SATELLITE DATA-RELAY ACTIVITIES IN ARIZONA

By F. C. Boner, J. W. H. Blee, and W. G. Shope, Jr.

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4158

Tucson, Arizona
1985

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
Federal Building, Box FB-44
300 West Congress Street
Tucson, Arizona 85701-1393
Telephone: (602) 629-6671

Copies of this report can be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, Colorado 80225
Telephone: (303) 234-5888

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For readers who prefer to use metric units, the conversion factors for the terms used in this report are listed below:

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
square foot (ft^2)	0.09294	square meter (m^2)
mile (mi)	1.609	kilometer (km)

SATELLITE DATA-RELAY ACTIVITIES IN ARIZONA

By

F. C. Boner, J. W. H. Blee, and W. G. Shope, Jr.

ABSTRACT

The U.S. Geological Survey (USGS) Arizona District collects data from automated streamflow stations for a wide variety of uses. Data from these stations are provided to Federal, State, and local agencies that have a responsibility to issue flood warnings; to generate forecasts of water availability; to monitor flow to insure compliance with treaties and other legal mandates; and to manage reservoirs for hydropower, flood abatement, and municipal and irrigation water supply. In the mid-1970's, the escalation of data-collection costs and a need for more timely data led the Arizona District to examine alternatives for remote-data acquisition. On the basis of successful data-communications experiments with NASA's Landsat satellite, an operational system for satellite-data relay was developed in 1976 using the National Oceanic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellite (GOES). A total of 62 data-collection platforms (DCP's) was operated in 1983.

Satellite-telemetry operations are controlled at the remote data-collection stations by small battery-operated data-collection platforms. The DCP's periodically collect data from the sensors, store the data in computer memory, and at preset times transmit the data to the GOES satellite. The satellite retransmits the data to Earth where a ground-receive station transmits or transfers the data by land communications to the USGS computer in Reston, Virginia, for processing. The satellite relay transfers the data from sensor to computer in minutes; therefore, the data are available to users on a near real-time basis.

INTRODUCTION

The U.S. Geological Survey (USGS) is collecting hydrologic data in Arizona from automated continuous streamflow-gaging stations. In addition to monitoring stream stages, many of the stations are continuously monitoring rainfall and water quality. Data from these stations are provided to Federal, State, and local agencies that have a responsibility to issue alerts in emergencies, such as floods; to generate forecasts of water availability; to monitor flow of water to insure compliance with treaties and other legal mandates; or to manage reservoirs for hydropower, flood abatement, and municipal and irrigation water supply. The data at the automated stations, which are recorded on punched paper tape or graphs, are manually collected every 4 to 6 weeks, and converted to a computer-compatible format in the Field Office. After transmittal to the USGS computer in Reston, Virginia, for streamflow-record computations, the data are printed out at USGS computer terminals in Arizona for use by water-data users.

The manual retrieval of data from automated recorders is expensive and time consuming owing to the remote locations of many of the key data-collection stations. In the mid-1970's, the escalation of costs for data collection and a need for more timely data led the USGS Arizona District to begin examining alternatives for remote-data acquisition. On the basis of successful data-communications experiments with the National Aeronautic and Space Administration's (NASA) Landsat satellite, an operational system for satellite-data relay was developed in 1976 using the National Oceanic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellite (GOES). Satellite-telemetry operations are controlled at the gaging station by a small battery-operated data-collection platform (DCP). The DCP periodically collects data from sensors, stores the data in computer memory, and, at preset times, transmits the data through an internal radio to the GOES satellite. The satellite, which acts as a relay point, retransmits the data to a ground-receive station that transfers the data by land communications to the USGS computer for processing. A satellite relay transfers the data from sensor to computer in minutes versus the weeks and months required for manual retrieval and processing; therefore, the data are available to users on a near real-time basis.

The network of stations supported by GOES satellite telemetry in Arizona was increased from 8 stations to 62 stations after major flooding in 1978-79. The major purpose of the network is to provide real-time river-stage data to the Arizona Flood Warning Office in Phoenix, which is operated jointly by the National Weather Service (NWS) and the Arizona Department of Water Resources (ADWR). In addition to the expansion of the telemetry system, procedures for handling data are changing from a centralized system located primarily in Reston, Virginia, to a distributive system in Arizona, Colorado, Washington, and several other States. This report describes the operation of the USGS satellite-telemetry system in Arizona, including the operations of DCP's, satellite-receive stations, and computerized data-handling procedures. The report also summarizes the performance, coordination, and management of the remote-telemetry system.

OVERVIEW OF ARIZONA DISTRICT SATELLITE-TELEMETRY DATA-COLLECTION SYSTEM

As of 1983, the USGS Arizona District operates 62 DCP's at stream-gaging stations in Arizona and New Mexico (fig. 1). This number includes the 44 stations in the flood-warning network that was established after severe flooding during 1978-79. Funding for the flood-warning network is provided by the Arizona Department of Water Resources and

