

The translation of the data to cards from paper tape, like the rest of the teletype operations, was slow, cumbersome, and vulnerable, but it was better than a manual system. The translation had the expected failures of tapes, cards, etc. No nonrecoverable failures were experienced, because this data translation procedure was done under human supervision.

All data processing was done using the Geological Survey's telecomputing system. Data were processed using an IBM 360/65 in Washington, D.C., but eventually the data were processed using an IBM 370/155 in the Survey's National Center in Reston, Virginia. The transition was made in the early fall of 1973 when the National Center was established. The goal of entering and retrieving a LANDSAT-DCS computer job on the same day was normally met about 80 percent of the time using the initial system, and more than 98 percent of the time using the Reston system. The detailed accounting of the failures in the computer system are beyond the scope of this report and the understanding of a remote user of the system, but a truly operational DCS system would require an on-line data processing system that was virtually fail-safe. The Reston system, which is a batchjob processor, was very satisfactory in an experimental mode.

LANDSAT-DCS PERFORMANCE CHARACTERISTICS

From the vantage point of a user of the LANDSAT Data Collection System, there were some characteristics of the system that were measurable. Mutual Visibility Periods (MVP) temporal characteristics of DCP transmission intervals, and data capacity of the system were among the characteristics that could be measured. The following narrative is this experimentar measure of some characteristics of the system.

The Data Collection System on LANDSAT contains the essential characteristics of a random-access data-relay system that may be most suitable for collecting data with a polar-orbiting satellite. The LANDSAT-DCS is inward looking, in the sense that the system does not interrogate the DCP's, but only relays data that are transmitted from the DCP's. Individual DCP's transmit data burst approximately every 180 seconds, but they transmit randomly relative to other DCP's. The random nature of the transmission is provided by inexpensive timers in the DCP's, which allow the period between transmissions for an individual DCP to vary within a range that was measured to be from about 160 to 200 seconds. Thus, if two DCP's emit data bursts simultaneously, and their transmissions interfere, the nonuniform timers provide for their subsequent data bursts to be well separated in time. Periodically the LANDSAT satellite travels through an area of mutual visibility between a DCP and a receiveing site, and an opportunity exists for data collected from the earth-resources sensor to be relayed to a receive site.

A total of 20 sites in the Delaware River basin were instrumented with LANDSAT-DCP's. The operational characteristics of the DCS could be defined after most of the sites in figure 3 were instrumented and operated for several months. An analysis of DCS data from the test site was performed to define the periods of mutual visibility for individual DCP's, as well as for the entire test site.

The period of the LANDSAT polar orbit is about 103 minutes, but the fundamental period of the orbit is 18 days. This fundamental period provides the LANDSAT imaging systems with

