THE COLORADO SATELLITE-LINKED WATER RESOURCES MONITORING SYSTEM

ANNUAL STATUS REPORT
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5TH EDITION

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I am pleased to release the FY 1989-90 Annual Status Report of the Colorado Satellite-Linked Water Resources Monitoring System. The report addresses all aspects of the monitoring system including examples of system utilization for all seven major drainage basins in the state of Colorado. The system has proven to be a highly effective tool in the management of our precious water resources. This has become especially apparent with the drought conditions that have prevailed in the state since 1988.

There are several key aspects of the system that I would like to point out:

- The system provides cost benefits estimated to be $1.5 million annually. Benefits-to-cost-ratio is approximately 6 to 1.
- The system is a public system with access available to all Colorado water users.
- The system can be easily expanded with additional monitoring stations and additional sensor types.
- The system has received national merit awards from the Council of State Governments and the National Society of Professional Engineers for innovation and design. The state of Colorado remains on the leading edge of technology in this area.

In FY 1989-90, the State Legislature provided $100,000 from the General Fund for operation of the monitoring system. The remainder of the $228,124 budget was to be collected from user fees. One hundred six thousand thirty-three dollars in fees were collected resulting in underfunding. Beginning in FY 1990-91, the General Fund appropriation has increased to $200,000. The remainder of the $238,124 budget will be collected from user fees. This is considered to be workable. Special thanks must be extended to State Senator James Rizzuto for his successful efforts in this area.

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COLORADO SATELLITE-LINKED WATER RESOURCES MONITORING SYSTEM

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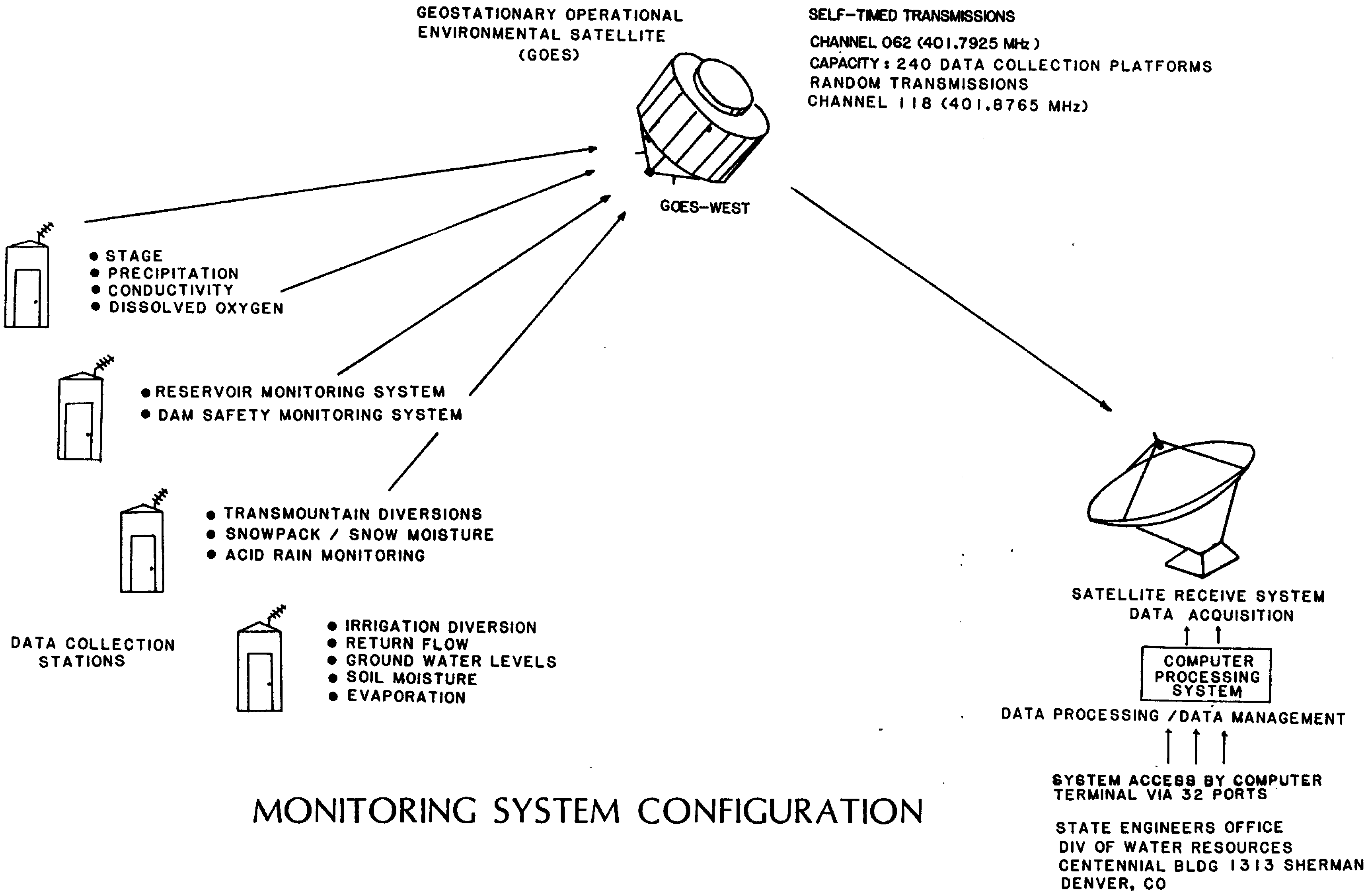
FIGURE 1