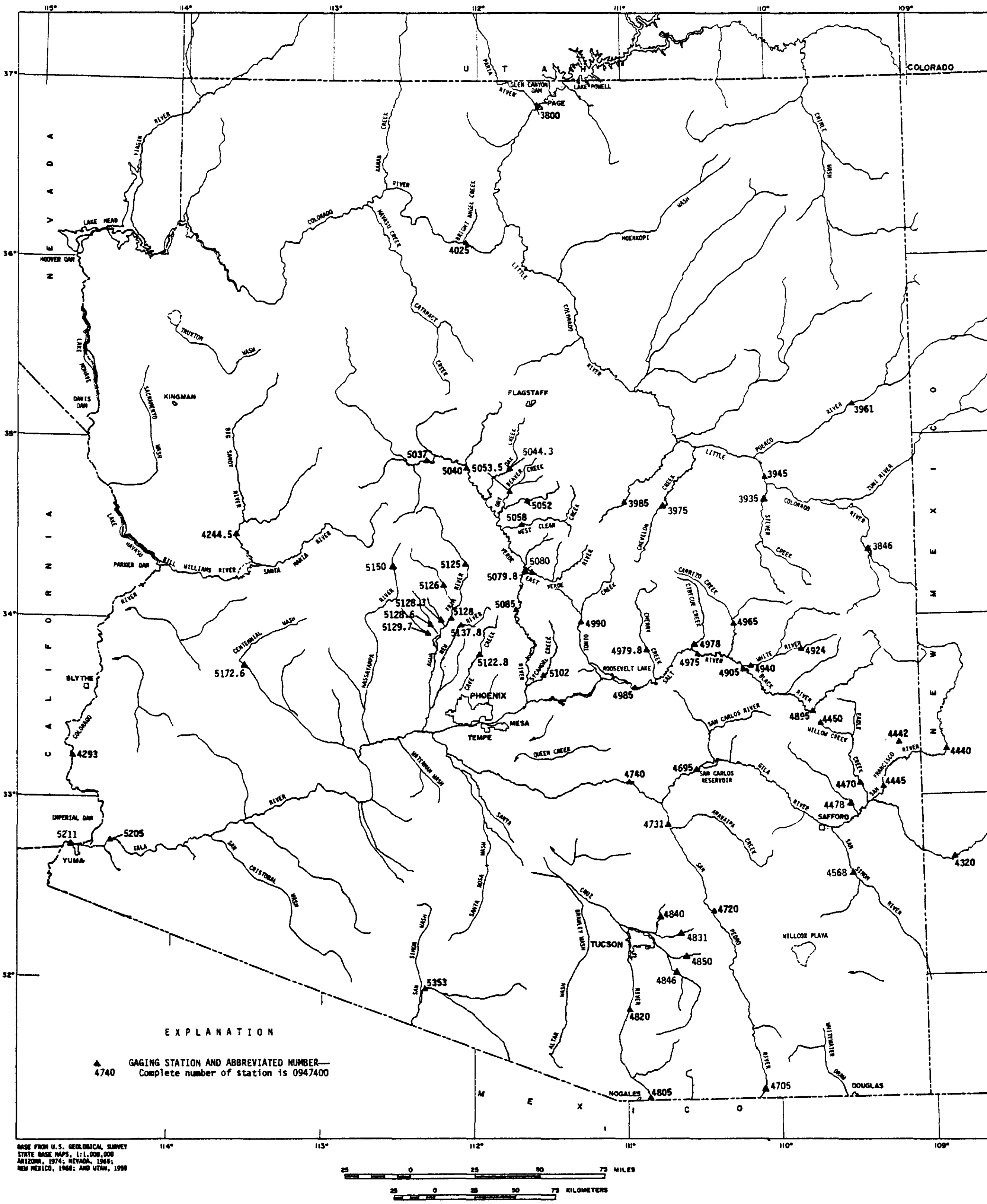

Figure 1.--Gaging stations in Arizona and New Mexico with data-collection platforms maintained by the Arizona District.

the Flood Control District of Maricopa County. The Salt River Project in central Arizona is funding seven satellite-telemetry stations in the Salt and Verde River basins for runoff monitoring and reservoir operations. The U.S. Bureau of Reclamation and U.S. Army Corps of Engineers also provide funding for the satellite-telemetry system in Arizona.

Each satellite-telemetry station is equipped with a DCP, data encoder, power supply, and antenna (fig. 2). Stream-stage data are encoded for entry into the DCP by a digital recorder with an encoding attachment or by a shaft encoder coupled to a digital or analog recorder. Rainfall data, which are collected at 45 stations where tipping-bucket rain gages have been installed, are entered into the DCP as an added component. The stream-stage and rainfall data are transmitted periodically by GOES satellite to the Direct Readout Ground Station (DRGS) in Phoenix (fig. 3). Data are assigned a date-time stamp by the DRGS before storage in the computer. The stored data are continuously transferred by dedicated telephone line to a NOVA 3 minicomputer[1]. After decoding and screening by the NOVA 3 minicomputer, the data are available for retrieval by water-data users.

ARIZONA DISTRICT OPERATIONS

Early in 1982, two committees were established in the USGS Arizona District to determine the most efficient way to utilize the satellite-telemetry capabilities. One committee investigates the data-collection phase of the system; the second committee looks at more efficient ways to use the data-collection system (DCS) for record computation. The committee consists of hydrologists and hydrologic technicians, and each Subdistrict Office is represented on both committees.

The operation of the DCS is under the supervision of the Assistant District Chief for Operations. The responsibilities of the Assistant District Chief for Operations are to:

1. Contact cooperators to arrange funding;
2. Coordinate needs of cooperators into the DCS; and
3. Supervise the District Equipment and Instrumentation Section, which is in Phoenix.

The District Equipment and Instrumentation Section is responsible for the design and operation of the DCS in Arizona and provides the following District-wide support:

1. Orders and distributes all DCS equipment;

---

[1]Use of brand names in this report is for indentification purposes only and does not constitute endorsement by the U.S. Geological Survey.