EROS-NASA
EARTH RESOURCE TECHNOLOGY SATELLITE EXPERIMENT
DATA COLLECTION SYSTEM
SUMMARY OF TEST SITE DATA RELAY PERIODS

TEST SITE =DELAWARE RIVER BASIN
PERIOD BEGINNING DAY 116 YEAR 1973
ENDING DAY 133 YEAR 1973

DAY	DDD HH MM SS	DDD HH MM SS	DDD HH MM SS	DDD HH MM SS	DDD HH MM SS	DDD HH MM SS
1	116 00 57 58	116 02 37 08	116 04 23 44	116 15 07 10	116 16 50 48	
	116 01 06 31	116 02 49 13	116 04 27 37	116 15 19 04	116 17 01 09	
	513	725	233	714	621	
2	117 01 02 07	117 02 42 50	117 04 27 43	117 13 32 50	117 15 12 34	117 16 56 36
	117 01 12 46	117 02 55 24	117 04 34 08	117 13 36 47	117 15 24 50	117 17 05 22
	639	754	385	237	736	526
3	118 01 08 16	118 02 48 36	118 04 35 55	118 13 38 08	118 15 19 18	118 17 01 30
	118 01 18 25	118 03 00 20	118 04 39 01	118 13 43 10	118 15 30 22	118 17 10 49
	609	704	186	302	664	559
4	119 01 13 14	119 02 54 05	119 04 42 37	119 13 43 42	119 15 24 41	119 17 08 41
	119 01 24 04	119 03 05 56	119 04 44 28	119 13 59 63	119 15 36 28	119 17 15 44
	650	711	111	981	707	423
5	120 01 18 32	120 02 59 53	120 13 49 29	120 15 29 17	120 17 15 37	
	120 01 30 24	120 03 11 59	120 13 58 23	120 15 41 47	120 17 22 01	
	712	726	534	750	384	
6	121 01 23 28	121 03 05 50	121 13 54 27	121 15 36 15	121 17 20 49	
	121 01 36 13	121 03 18 10	121 14 04 52	121 15 47 21	121 17 27 31	
	765	740	625	666	402	
7	122 01 28 53	122 03 12 05	122 14 00 06	122 15 41 45	122 17 27 06	
	122 01 41 54	122 03 23 01	122 14 11 24	122 15 52 55	122 17 30 26	
	781	656	678	670	200	
8	123 01 34 21	123 03 17 35	123 14 05 31	123 15 46 13	123 17 31 52	
	123 01 47 15	123 03 28 37	123 14 16 35	123 15 58 21	123 17 37 55	
	774	662	664	728	363	
9	124 01 40 23	124 03 23 35	124 14 11 35	124 15 52 13	124 17 37 17	
	124 01 53 06	124 03 34 35	124 14 22 49	124 16 03 56	124 17 42 46	
	763	660	674	703	329	

Figure 12a: Computer Summary of Test Site Mutual Visibility Periods

EROS-NASA
EARTH RESOURCE TECHNOLOGY SATELLITE EXPERIMENT
DATA COLLECTION SYSTEM
SUMMARY OF TEST SITE DATA RELAY PERIODS

TEST SITE =DELAWARE RIVER BASIN
PERIOD BEGINNING DAY 116 YEAR 1973
ENDING DAY 133 YEAR 1973

DAY	DDD HH MM SS	DDD HH MM SS	DDD HH MM SS	DDD HH MM SS	DDD HH MM SS	DDD HH MM SS
10	125 01 45 23 125 01 57 01 698	125 03 29 33 125 03 40 14 641	125 14 17 07 125 14 28 29 682	125 15 58 25 125 16 10 24 719	125 17 43 56 125 17 47 05 189	
11	126 01 51 38 126 02 04 41 783	126 03 35 59 126 03 44 59 540	126 14 22 43 126 14 31 56 553	126 16 04 45 126 16 16 02 677	126 17 48 17 126 17 52 32 255	
12	127 01 57 39 127 02 09 48 729	127 03 41 14 127 03 51 55 641	127 14 27 50 127 14 38 02 612	127 16 09 45 127 16 22 46 781	127 17 56 11 127 17 56 52 41	
13	128 00 24 46 128 00 31 10 384	128 02 03 00 128 02 15 41 761	128 03 46 19 128 03 56 53 634	128 14 33 33 128 14 44 42 669	128 16 16 13 128 16 28 44 751	128 18 01 11 128 18 02 27 76
14	129 00 30 03 129 00 37 13 430	129 02 08 40 129 02 19 58 678	129 03 52 26 129 04 01 54 568	129 14 39 30 129 14 50 30 660	129 16 21 11 129 16 33 21 730	
15	130 00 35 27 130 00 42 51 444	130 02 14 09 130 02 26 29 740	130 03 57 07 130 04 06 26 559	130 14 45 15 130 14 56 30 675	130 16 27 29 130 16 39 17 708	
16	131 00 41 25 131 00 49 50 505	131 02 19 23 131 02 32 03 760	131 04 03 23 131 04 12 33 550	131 14 50 10 131 15 01 34 684	131 16 32 47 131 16 44 45 718	
17	132 00 46 38 132 00 55 46 548	132 02 24 58 132 02 38 20 802	132 04 10 23 132 04 17 37 434	132 14 55 58 132 15 07 29 691	132 16 39 12 132 16 50 02 650	
18	133 00 51 06 133 01 01 49 643	133 02 32 00 133 02 43 46 706	133 04 16 48 133 04 23 00 372	133 15 01 16 133 15 13 12 716	133 16 44 34 133 16 56 26 592	

TOTAL NUMBER OF ORBITS= 94 TOTAL MUTUAL VISIBILITY PERIOD OF THE TEST SITE = 55678 SECONDS.