MONITORING SYSTEM CONFIGURATION

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INTRODUCTION

The Colorado satellite-linked monitoring system provides real-time water resources data on a continuous basis from key gaging stations across the state of Colorado. The computerized system can be accessed by computer terminal or by phone from any location via phone communications. These data and appropriate applications software provide for more effective water rights administration, computerized hydrologic records development, flood warning, and water resources management.

The system was provided to the State Engineer by the Colorado Water Resources and Power Development Authority pursuant to Section 37-95-107(5), C.R.S. (1983), by enactment of Senate Joint Resolution No. 20. The Authority's Board was convinced through a two-year demonstration project in the Arkansas River and Rio Grande basins that the system could be an important tool in water resources management. Since the enhancement of water resources management is one of its goals, the Authority elected to fund the installation of the system and its first year (FY 84-85) of operation at a total cost of $1.8 million.

The Authority awarded the contract, under competitive procurement, to the Sutron Corporation, Herndon, Virginia, in May, 1984. The original contract called for Sutron to provide a turn-key system including remote data collection hardware for 82 stations, receive site, central computer, and operating/applications software. In March 1985, the Authority approved an expansion of the monitoring network by an additional 68 stations. This effectively brought the statewide network to 150 stations. The system acceptance test was successfully run on August 8, 1985. The system was formally dedicated on October 4, 1985. At that time, the Authority turned the system over to the state of Colorado under the jurisdiction of the Office of the State Engineer.

The Colorado satellite-linked water resources monitoring system received national merit awards in 1985 and 1986. The National Society of Professional Engineers selected the system as one of ten outstanding national engineering achievements for 1985. The Council of State Governments selected the system as one of eight of the top innovative programs instituted by state government in the nation for 1986. Colorado remains the only state in the nation to operate a statewide monitoring system of this type. Colorado remains in the forefront in utilization of this technology with other western states in the planning process to install and operate similar systems. These states include Utah, Texas, California, Idaho, Washington, Arizona, New Mexico, and Hawaii.

The interest in real-time data collection for monitoring water resources and other natural resources data is growing at an incredible rate due to the need for such data and the cost effectiveness. Various federal agencies, water conservancy districts, municipalities, and private entities now operate over 150 satellite-linked data collection stations in Colorado in addition to the state operated network.

PROJECT MANAGER'S REPORT

The Colorado satellite-linked monitoring system, providing real-time water resources data on a continuous basis from key gaging stations across the state of Colorado, remains an integral tool in the hands of the State Engineer, Division Engineers, and Water Commissioners in its primary utility, water rights administration. The system represents an important technological advance in the state's ability to monitor and evaluate current hydrologic conditions in order to effectively carry out the statutory responsibilities of water rights administration.

The following goals and objectives set for FY 89-90 were achieved to a satisfactory degree:

- Obtain increased General Fund support for the system's operations and maintenance beginning in FY 90-91. The General Fund appropriation was increased from $100,000 to $200,000.

- Provide technical assistance to various water resources management entities in the state to encourage the purchase, installation, and operation of satellite-linked data collection hardware.

- Control operations and maintenance costs.