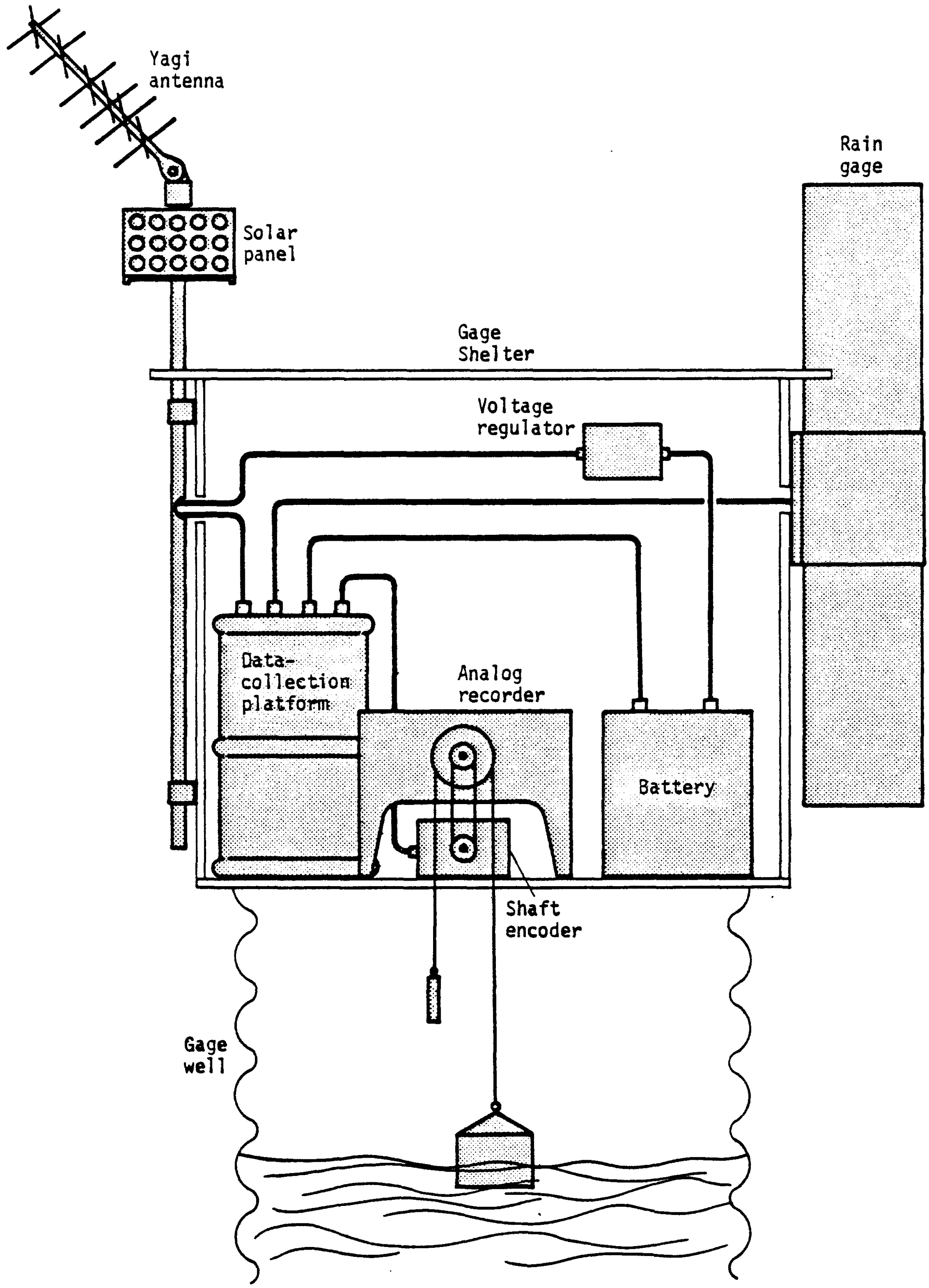

Figure 2.--Typical gaging station and data-collection platform equipment.

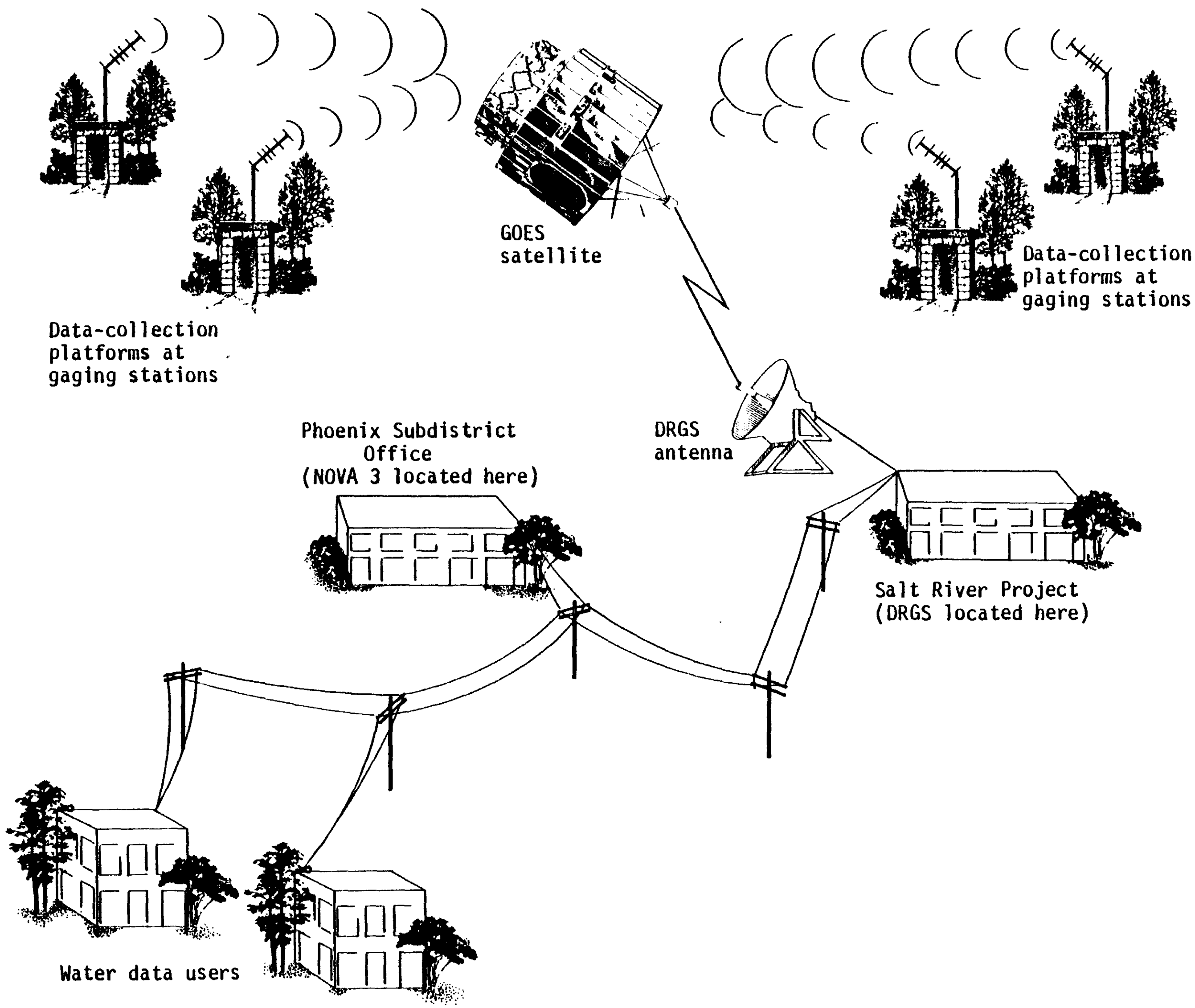

Figure 3.--Data-flow scheme of satellite-telemetry system in Arizona.

2. Provides bench tests and prepares all new and repaired equipment for field installation;
3. Provides initial installation of DCS equipment of each site;
4. Provides all repairs and maintains records of instrumentation failure;
5. Provides training on all operation, maintenance, and trouble-shooting of DCS equipment; and
6. Operates and maintains the DRGS and NOVA 3 minicomputer.