Figure 12b: Computer Summary of Test Site Mutual Visibility Periods an opportunity to image any particular scene on the earth's surface once every 18 days. Periodically the LANDSAT orbit is trimmed slightly. But if one characterizes the mutual-visibility aspects of the DCS for any 18-day period, then one has a good measure of this characteristic for all successive 18-day periods. Figure 12a and 12b are a tabulation of the mutual-visibility periods in the Delaware River basin test site for the 18-day period beginning on day 116, 1973, through day 133, 1973 (April 26, 1973-May 13, 1973). Each row of entires on the computer printout contains the mutual visibility periods for each of the 18 days during the period. Each entry is of the form:

$$\begin{array}{cccc} DDD_1 & HH_1 & MM_1 & SS_1 \\ DDD_2 & HH_2 & MM_2 & SS_2 \\ & & & d \end{array}$$

where:

DDD_1 HH_1 MM_1 SS_1 are the day, hour, minute, and second, measured in Greenwich Mean Time, of the first transmission from any test site DCP during an ERTS orbit.

"d" is the duration, in seconds, of the mutual visibility period, as deliminited by the two times above.

On every day there are at least five MVP's and on a few days there are six. The maximum length of a mutual visibility period is normally about 800 seconds, and the minimum length can be as short as a few seconds. Whenever the length of the period is in excess of about 400 to 500 seconds, one could expect to receive transmissions from virtually every test site DCP at least once, and normally several times during the period. Characteristically, there were at least four MVP's of this length every day, with two occurring in each of the time periods 00:30 to 4:30 GMT and 13:30 to 18:00 GMT (7:30 to 11:30 p.m. EST and 8:30 a.m. to 1:00 p.m. EST). The short-duration MVP's characteristically provide data only from DCP's that operate in geographic locations that have excellent visibility of the sky and, therefore, of LANDSAT. On the bottom of figure 12b one can see that there were a total number of 94 orbits when there was mutual visibility from LANDSAT of the test site and a ground receiving site, and that the sum of the durations of the 94 mutual-visibility periods was in excess of 55,000 seconds. Analysis of several 18-day periods indicates that the total number of orbits varies by about one or two, because some of the very short MVP's are completely missed, and the total mutual-visibility periods remains at about 55,000 seconds. This is about 3.5 percent of the total length of the 18 day cycle, which is about 1.6×10^6 seconds.

The range of the beginning times for any MVP generally was about 2 minutes, and the duration of a MVP was relatively constant from one 18-day period to the next. Thus, the performance characteristics of the set of DCP's in the test site, insofar as mutual visibility was concerned, was well characterized by the computer analysis shown in figure 12a and 12b.

There is merit in performing an analysis of the mutual-visibility characteristics of individual DCP's in order to estimate the effect of local terrain, both natural and man made, on the mutual-visibility opportunities for a variety of geographic sites. Figure 13 is a computer analysis of the mutual-visibility periods of the DCP with identification number 6114 for the same 18-day period summarized in figure 12a and 12b. As in previous figures, each row of entries summarizes DCP MVP's for each of the 18 days in the period. Each entry is of the form:

DDD HH MM SS

t - r

where:

DDD HH MM SS are the day, hour, minute, and second, measured in GMT, of the first transmission of this DCP during a MVP.

"t" is the elapsed time measured in seconds between the first and last transmission from this DCP during the MVP--a measure of the length of a DCP mutual-visibility period.

"r" is the ratio t/d where t is defined above and d is the entry in figure 12a and 12b that defines the duration of the test site MVP.

If there is only one transmission from a DCP during a MVP, then t is arbitrarily set at 90 seconds, which is one-half the temporal transmission period of the DCP.

A cursory examination of figure 13 shows that this DCP relayed data during each of the 94 test site MVP's as well it should. This performance was due to its geographic location.