- Increase system utilization to facilitate data editing and the development of the final hydrologic record.

- Assimilate system utilization into other state agencies.

The following goals and objectives set for FY 89-90 were not achieved to satisfaction:

- Increase the network by 5%. A funding proposal to the Colorado Water Resources and Power Development Authority to expand the monitoring network by 13% to enhance drought management was deferred until FY 90-91.

- Increase central system capabilities to meet growing demands. A funding proposal to the Colorado Water Resources and Power Development Authority to upgrade the central computer was deferred until FY 90-91.

- Develop and implement standard operating procedures relative to data quality assurance.

Expenditures for the operation of the monitoring system for FY 89-90 amounted to $209,613. The projected budget was $228,124. Cost reductions of $18,511 were primarily the result of balancing expenditures to meet available funds. Total funding available was $222,013 including $6,087 in a reserve fund balance. User fees/contributions collected were $106,033 in FY 89-90 up from $103,350 collected in FY 88-89. A fund balance of $12,400 was carried over for emergency expenditures. The FY 90-91 operating budget is projected to be $238,124.

WATERTALK access to obtain up-to-date flow information at selected gaging stations across the state increased by the general public. There were 1800-2000 calls per month handled during runoff season. Efforts will be taken to further enhance WATERTALK by providing additional information including water quality conditions and planned reservoir releases. A "900" number phone link was considered but is currently not a viable alternative due to excessive equipment capital costs and monthly line charges.

The inclination of GOES-WEST (GOES-6) exceeded 2.2° by May 1990 prompting a switch to GOES-Central (GOES-7), located at 97.8° west. The data collection system functioned moderately well after this change; however, problems with phase-lock began to seriously impair the system by late summer. A new receiver with more sensitive reception was obtained from Sutron. This did not solve the problem. The problem was most serious Monday-Friday during mid-day hours. It was ascertained that cellular telephone broadcasts were interfering with GOES reception. It was apparent that excessive rebroadcast of cellular transmissions was creating a strong second harmonic interference. A complaint to the Federal Communications Commission resolved the problem.

The National Oceanic and Atmospheric Administration-National Satellite Data Information Service (NOAA-NESDIS) continues to hold quarterly meetings for users of the Geostationary Operational Environmental Satellite (GOES). The Project Manager and the System Analyst each attended a meeting this year.

Problems in obtaining a DOMSAT link have delayed activation of the NOAA-PORT GOES communications system until early 1991. Activation of this system would be a significant step forward in improving long-term data reception needs. GOES-NEXT has been delayed by two years and is now scheduled for February, 1992.

An additional FTE should be seriously considered and possibly incorporated into the FY 91-92 budget. The position, System Maintenance Manager, would be responsible for both coordinating and carrying out the sustained operation and maintenance of the remote data collection hardware. As the system becomes more integrated into real-time water rights administration, there develops a greater need to maintain the operation of the monitoring network on a continuous and consistent basis. This requires a full-time position. A summer intern was hired June-August, 1989, to assist in overall system operations and maintenance. This worked very well and will be requested again in FY 90-91 if funds are available.

I. PROGRAM DESCRIPTION

The monitoring system represents state-of-the-art technology in real-time data collection. Although the system utilizes space age technology, it is relatively simple. Conventional data collection hardware and data processing techniques have been incorporated into the system configuration.

A. System Configuration

The system is comprised of seven basic components:

1. Gaging stations
2. Remote data collection hardware
3. Transmission receive hardware
4. Central computer
5. Applications software
6. Computer terminals for data base access
7. Satellite communications link

The remote data collection hardware is generally installed at pre-existing stream, diversion, and reservoir gaging stations. The hardware interfaces with on-site sensors. The sensor may be either a float operating in a stilling well hydraulically connected to the stream or reservoir, a manometer or other type of pressure transducer, or a direct discharge meter.

The remote site data collection hardware installed in these gaging stations includes a Data Collection Platform (DCP), an incremental analog-to-digital shaft encoder, an environmentally secure NEMA enclosure, a Yagi antenna, a 12-volt battery, a solar panel, and complimentary cables. The DCP is comprised of a sensor interface module, a microprocessor, and a UHF transmitter. The sensor interface module is capable of handling up to 16 sensors. The microprocessor provides for programmable input of data measurement and transmission scheduling, data manipulation, and data storage. The DCP is programmable by utilizing a portable terminal via an RS-232 port. The DCP measures approximately 10"x8"x4". The shaft encoder converts incremental stage values from analog to digital in hundredth of a foot intervals. The shaft encoder communicates directly with the DCP. The shaft encoders were modified with digital displays/data resets. This provides for easy sensor calibration and data display for station operators. The unit measures approximately 8"x6"x6". The NEMA enclosure houses the DCP and the battery. The unit measures approximately 24"x20"x10".