A central test and repair shop for all District equipment is considered the most efficient method of operation. The field person identifies faulty equipment, replaces it with a spare unit, and sends the faulty equipment to Phoenix for repair. If factory repair of equipment is required, the Section makes arrangements with the vendors for repair. Records are kept of the specific types of equipment failure. Early in the operation of the DCS, recurring problems or weaknesses were noted in equipment components, and modifications in the equipment were made by the vendor to improve reliability.

Training of District personnel in the operation and maintenance of the DCS was conducted in three stages. Stage 1 was the initial training conducted at each Subdistrict or Field Office when the DCS equipment was installed. As many trainees as possible helped install the equipment at each field site. Training in DCP programming and trouble shooting was conducted at each Subdistrict or Field Office. Stage 2 of the training program was 2 or 3 months after installation of the DCS. By this time, field personnel had some practical experience with the DCS equipment and programming procedures. The training was the same as in Stage 1; however, testing and programming procedures were emphasized. Stage 3 was a 3-day training session held in Phoenix for all field personnel involved in the DCS program. Stage 3 was held about 1 year after Stage 2 and consisted of a review of DCP programming; trouble shooting; additional detailed information on encoders, power supplies, sensors, and system monitoring; and use of DCS data in streamflow-record computations. Instructions for DCP installation were given on the last day, and the trainees installed equipment at a new site under the instructor's supervision.

Operation of the DCS requires constant monitoring of the data being received by the DRGS. Daily retrieval of data is made from the DRGS through the NOVA 3 minicomputer. A review of the data identifies which DCP's are not transmitting, which DCP's are sending alert transmissions, if DCP transmissions are within their assigned time slots, and if the data are meaningful. Continued malfunctions are reported to the controlling Field Office. Field Offices retrieve the DCP data frequently; during periods of potential or actual runoff, retrievals may be made at least once a day.

Although the Arizona District was not the first to become involved in satellite-telemetry data, the District has been instrumental in developing new equipment for use in the DCS. One such piece of equipment is the incremental shaft encoder. Originally, digital recorders with a special attachment (Leupold and Stevens with Module A) were used to encode stage data for entry into the DCP. Because of the large amount of surge in the stilling wells at many Arizona gages, digital recorders could not be used because the float-shaft memory-spring mechanism would jam. An absolute shaft encoder was incorporated into the system to eliminate the use of the digital recorders. The DCP manufacturer developed an interface to change the absolute shaft encoder output to look like digital-recorder output to the DCP. The shaft encoder concept proved so dependable that the Arizona District and the USGS Hydrologic Instrumentation Facility (HIF) worked together to develop an encoder that would be less costly than the expensive absolute shaft encoder; hence, the first incremental shaft encoder was developed. Incremental shaft encoders are currently available from private manufacturers. In order to provide a backup record of river stage, shaft encoders are coupled by gears and belts to graphic recorders. Failure of the DCP, therefore, does not affect the operation of the graphic recorder because there is no power link between the DCP and the graphic recorder.

DATA PROCESSING

Satellite-Telemetry Station

Processing of river-stage and precipitation data at selected stations begins at the gaging stations. Stage data are encoded for entry into the DCP at regulated 15-minute intervals. The data are stored in the DCP for transmission at 3-hour intervals. As a transmission is made from a Handar DCP, all the stage values for the most recent 6-hour period are sent to the GOES satellite. The 6-hour period includes 3 hours of new data plus 3 hours of previously transmitted data. The additional 3 hours of stored data is provided as a backup in the system in case the previous transmission was not received. La Barge CDCP's store as much as 12 hours of data. The duration of each transmission generally is less than 50 seconds.

Most brands of DCP's transmit alert transmissions whenever river stage equals or exceeds a predetermined limit or if precipitation equals or exceeds 0.5 in. in a 15-minute period (intensity rate of 2 in./hr). When the tested sample—either stage or precipitation—equals or exceeds the predetermined limit, the DCP will transmit values for all sampled components on a secondary channel at random times between 15-minute samples. The transmissions contain only the most recent stage and rainfall data and have a duration of 2 or 3 seconds. The USGS Arizona District system includes 45 Handar Model 524's, 9 Handar Model 560's, and 8 La Barge CDCP's. Of the three types of DCP's used in the Arizona District, only the Handar Model 524's and 560's are capable of making alert transmissions.

Geostationary Operational Environmental Satellite

The Geostationary Operational Environmental Satellite (GOES) acts as the repeater in a radio-telemetry system. The satellite is in stationary orbit about 23,500 mi from Earth and relays the DCP data back to Earth for reception by a ground station. All DCP stations in Arizona use the west GOES satellite located at long 135°W above the Equator. As of 1983, there was no charge for the relay of data by the satellite.

Direct Readout Ground Station

The Direct Readout Ground Station (DRGS) is a Synergetics Model 10C located at the Salt River Project, 5 mi east of the Phoenix Subdistrict Office. Transmissions from the Arizona DCP's are relayed back to Earth by the GOES satellite and are received by the DRGS (fig. 4). Transmissions are timed so that only one DCP is transmitting during any 1-minute period on a specified channel. The frequency-agile demodulator in the DRGS is programmed to receive transmissions on a specific channel during a specific time period. The DRGS is capable of receiving as many simultaneous transmissions on different channels as there are demodulators. A second demodulator in the DRGS is dedicated to receiving the random-alert channel transmissions. Performance of each DCP transmission can be checked with the DCP performance monitor contained in each demodulator. The unit measures the effective isotropic radiated power, the frequency offset, signal-plus-noise-over-noise ratio, and the modulation index of each DCP message.

Messages received through the demodulators are received by the DRGS minicomputer controller, which assigns a date-time stamp to each message. The date-time stamp is in the form of an ASCII character string. The controller—a Data General S-20—stores the messages in a circular fashion on a Winchester 25-megabyte hard disk. Newly arrived messages displace the oldest messages. Data on the hard disk, which include the date-time stamp and auxiliary header information, are now available for transfer to a remote terminal or computer using asynchronous communications.