DATA COLLECTION PLATFORM PERFORMANCE FOR SUM OF PLATFORM VISIBILITY PERIODS
DCP ID = 6114
TEST SITE=DELAWARE RIVER BASIN

1	116 0 58 46 385-0.75	116 2 38 11 578-0.79	116 4 27 37 90-0.38	116 15 7 57 583-0.81	116 16 51 28 581-0.93	
2	117 1 4 57 386-0.60	117 2 44 50 580-0.76	117 4 27 43 385-1.00	117 13 33 28 195-0.82	117 15 14 8 584-0.79	117 16 57 48 388-0.73
3	118 1 9 20 545-0.89	118 2 50 19 559-0.79	118 4 35 55 186-1.00	118 13 39 35 190-0.62	118 15 20 34 567-0.85	118 17 4 31 378-0.67
4	119 1 14 13 573-0.88	119 2 56 0 572-0.80	119 4 43 54 90-0.81	119 13 45 59 371-0.37	119 15 24 42 555-0.78	119 17 9 34 370-0.87
5	120 1 22 41 363-0.50	120 3 2 34 545-0.75	120 13 52 16 367-0.68	120 15 29 17 719-0.95	120 17 16 7 354-0.92	
6	121 1 24 56 553-0.72	121 3 5 59 731-0.98	121 13 56 55 181-0.28	121 15 37 9 550-0.62	121 17 21 22 369-0.91	
7	122 1 29 42 732-0.93	122 3 16 36 367-0.55	122 14 2 12 552-0.81	122 15 42 19 544-0.81	122 17 27 26 180-0.90	
8	123 1 35 42 548-0.70	123 3 19 0 547-0.82	123 14 5 48 547-0.82	123 15 48 54 545-0.74	123 17 31 52 363-1.00	
9	124 1 43 45 553-0.72	124 3 24 58 551-0.83	124 14 11 35 530-0.78	124 15 52 13 542-0.77	124 17 39 40 186-0.56	
10	125 1 47 4 565-0.80	125 3 30 47 567-0.88	125 14 18 57 572-0.83	125 16 0 12 566-0.78	125 17 43 57 188-0.99	
11	126 1 52 39 722-0.92	126 3 37 48 369-0.66	126 14 22 43 551-0.99	126 16 7 6 368-0.54	126 17 50 59 90-0.35	
12	127 2 0 20 537-0.73	127 3 41 53 359-0.56	127 14 30 40 356-0.58	127 16 10 56 526-0.67	127 17 56 52 90-2.19	
13	128 0 26 44 185-0.48	128 2 5 32 556-0.73	128 3 47 37 556-0.87	128 14 36 16 375-0.56	128 16 16 13 562-0.74	
14	129 0 31 26 90-0.20	129 2 10 41 557-0.82	129 3 55 43 371-0.65	129 14 39 39 543-0.82	129 16 21 36 538-0.73	
15	130 0 35 35 353-0.79	130 2 15 51 532-0.71	130 3 59 34 356-0.63	130 14 46 47 523-0.77	130 16 29 33 527-0.74	
16	131 0 42 16 362-0.71	131 2 19 23 731-0.96	131 4 6 1 367-0.66	131 14 52 28 537-0.78	131 16 36 38 357-0.49	
17	132 0 47 37 358-0.65	132 2 25 49 714-0.89	132 4 10 23 360-0.82	132 14 57 20 527-0.76	132 16 39 12 524-0.80	
18	133 0 52 43 546-0.84	133 2 32 18 540-0.76	133 4 17 1 359-0.96	133 15 1 36 708-0.98	133 16 44 47 533-0.90	

RATIO OF MUTUAL VISIBILITY OF THIS PLATFORM RELATIVE TO THE ENTIRE TEST SITE IS 0.76 ORBIT COUNT = 94

Figure 13: Computer Summary of Individual Mutual Visibility Periods For DCP ID 6114

The DCP was on a small island in Delaware Bay where there is a virtually unobstructed view of the horizon. On several days, r was equal to 1.00, which indicates that the first and last test-site transmission came from this DCP. Finally, on the bottom of figure 13, and in addition to the orbit count, there is a second measure of the visibility of this DCP--the ratio of the mutual visibility of the DCP relative to the entire test site. This is the ratio of the sum of the DCP "t's" to the sum of the test site "d's". The highest value of this ratio falls in the range 0.74 to 0.76, which was determined in an analysis of several 18-day periods for this DCP. A ratio of 0.75 means that the mutual-visibility period sum for this DCP was about 0.75 x 55,000 seconds, which turns out to be about 2.6 percent of the total 18-day period. Values of this ratio for a Delaware River basin DCP can be as low as 0.16, which is shown in figure 14.