The transmission receive hardware basically consists of a 5-meter parabolic dish, downconverter, receiver, amplifier, multiplexor, and eight frequency agile programmable demodulators. This Direct Readout Ground Station is located at the Centennial Building, the Office of the State Engineer.

The central computer is a Digital Equipment Corporation (DEC) VAX 11/750 with 4 Megabytes of physical memory. It has two 456 Megabyte hard disks for program and data storage, one 9-track 1600 bits per inch tape drive for data exchange, one 8mm high capacity tape drive for back-ups and archiving, a printing terminal for system control operations, and a 600 line per minute line printer for reports and other large listings. For terminal and modem communications, there are 32 asynchronous input/output ports. These allow users to access the system locally through several terminals in the Centennial Building and remotely over telephone lines through four 2400 baud and eight 1200 baud modems. The communication ports also control four DECtalk voice synthesizer units, used for the WATERTALK system. One asynchronous port control and receives data from the receive site electronics. The system has one port for an out-dialing voice synthesizer to generate alarm telephone calls to the National Weather Service. The central computer hardware is located in the Centennial Building at the Office of the State Engineer.

The operating system software is DEC VMS (virtual memory system) version 5.0. This software controls the operation of the computer, the manner in which the system memory is used and how the users interact with the application software. All applications are written in the FORTRAN programming language. The primary application, HYDROMET, was developed by the Sutron Corporation. Enhancements and additional software were developed by the Office of the State Engineer.

Each of the seven Division offices has at least one Personal Computer (PC) with a printer and a modem to access the main system using the State of Colorado microwave telecommunications system. Several Water Commissioners also have PCs and modems to access the system. Field staff who maintain and operate the DCPs have small hand-held terminals used to program and test the DCPs. With a modem, field personnel can also access the main computer system.

The communications link for data transmissions is the Geostationary Operational Environmental Satellite (GOES). GOES is a series of federal communications satellite operated by the National Oceanic and Atmospheric Administration, National Environmental Satellite Data and Information Service (NOAA-NESDIS). The GOES satellites are in an equatorial, geostationary orbit at a point 22,500 miles in space. This type of orbit allows for a continuous line-of-site to be maintained with both remote transmitters and the Direct Readout Ground Station. NOAA-NESDIS and the Federal Communications Commission have provided the Colorado State Engineer's Office with 223 transmission slots on satellite channel 62, allowing for 223 DCPs to transmit self-timed transmissions at separate 4-hour intervals. They also provide the use of channel 118 for transmitting random emergency alarm messages. We also receive data transmitted by other organizations on nine other channels. Currently, there are no fees for the use of the GOES system.

B. System Operations

Throughout 1989 and the first 6 months of 1990, the Division of Water Resources was using the GOES-West (GOES-6) satellite, located at 136° west longitude. This satellite's orbit has continuously deteriorated since it's last stabilization maneuver in May, 1988. It has no remaining fuel for orbital adjustments. In May it's inclination (up and down movement) exceeded 2.2°, and the receiving antenna no longer had a continuous line-of-sight. To overcome this problem, we switched operations to GOES-Central (GOES-7). Its orbit is seasonally adjusted between 98° west and 108° west. This movement is because the National Weather Service uses GOES-7 weather imagery systems to monitor seasonal hurricane activity. This does not create problems for the Office of the State Engineer's activities. The inclination of this satellite is only 0.03°. It has enough fuel for 3 to 5 years of orbit maintenance maneuvers.

Shortly after the change to GOES-7, Radio Frequency Interference (RFI) began to overload the receiver causing significant data loss, primarily during business hours on Monday through Friday. The most likely cause of this RFI is retransmission of mobile cellular telephone traffic through cellular repeaters. An upgraded receiver alleviated but did not eliminate this RFI. Discussions with the FCC in September seem to have resolved this problem, and the reception is now excellent.