Eight interactive terminals are available for remote communication with the DRGS, and three terminals are equipped with modems. One terminal has a 300-baud auto-answer modem, and a second terminal is equipped with a 1200-baud modem. Both terminals can be used by State and local agencies to receive satellite-telemetry data directly from the DRGS in the event the NOVA 3 minicomputer is inoperative. The third terminal is equipped with a 2400-baud modem and a Micom error controller for satellite-telemetry data output by a four-wire dedicated line to the NOVA 3 minicomputer at the Phoenix Subdistrict Office.

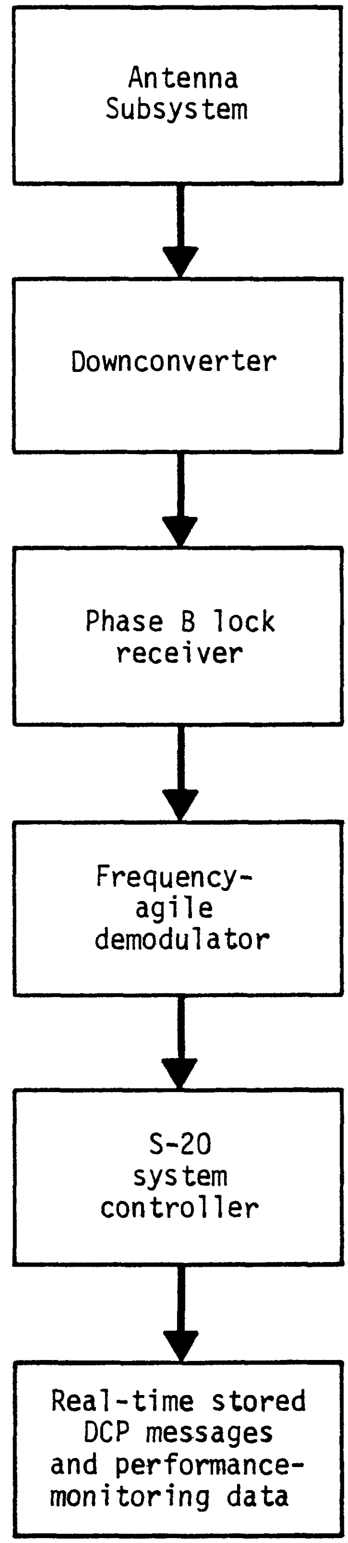

Figure 4.--Block diagram of Synergetics Model 10C direct-readout ground station.

NOVA 3 Minicomputer

The functions of the NOVA 3 minicomputer for processing satellite-telemetry data are listed below:

1. Receives satellite-telemetry data from the DRGS;
2. Decodes, interprets, and stores the data in hydrologic-data files;
3. Screens the data for critical events and generates emergency messages to the emergency computer terminal and interested agencies;
4. Allows users to simultaneously access and display the hydrologic-data files;
5. Allows the system operator and selected users to make corrections to erroneous data and to enter missing values in data;
6. Permits the system operator to build and maintain the DCP Master Information Files that contain control data and historical data on each DCP that is monitored by the District;
7. Generates station archive data files on magnetic tape or disk;
8. Transfers the satellite-telemetry data to the USGS WATSTORE data base from the archive data files or as optionally directed from the data files; and
9. Permits a DRGS in another District to be accessed if the primary DRGS fails.

The NOVA 3 minicomputer is connected to the receive station by a dedicated telephone line that continuously transfers data at high speeds. After the data are decoded and screened by the NOVA 3 minicomputer, the information is available for retrieval by the users. A user may view the data immediately or may retrieve stored data for as long as 2 weeks.

The NOVA 3 minicomputer permits as many as seven users to access the data simultaneously. The computer interacts with the user by prompting the user for specific information about the station or network identification, types of data, and time periods to be retrieved. Data are printed on the terminal screen within a matter of seconds following the completion of the request. Capabilities are available to update or to enter missing data, but these functions are normally restricted to USGS personnel. Users may use a variety of teletype or cathode-ray tube (CRT) terminals using slow (300 baud) to moderate (1200 baud) speed data-transfer rates. The assignment of computer ports, data-transfer rates, update authority, and user-access permission are controlled by the computer operator.

Field technicians can detect potential failures in the sensors or a critical hydrologic event by examining the data as they are received. The NOVA 3 minicomputer assists in this operation through the automated data-screening procedure. Before access to the data is allowed, the computer screens the data for the following conditions.

> Lower bound of the instrument.--The engineering value that corresponds to the logical minimum instrument reading of the sensor.
>
> Upper bound of the instrument.--The engineering value that corresponds to the logical maximum instrument reading of the sensor.
>
> Critical maximum.--The maximum threshold limit for an emergency condition.
>
> Critical minimum.--The minimum threshold limit for an emergency condition.
>
> Warning maximum.--The maximum threshold limit for a warning condition.
>
> Warning minimum.--The minimum threshold limit for a warning condition.
>
> Change differential.--The rate of change threshold limit for an emergency condition.
>
> Change number.--The number of sensor readings between each check of the change differential. For example, a change of 1 ft in 30 minutes (two sensor update cycles of 15 minutes each) might indicate an emergency condition.
>
> Lockup differential.--The amount by which a condition must change that otherwise would indicate a sensor malfunction.
>
> Lockup number.--The number of sensor readings between each check of the lockup differential. For example, if the reading did not change by more than ±0.10 ft for 10 successive readings, a lockup would be assumed.

The screening operation will produce a code that will be attached to the data and will appear on the retrieved listings. When emergency data are detected by the computer screening software or detected because an alert transmission was generated by the DCP, a message will be printed on an operator-selected console, terminal, or printer immediately following reception of the data at the NOVA 3 minicomputer.

The techniques discussed above include the quality controls that can be used in satellite-telemetry data acquisition. In addition to these techniques, the USGS Arizona District also employs manual checks to insure high-quality data. Many of these checks require the manual retrieval of hard-copy data from recorders in the gaging station. In addition to providing a cross check, the hard copy serves as a backup in case of malfunction in the telemetry system. At many of the stations in Arizona, an analog recorder operates independently of the automated telemetry. The analog recorder produces a graphic trace of the stream-stage conditions that can be compared with telemetry data for editing purposes.

Data-screening or data-verification software for the NOVA 3 minicomputer was developed as a prototype system that served as a model for the National Satellite-Telemetry Data-Collection System under development by the USGS. The national system is being developed for a series of Prime minicomputers that will be located at all USGS District Offices. The computers are part of the USGS's distributive efforts to give control of data communication and computer resources to the responsible offices. After a test period, the software will be placed on the Prime minicomputer that is located in Tucson, Arizona. Simultaneously, the software will be available to other USGS offices.