The analysis in figure 14 is identical to that shown in figure 13 but is for DCP ID 6124, which is in an urban area near Trenton, N.J. There are many entries in the compilation where all the fields in the entry are filled with zeroes. This denotes the existence of a MVP for the test site, but no transmission was relayed for this individual DCP. The orbit count for this DCP is down to 50. Nevertheless, on each day (except day 123) there was at least one successful transmission relayed from DCP during the morning and evening data-relay periods, although mutual visibility was available for less than 1 percent of the time.

All of the DCP's in the Delaware River basin test site transmit data burst at intervals of about 180 seconds. The DCP's are also capable of transmitting data bursts at about 90 seconds intervals. The mutual visibility ratio and orbit count of DCP ID 6124 could undoubtedly be improved if the temporal-transmission period were decreased to 90 seconds from 180 seconds. This, however, would increase the apparent number of DCP's in the system and increase mutual interference.

A summary of orbit counts, and mutual-visibility ratios for the 18 DCP's functioning during this 18-day period is shown in Table 3. The mutual-visibility ratio is an attempt to normalize the mutual-visibility of a point to the entire test site and is formed by the ratio of the sum of the mutual-visibility periods of the test site. There is a general trend of increasing ratio and orbit count from congested urban areas in Philadelphia and Trenton to rural areas. The extreme value is at Reedy Island, where there is a virtually unobstructed view of the sky in the hemisphere above the station.

DATA COLLECTION PLATFORM PERFORMANCE FOR SUM OF PLATFORM VISIBILITY PERIODS
DCP ID = 6124
TEST SITE=DELAWARE RIVER BASIN

1	116 0 59 58 181-0.35	116 2 39 34 181-0.24	0 0 0 0 0-0.00	116 15 13 1 182-0.25	0 0 0 0 0-0.00	
2	117 1 3 53 181-0.28	117 2 46 20 181-0.24	0 0 0 0 0-0.00	117 13 36 47 90-0.37	117 15 19 13 180-0.24	0 0 0 0 0-0.00
3	118 1 13 16 90-0.14	118 2 49 44 181-0.25	0 0 0 0 0-0.00	0 0 0 0 0-0.00	118 15 25 59 90-0.13	0 0 0 0 0-0.00
4	119 1 14 2 368-0.56	119 2 58 15 90-0.12	0 0 0 0 0-0.00	119 13 46 56 90-0.09	119 15 28 40 185-0.26	0 0 0 0 0-0.00
5	120 1 24 34 90-0.12	120 3 3 28 185-0.25	120 13 53 9 186-0.34	120 15 35 19 186-0.24	0 0 0 0 0-0.00	
6	121 1 27 23 183-0.23	0 0 0 0 0-0.00	121 13 56 56 181-0.28	121 15 42 45 90-0.13	0 0 0 0 0-0.00	
7	122 1 33 17 184-0.23	0 0 0 0 0-0.00	122 14 3 41 90-0.13	122 15 47 45 184-0.27	0 0 0 0 0-0.00	
8	0 0 0 0 0-0.00	0 0 0 0 0-0.00	123 14 11 8 183-0.27	123 15 54 46 90-0.1?	0 0 0 0 0-0.00	
9	124 1 45 23 183-0.23	0 0 0 0 0-0.00	124 14 14 24 183-0.27	0 0 0 0 0-0.00	0 0 0 0 0-0.00	
10	125 1 47 47 362-0.51	0 0 0 0 0-0.00	125 14 20 0 362-0.53	0 0 0 0 0-0.00	0 0 0 0 0-0.00	
11	126 1 54 45 182-0.23	0 0 0 0 0-0.00	126 14 29 16 90-0.16	0 0 0 0 0-0.00	0 0 0 0 0-0.00	
12	127 2 0 20 183-0.25	0 0 0 0 0-0.00	127 14 31 59 183-0.29	0 0 0 0 0-0.00	0 0 0 0 0-0.00	
13	0 0 0 0 0-0.00	128 2 5 30 183-0.24	0 0 0 0 0-0.00	128 14 37 19 367-0.54	0 0 0 0 0-0.00	0 0 0 0 0-0.00
14	129 0 33 43 90-0.20	129 2 11 39 183-0.26	0 0 0 0 0-0.00	129 14 41 40 368-0.55	0 0 0 0 0-0.00	
15	0 0 0 0 0-0.00	130 2 17 46 183-0.24	0 0 0 0 0-0.00	130 14 48 9 183-0.27	0 0 0 0 0-0.00	
16	131 0 41 41 182-0.36	131 2 24 59 90-0.11	0 0 0 0 0-0.00	131 14 54 55 182-0.26	0 0 0 0 0-0.00	
17	132 0 49 20 90-0.16	132 2 29 19 182-0.22	0 0 0 0 0-0.00	132 15 0 26 182-0.26	0 0 0 0 0-0.00	
18	133 0 54 19 181-0.28	133 2 34 20 182-0.25	0 0 0 0 0-0.00	133 15 5 11 365-0.50	0 0 0 0 0-0.00	

RATIO OF MUTUAL VISIBILITY OF THIS PLATFORM RELATIVE TO THE ENTIRE TEST SITE IS 0.16 ORBIT COUNT = 50

Figure 14: Computer Summary of Individual Mutual Visibility Periods for DCP ID 6124

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USGS DELAWARE RIVER BASIN DATA COLLECTION SYSTEM EXPERIMENT
TABLE 3

DATA COLLECTION PLATFORM DISTRIBUTION

SEQUENCE NUMBER	STATION NAME	DCP-ID (OCTAL)	ORBIT COUNT	MUTUAL VISIBILITY RATIO
1	SHIP JOHN SHOAL LIGHTHOUSE	--	--	--
2	DELAWARE RIVER AT REEDY ISLAND	6114	94	0.76
3	DELAWARE RIVER AT DEL. MEM. BR.	6067	87	0.53
4	DELAWARE RIVER AT CHESTER	6332	87	0.72
5	DELAWARE RIVER AT PIER 11, PHILA.	6371	38	0.08
6	DELAWARE RIVER AT TORRESDALE	6331	73	0.29
7	DELAWARE RIVER AT BRISTOL	6275	64	0.27
8	DELAWARE RIVER AT TRENTON	6124	50	0.16
9	DELAWARE RIVER AT EASTON	6312	67	0.41
10	LEHIGH RIVER AT EASTON	6306	77	0.46
11	DELAWARE RIVER NR EAST STROUDSBURG	6030	75	0.53
12	SCHUYLKILL RIVER AT BELMONT	--	--	--
13	DELAWARE RIVER AT MONTAGUE	6116	81	0.59
14	DELAWARE RIVER BELOW TOCKS ISLAND	6223	76	0.35
15	DELAWARE RIVER AT TRENTON	6277	63	0.29
16	LEHIGH RIVER AT BETHLEHEM	6227	65	0.32
17	SCHUYLKILL RIVER AT PHILA.	6115	83	0.61
18	SALEM CITY NUMBER 1	6046	83	0.45
19	PENNS GROVE NUMBER 24	6215	93	0.71
20	SHELL CHEM. CO. NUMBER 5	6322	90	0.69

Quantitative measures could be developed to predict the mutual visibility characteristics of a location as a function to the visibility of the sky.

One of the important characteristics of a random-access, inward-looking satellite data-relay system is that data bursts from two or more DCP's can cause mutual interferences, resulting in loss of data from those bursts. An important characteristic of such a system is the amount of data lost due to mutual interference. The following analysis indicates that only about 5 percent of the data bursts from a DCP may be lost to mutual interference. The system has always had less than 200 DCP's operating at any given time.

Figure 15 contains the partial results of an analysis that attempts to quantify the mutual-interference history of the test site DCP's. Only six are summarized in figure 15.