Streamflow-Record Computations

After the data are tranferred to the interim National Water Information System (NWIS) unit-values file, streamflow records are computed. Instructions for computations are similar to those in the WATSTORE User's Guide, volume 5.

Data from GOES telemetry often contain blank entries owing to missed transmissions. As many as 99 blank entries can be filled in by using an XDATE option card when making the primary computation. Arizona District policy is to limit the interpolation of stage values to 15, which allows for one missed transmission (3 hours of 15-minute values) plus three other missing values. The periods of interpolated data for each station are listed on the computer output sheet in front of the primary computation sheets. Backup charts from digital or analog recorders are used to verify the interpolated stage values if the change in stage during the missing period exceeds a tenth of a foot.

The DCP data that are entered into the unit-values file are archived automatically for permanent storage every 3 to 4 months. After the primary computations are made and the daily values table is completed, the unit values could be deleted. The Arizona District prefers to archive the data for possible future use.

PERFORMANCE OF THE SYSTEM

Overall performance of the system in Arizona is good. A lack of spare units is the main reason for most down time. A tabulation of the number of days the DCP's were not transmitting from the 44 flood-warning stations during the 10-month period—February to November 1983—is given in table 1. The DCP's did not transmit data 8.7 percent of the time; actual DCP failure accounted for 3.0 percent of this time (table 1). Most of the down time (3.4 percent) was caused by a lack of spare DCP's, which could have been installed while repairs were being made to the other DCP's. Damaged or stolen antennas and solar panels and other miscellaneous problems accounted for 2.3 percent of the down time. To reduce vandalism to the antennas and solar panels, a 2-square-foot steel plate was placed on the mast just below the solar panel and held by a bolt with a padlock. The steel plate is lowered when maintenance to the antenna or solar panel is required.

Table 1.--Number of days that data-collection platforms were inoperative at 44 flood-warning stations in Arizona, February to November 1983

Month	Actual DCP failure		Spare DCP's not available		Vandalism of antenna or solar panel[1]		Total	
	Number of days	Percentage[2]	Number of days	Percentage[2]	Number of days	Percentage[2]	Number of days	Percentage[2]
February...	14	1.1	65	5.3	39	3.2	118	9.6
March......	28	2.1	93	6.8	24	1.8	145	10.6
April......	5	.4	90	6.8	40	3.0	135	10.2
May........	48	3.5	86	6.3	18	1.3	152	11.1
June.......	63	4.8	44	3.3	15	1.1	122	9.2
July.......	40	2.9	57	4.2	20	1.5	117	8.6
August.....	39	2.9	16	1.2	37	2.7	92	6.7
September..	28	2.1	0	0.0	33	2.5	61	4.6
October....	[3]36	2.6	0	0.0	67	4.9	103	7.6
November...	[3]100	7.6	0	0.0	9	.7	109	8.3
Average for 10-month period	401	3.0	451	3.4	302	2.3	1,154	8.7

[1]Miscellaneous problems are also included.

[2]Percentage is the number of days stations did not operate divided by the number of station days for the month, times 100.

[3]Does not include the 42 days of no operation owing to flood damage to gage well and water overtopping recorder shelter.

During the same 10-month period, the DRGS did not receive data transmissions 9.3 percent of the total available time (table 2). Actual DRGS equipment failure, caused mainly by hardware failure of the disk controller and a faulty memory board, amounted to 5.8 percent.

Table 2.--Number of hours the direct-readout ground station was inoperative, February to November 1983

Month	Equipment failure	Preventive maintenance	Power-supply failure	Other	Total
February...	17	0	72	0	89
March......	0	4	14	0	18
April......	0	0	46	3	49
May........	0	0	65	0	65
June.......	0	6	0	0	6
July.......	2	6	0	0	8
August.....	183	3	20	0	206
September..	72	2	0	0	74
October....	90	4	0	13	107
November...	56	0	0	0	56
Total......	420	25	217	16	678
Percentage of time during 10-month period....	5.8	0.3	3.0	0.2	9.3

The power supply for the DRGS caused considerable down time from February through May. In late May the DRGS was connected to a separate and constant power supply, which virtually eliminated this cause of down time (table 2).

An accounting of DCP, encoder, and other types of DCP station failure for the 17-month period from May 1982 to September 1983 is shown in table 3. The most common instrument failures are the DCP's, which show an overall failure rate of 52 percent. The digital recorder with the encoder attachment had a failure rate of 43 percent and was the second most common cause of failure. Shaft encoders overall had a 17-percent failure rate. A fairly complete record has been kept of the identifiable causes of component failure of the Handar Models 524 and 560 (table 4). A summary of the failures of Handar Models 524 and 560 for different time periods is given in table 5. In the Arizona District, equipment failure or vandalism occurred 66 times during the 17-month period from May 1982 to September 1983. Stations were off the air or reported bad data in 63 occurrences, which is an average of 3.9 failures per month, or 1 failure for each station during the 17-month period.

The number of spare DCP units required to keep the system operating at maximum level depends on the failure rate, number of active DCP's, turn-around time for repair of components, and number of offices responsible for servicing telemetry stations. For the five Field Offices in

Table 3.--Number and types of malfunctions at data-collection platform stations

Month	Platforms			Encoders					Other					
	Handar 524	Handar 560	La Barge CDCP	Vernitec absolute	HIF absolute	Handar incremental	HIF incremental	L & S with Model A	Solar panel	HIF regulator	Platform timing	Battery	Programming error	Antenna
							1982							
May	3	---	1	---	---	---	---	2	---	---	2	---	1	---
June	2	---	---	---	---	---	2	---	---	---	---	---	---	---
July	3	---	---	---	---	---	---	---	---	---	---	---	---	---
August	2	---	---	---	---	---	---	1	[1]1	---	1	---	---	---
September	1	1	---	1	---	---	---	---	---	---	---	[1]1	---	1
October	1	1	---	---	---	---	---	1	---	---	---	---	---	[1]1
November	---	---	1	---	1	---	---	1	---	---	---	---	---	---
December	3	1	---	1	---	---	---	---	---	---	---	---	---	[1]1
							1983							
January	---	---	---	---	---	---	---	---	---	---	---	---	---	---
February	1	---	---	---	---	---	---	1	---	---	---	---	---	---
March	1	---	1	---	---	---	---	---	[1]1	1	---	---	---	---
April	2	1	---	1	1	---	---	1	---	1	---	---	---	---
May	---	1	---	---	---	---	---	---	---	---	---	---	1	---
June	2	---	---	---	---	---	---	1	---	---	1	---	---	---
July	---	1	---	---	---	---	---	2	---	---	---	---	---	---
August	1	---	---	---	---	---	---	---	---	---	---	---	---	[1]1
September	---	---	---	1	---	---	---	---	---	1	---	---	---	1
Total	22	6	4	3	2	0	2	10	2	3	4	1	2	5
Total units in use	45	9	8	20	2	15	4	23	61	62	---	62	---	62
Percentage of failure rate[2]	49	67	50	15	100	0	50	43	3	5	---	2	---	8

[1]Vandalized.