The fourth DCP in the figure, identification number 6114, transmitted a total of 315 messages that were successfully relayed during the 18-day period. Twenty-four of the messages classified as "duplicate messages," were received simultaneously at both receiving stations. Whenever two or more messages are received during a particular MVP, it becomes possible to compute the period of time that elapsed between successive transmissions. For example, the periods between successive transmissions from DCP ID 6114 fell into 11 intervals, as shown in table 4.

Table 4

A Summary of DCP Transmission Periods for a Typical 18-Day Cycle

	Number of events in interval	Range of transmission period interval (in seconds)
	3	173-174
	14	175-176
	22	177-178
	33	179-180
	33	181-182
	34	183-184
	24	185-186
	10	187-188
	14	189-190
	27	191-195
	7	361-400
Sum	221	

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EARTH RESOURCES TECHNOLOGY SATELLITE EXPERIMENT
DATA COLLECTION SYSTEM
SUMMARY OF DCP TEMPORAL TRANSMISSION INTERVALS WITHIN MUTUAL VISIBILITY PERIODS
NUMBER OF EVENTS IN INTERVAL

TEST SITE= DELAWARE RIVER BASIN
PERIOD BEGINNING DAY 116 YEAR 1973
ENDING DAY 133 YEAR 1973

UPPER LIMIT OF INTERVAL (IN SECONDS)

DCP ID	20	40	60	80	100	110	120	130	140	145	150	155	160	165	170	172	174	176	178	180	182	184	186	188	190	195	200	205	210	215	220	240	280	320	360	400	440	480	520	1000
6030																					1	16	23	25	35	49										7				
6046																	13	25	23	33	23	11													4	1				
6067																					2	8	14	14	9	40	22	4								15				1
6114																	3	14	22	33	33	34	24	10	14	27										7				
6115																					6	7	12	24	22	70	33	1								1				
6116																									7	43	69	34								5				

6030
TOTAL MESSAGES = 226
DUPLICATE MESSAGES = 14
INTERFERENCE ESTIMATE = 2.35[illegible] OF 85 INTERMEDIATE MESSAGES

6046
TOTAL MESSAGES = 216
DUPLICATE MESSAGES = 18
INTERFERENCE ESTIMATE = 7.93[illegible] OF 63 INTERMEDIATE MESSAGES

6067
TOTAL MESSAGES = 216
DUPLICATE MESSAGES = 11
INTERFERENCE ESTIMATE = 21.79[illegible] OF 78 INTERMEDIATE MESSAGES

6114
TOTAL MESSAGES = 31[illegible]
DUPLICATE MESSAGES = 26
INTERFERENCE ESTIMATE = [illegible].00[illegible] OF 140 INTERMEDIATE MESSAGES

6115
TOTAL MESSAGES = [illegible]
DUPLICATE MESSAGES = 21
INTERFERENCE ESTIMATE = 1.06[illegible] OF 9[illegible] INTERMEDIATE MESSAGES

6116
TOTAL MESSAGES = [illegible]
DUPLICATE MESSAGES = [illegible]
INTERFERENCE ESTIMATE = [illegible] OF [illegible] INTERMEDIATE MESSAGES

Figure 15: An Estimate of Mutual Visibility Interference

The sum of the events in the interval indicate that there were 221 measurable periods between transmissions. The periods in the range from 173 to 195 seconds obviously were due to successive transmissions of the DCP and demonstrate that the timer can be seen to be unique for each DCP. Detailed analyses of these data often revealed a diurnal variability in the timer, presumably due to environmental conditions.

There are seven periods in the range of 361-400 seconds, obviously caused by intermediate transmissions being lost due to mutual interference or some other reason. DCP 6114 was where there was virtually no obstruction of the horizon; so, a reasonable assumption is that the seven intermediate transmissions lost were due to mutual interference only, and not due to the existence of nearby stationary physical obstructions. Thus, seven transmissions were lost in all probability to mutual interference. There may have been more than seven transmissions that were lost to interference because if a transmission lost due to mutual interference were normally the first or last one of the MVP, then one would have difficulty estimating the loss with a high degree of confidence. It is possible to make a detailed accounting of each MVP, count the number of transmissions between the first and last transmission of a MVP, and compare this number to the known number of transmissions lost. For this MVP, during this 18-day period, there were a total of 134 successful intermediate transmissions, and seven were lost. Thus out of a total of 7 + 134 transmissions seven messages (or about 5 percent of the 141 intermediate transmissions) suffered mutual interferences with other DCP transmissions.

The other DCP's summarized figure 15, except DCP ID 6067, show anywhere from one to five periods in the 400-second range, indicating intermediate data losses probably due to mutual interference. As the total number of messages from a DCP decreases, the number of intermediate transmissions falls off rapidly, and the transmission loss to mutual interference remains low. DCP ID 6067 had an unusually high number of intermediate messages lost because the DCP was directly beneath the Delaware Memorial Bridge. A significant number of lost transmissions could be expected when LANDSAT was shielded from the DCP antenna by the bridge structure.

The performance characteristics of the DCS for the Delaware River basin test site may be broadly summarized by stating that at most DCP locations were the temporal transmission period was nominally 180 seconds, from one to four transmissions per MVP are being relayed during four or five MVP's per day.

Mutual interference between DCP's is estimated to be in the neighborhood of 5 percent at a time when there is a total of less than 200 field operating DCP's (during the 18-day period from April 26, 1973 - May 13, 1973). The LANDSAT-DCS design goal was one message per 12-hour period from 1000 platforms that are mutually visible to the receive site and LANDSAT satellite.

CONCLUSIONS

This experiment successfully demonstrated that standard U.S. Geological Survey field instrumentation could be easily interfaced with the LANDSAT-DCS and the data made to flow smoothly to water-resources management agencies. The experiment was conducted in the Delaware River basin, a typical river basin, using U.S. Geological Survey resources and facilities that are typical of the Survey's national field activities.

The Data Collection System on LANDSAT was an excellent demonstration system to show the actual and potential user communities that satellite data-relay technology can perform the data-relay function efficiently and economically. The DCP is inexpensive, reliable, and simple to operate, interface, and power. The spacecraft system and ground-data handling systems, provides a smooth, uninterrupted flow of about 10,000 DCP messages per month from the field to this user. However, the Data Collection System and the data handling system, as described in this report, are insufficient to meet the requirements of an operational data collection, processing, and dissemination system for the WRD.

A truly operational system could not be deployed using the systems described herein unless some modifications are made. For example, the U.S. Geological Survey's field instruments cannot provide an efficient flow of data into a telemetered system because most field instruments are designed to record data on site, and are not designed to act as efficient telemetry interfaces. Redesign of the field instruments to interface with a telemetry system presents no technical obstacles. The LANDSAT-DCS is not sufficient as an operational system because of the low DCP capacity of the system (1,000 DCP's), the low data rate of the system when operating to capacity (one message per 12 hours), and the two hiatuses each day when no data are relayed (approximately from 1230 to 2000 hours and from 0100 to 0800 hours). Finally, the U.S. Geological Survey computer network is not sufficient because the main computational resources are general purpose computers that do not operate 7 days a week. A truly operational system, which would require fail-safe redundant computer resources that could guarantee continuous operation, is technically possible.

No significant technical obstacles exist that would prevent a multi-satellite, polar-orbiting, multiband system from meeting the needs of water-resource manager. Such a system probably could provide a nearly continuous flow of data from a large number of stations to resource managers and could meet the basic data collection requirements of the Water Resoruces Division.

It became obvious during the execution of the project that satellite data collection systems were also potentially powerful tools for operators of water resources data systems, as well as for the resource managers. If real-time data could be collected from a large water-resources monitoring system at a sufficiently modest cost, the cost could be offset by savings in manpower required to operate the system. Savings in manpower could be realized by deploying manpower more strategically, which could be done by a continuing anaylsis of real-time data that would be useful for monitoring the status of the system as well as the status of water resources.

The set of elements required for an automatic environment data collection-and-processing system would be complete if an operational satellite DCS were available. The Geological Survey operates a system of environmental instruments, a national telecomputing network, and maintains national water-resources data files. These systems and files could be upgraded to interface with an operational satellite Data Collection System and provide an efficient and rapid flow of wate resources data from the field to ultimate data users.

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