[2]Percentage of failure rate is the number of units that failed divided by the number of units in use, times 100.

Table 4.--Compilation of component failures of Handar data-collection platforms, April 1981-September 1983

Item	Handar 524[1]	Handar 560[2]
Integrated circuits..................	14	3
Transistors..........................	15	1
Capacitors...........................	15	27
Diodes...............................	1	--
Resistors and pots...................	2	1
Power supply.........................	1	--
Open traces..........................	3	--
Adjustments..........................	5	--
Parts in backwards or not seated......	3	--
Other................................	7	--

[1]System included 44 active platforms.

[2]System included 9 active platforms.

Table 5.--Summary of failures of Handar data-collection platforms

Type of platform	Number of active platforms	Number of failures		Percentage of failure	
		Actual	Prorated[2]	Actual	Prorated[2]
		April 1981-March 1982			
Handar 524.......	44	17	--	39	--
		April 1982-March 1983			
Handar 524.......	46	20	--	43	--
Handar 560.......	[1]6	2	--	33	--
		April 1983-September 1983			
Handar 524.......	45	8	16	--	36
Handar 560.......	9	4	8	--	89

[1]Five out of the six failures of the Handar Model 560 were caused by the same group of capacitors failing.

[2]Prorated for entire year on basis of first 6 months.

the Arizona District, an average turn-around time for repairs was about 30 days. The failure rate of the DCP's was about two per month for 62 active stations, and a minimum of eight spare DCP's were required. Each office should have the necessary spare components to make any repair or replacement to put a station back into operation. Without an adequate supply of spare DCP's, down time becomes longer and the number of return trips to the stations is higher.

Stage data are typically encoded to the DCP by a digital recorder with encoder attachment or by an incremental-shaft encoder. The incremental-shaft encoder, which is coupled to a digital or analog recorder driven by float tape or servo-manometer, is the best means of encoding stage data to the DCP. The arrangement is advantageous for two major reasons:

1. Most incremental-shaft encoders have fewer failures than the digital recorder with encoder.

2. When using a digital recorder with encoder in conjunction with a DCP, the digital-recorder punch cycle must be controlled by the DCP.

If the DCP controller fails, both the telemetry data and the digital-tape record will be lost. In contrast, if an incremental-shaft encoder is used and a standard timer is used with the digital recorder, failure of the DCP controller will not affect the digital-tape record. Sampling at a high rate is another advantage of the incremental-shaft encoder. This feature can be useful at stations where large amounts of surge occur during floods. By sampling the encoder every second or so for a 1- to 2-minute period and by having the platform average the samples, the mean of the surge can be determined for the recorded point gage height.

Failures of digital recorders with encoder attachments tend to be intermittent and difficult to detect. The easiest method to check for faulty encoding is by processing data and producing a primary computation. If the encoding errors are ambiguous, stage values will exceed those of the rating and the mean discharge for the affected day will not be computed. The maximum gage height is listed and may be checked for unreasonably high values. The fact that the processing of digital-stage data does not allow record computation for periods containing encoding errors makes computing streamflow data difficult. A small percentage of erroneous values distributed throughout the data can cause a large percentage of the record not to be computed. This problem needs to be approached in two ways:

1. Have reliable encoders.

2. Have a data-processing program that can identify types of erroneous data and allow substitution by the user.

BACKUP STRATEGY

The Arizona District is collecting hard-copy backup stage data at each satellite-telemetry site. Digital-punch tapes or analog-strip charts are available to verify the DCP data or to use in the event of a DCP or DCS failure. Tapes and charts are not processed unless needed to fill in missing periods. The Colorado and Arizona Districts are in the process of acquiring necessary equipment to receive data simultaneously from the same DCP sites. Arrangements also are in progress for both Districts to receive DCP data for most of the western States. If both receive sites are receiving data, total backup is possible. Thus, if one DRGS were to fail, the other would collect the data during that period of down time.

COSTS AND BENEFITS

The cost of installing DCP equipment at a gaging station can vary considerably between stations and depends on space availability in the gage shelter, power-supply needs, specific DCP equipment requirements, and exterior requirements for antenna and solar-panel mounting and protection. One-time costs for site evaluation, equipment, and installation could range from $7,000 to $10,000 in addition to any costs for station modification.

Personnel who service the DCP equipment will need programming and testing equipment and miscellaneous tools. Programming equipment could range from $3,000 to $5,000. The cost increases if more than one type of DCP is serviced because each model of DCP generally requires different programming equipment.

Special trips to stations are required if a DCP begins interfering with another DCP by transmitting in the wrong time period or if data from a nonoperating site are needed on a daily basis. Some special trips are balanced because routine station visits are not necessary when the DCP is functioning properly and a discharge measurement is not required.

Some office time is required to monitor the performance of each DCP on a day-by-day basis. Potential problems can be identified so that preventive maintenance can be performed on the next routine visit. For example, an observed time drift would indicate that reprogramming is needed during the next visit, or a drop in the battery voltage could indicate a problem with the solar panel, regulator, or batteries. The annual operating costs associated with a real-time data site must include a share of the day-by-day monitoring expense, which amounts to about 15 to 30 minutes a day per office. Cost of data entry into the WATSTORE data files for each station averages about $300 annually. This cost should be reduced when the new Distributed Information System (DIS) becomes operational. Operation and maintenance costs for 1984 were $1,200 per DCP station in the Federal-State cooperative program.

The initial DRGS cost, which included modems, error controllers, and operator training, was over $120,000 in 1981. Since then, the acquisition cost of a similar unit has been reduced to about $80,000. Operating costs for the 1984 fiscal year are estimated to be $60,000, which includes leasing of telephone lines and modems, DRGS and NOVA maintenance contracts, space rental, electrical and air-conditioning expenses, operator salary, and miscellaneous supplies.

Funding of the initial purchase of the DRGS and annual operating expenses have been shared by the USGS, the Arizona Department of Water Resources, Flood Control District of Maricopa County, Salt River Project, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers.

Many benefits are derived from satellite-telemetry data. Visits to gaging stations generally can be reduced during low-flow or no-flow periods where a gaging station has a fairly stable stage-discharge relation. In the arid Southwest, localized heavy rainfall may or may not produce a flow event of enough significance to require a discharge measurement. Many nonproductive trips have been eliminated in the Arizona District in the past 2 years by using DCP data to monitor stream response to a rainfall event.

Preliminary streamflow records at 15 gaging stations equipped with DCP's are provided to cooperators in Arizona at monthend. In the past, a visit to the station to make a discharge measurement and retrieve the stage record was made on or near the end of the month. If made prior to the last day of the month, the remaining days would be estimated. Because satellite-telemetry data are available, trips can be scheduled before monthend and stage data are available in the office from the DCS for the remaining period.

Discharge measurements can be obtained to improve the rating curves by scheduling station visits at specific stages rather than on a set routine. In the event of high flow, the hydrographer can visit a station to obtain a discharge measurement and eliminate the need for an expensive indirect measurement to determine the peak flow.

The amount of lost stage record has been reduced in part by the equivalent of two stage-recording devices—the DCP and a hard-copy backup. Monitoring the satellite-telemetry data can also indicate that a stilling well has become plugged with mud or debris or that a servo-manometer has become inoperative. Data from 146 stream gages throughout Arizona for the 1981 and 1982 water years were analyzed to determine if there were any differences in the amount of lost record between DCP stations and non-DCP stations (table 6).

On the basis of the data given in table 6, stations equipped with a DCP required fewer visits and had a reduction in the amount of lost record. The reduction in visits to stations was a management decision that was based on DCP data that indicated the station was operating satisfactorily and there had been no change in flow. Although

Table 6.--Comparison of mean station visits and mean days of lost record

Mean	Non-DCP gaging station	DCP gaging station
Station visits, 1981....................	17.2	15.7
Station visits, 1982....................	14.5	13.5
Days of lost record, 1981................	54.4	39.6
Days of lost record, 1982................	41.8	14.9

both DCP and non-DCP stations showed a reduction in lost record from 1981 to 1982, the reduction at the DCP stations was much greater. In many cases, DCP data are complete enough for the water-year records so that backup digital tapes and analog charts do not require processing. Only those periods of missing DCP data require computation of stage from backup recorders.

Manual processing of digital tapes or analog strip-charts is reduced by satellite-telemetry data stored in the daily values file. An estimated 2 days are saved per station by not having to process digital tapes, manually check mean stage values, and manually compute subdivided daily-discharge computations at analog-recorder stations.

Other agencies benefit from the availability of satellite-telemetry data. The Flood Warning Office uses satellite-telemetry data for flood routing, flood watches, and flood warnings. The 44 DCP stations in the Statewide flood-warning network were selected to give at least a 3-hour warning of an impending flood event. The Flood Control District of Maricopa County also obtains satellite-telemetry data for flood-warning purposes near Phoenix and several small nearby communities.

Satellite-telemetry data are used for efficient operation of the reservoirs in the Salt River Project area. Although the reservoirs on the Salt and Verde Rivers are not designed for flood control, advance information of high flows can allow personnel some lead time to control outflow by releasing water at lower rates than could be allowed with no advance information. Nearly as important is knowing when the high reservoir inflows are returning to normal so outflows can be reduced in order to meet future irrigation and power-generation demands.

SUMMARY AND CONCLUSIONS

Manual retrieval of data from many of the remote key gaging stations in Arizona is expensive and time consuming. River-stage and rainfall data are being acquired from more than 60 gaging stations using the Arizona District Data-Collection System (DCS). The system consists of a stage sensor that drives a data encoder for entry of stage data into the Data-Collection Platform (DCP), the DCP that transmits the data to the Geostationary Operational Environmental Satellite (GOES), and the Direct Readout Ground Station (DRGS) in Phoenix that receives the data from the satellite. A minicomputer, which is connected by telephone line to the DRGS, receives data from the DRGS, decodes and stores the data, and disseminates the data to cooperators and other users.

Dependability in the encoding of sensor data for the DCP has been improved with the development and use of the incremental shaft encoder. Backup in the DCS is being accomplished by collecting hard-copy backup stage data at each station and with the planned backup of the DRGS sites in the Colorado and Arizona Districts.

The Arizona District is using the satellite-telemetry data in the computation of daily streamflow. Backup digital tapes and analog-recorder charts are available for verification of the DCP data and for filling in missing periods of record.

DCP down time occurred 8.7 percent of the time during February to November 1983 for the 44 flood-warning stations, of which only 3.0 percent of the down time was caused by actual DCP failure. A lack of spare replacement units and other component problems accounted for the other 5.7 percent of down time.

The DRGS was down 9.3 percent of the time during February to November 1983; 5.8 percent was caused by actual hardware failure, 0.3 percent was for preventive maintenance, and 3.2 percent was caused by power-supply failure and other causes.

Benefits that are derived from the DCS include scheduling of field visits to DCP sites to obtain discharge measurements at desired stages, more flexability in scheduling visits to provisional-record stations, fewer visits during low-flow or no-flow periods, and knowing when a gage well or servo-manometer becomes inoperative. In addition fewer visits were made and record loss decreased significantly. Other Federal, State, and county agencies use satellite-telemetry data for flood routing, reservoir regulation, and water-management decisions to meet irrigation and power-generation demands.

Some performance characteristics of the DCS are identified in this report. More data are required to properly evaluate the accuracy, efficiency, and cost effectiveness of the entire system. Another area that needs more study is how and where dependability of equipment components can be improved. More rigid specifications on components within the DCP could reduce the failure rate. Additions are needed in minicomputer software to allow flagging of stage values that are manually entered as well as interpolated values entered by the computer. As program development and improved operation reduces lost or erroneous records, the cost of obtaining backup records may not be justified.