The launch of the next GOES satellite has again been postponed. The new launch date is spring of 1992. This will not adversely affect our operations.

After several delays, a new reception system proposed by NOAA-NESDIS is scheduled to begin in the spring of 1991. Under this system, all messages from the GOES satellites would be received at NOAA's main data acquisition station and then retransmitted through a domestic communications satellite (DOMSAT). The data from the DOMSAT could be received with a small (1.8 meter) dish antenna. The cost for a receiving system is approximately $10,000. Because of this cost, the uncertainty concerning the date of actual startup, and concerns about operational reliability, the Division of Water Resources will not immediately use this new technology. GOES-7 and the current receive system will remain adequate for several years.

The DCPs collect data measurements at 15-minute, 30-minute, or ?-minute intervals, as needed. In most cases 8-hours of these data are stored and transmitted at 4-hour intervals in the standard transmission mode. This provides replicate data in case of a missed transmission. When the DCPs detect that streamflow conditions exceed programmed levels, they transmit random messages, providing real-time alarm warnings. Incoming data transmissions are processed on a real-time basis. The system converts the raw data, generally river stage, into engineering units and calculates discharge or reservoir content values using rating tables or formulas. The results are then time-stamped. The most up-to-date shifts, as determined by actual measurements, are used in these calculations to reflect changes in the stream channel characteristics.

Selected DCPs also transmit meteorological and water quality data. The system processes this information in a similar manner.

Every morning the system reads the previous day's data and calculates mean values, minimums, maximums, and other statistics, placing the results in a separate data base. In order to preserve the integrity of the data, we no longer edit the original real-time data. A subset of the original data is extracted for editing and hydrologic record development. The Division of Water Resources hydrographers also use this system to manually enter and edit stations not included in the GOES-linked system. Only authorized users can edit the data.

Maintaining data base integrity is a primary operations goal. Real-time data are of no value unless the data are accurate. Considerable effort is maintained to ensure that the remote hardware/sensor interface remains in calibration. This effort becomes compounded by the fact that nearly 65% of the stations in the state's monitoring network are operated by other entities that generally are not utilizing the data to make real-time decisions. Stations are typically visited by a hydrographer on a 2 to 4 week interval. On-site measurements are made along with any necessary calibrations. Normal data ranges for each station are entered into the central computer. If data values fall outside of the expected range, they are flagged accordingly. Flagged values are not utilized in computing mean daily values. Each day the computer reports the number of "data quality" flags for each station.

Computer generated system diagnostics reports assist in monitoring the operating qualities of the remote data collection hardware. The report tabulates the operations characteristics for each station for the previous day. The report lists the number of received, scheduled, and missed transmissions, any message length errors, transmission time errors, errors in transmission quality including power (EIRP) and frequency, any deficiency in remote power supplies, and the number of missing values and parity errors for each station. Frequently, hardware operating problems can be detected before reaching a critical (non-operative) stage.

The Division of Water Resources is responsible for system maintenance. Field personnel from each Division received training from Sutron technicians in the operations and maintenance of the system hardware. Selected staff engineers receive a week of follow-up training at Sutron's facilities in Herndon, Virginia each year. Training is directed at system diagnostics, hardware calibration, and basic repairs. Each Division is supplied with a minimum of two sets of replacement hardware. If a component malfunctions and cannot be repaired in the field, that component is replaced and returned to the manufacturer for repair.

Communications with NOAA-NESDIS, other GOES DCS users, and the Colorado user community is essential. NOAA-NESDIS coordinates the activities of two national GOES DCS user groups, the Technical Working Group and the Direct Readout Ground Station Working Group. Meetings are held quarterly to discuss GOES DCS operations, future system improvements, system utility, and to facilitate communications between users. These meetings have proven to be beneficial. The Project Manager attends two of the four meetings annually. Within the state of Colorado, a consortium of governmental agencies (federal, state, and municipal) have formed a committee to coordinate activities within the state related to hydrology-meteorology. The Hydromet Committee has been instrumental in promoting real-time data collection in Colorado.

The monitoring system continues to operate with only two full-time employees, the Project Manager and the Systems Analyst/Programmer. The Project Manager's responsibilities include the coordination of daily operations, network development, system enhancement, maintaining communications with the user community, interagency/intraagency coordination, user fee development, budget management, and the coordination of the development of system applications and utilization. The Systems Analyst/Programmer's responsibilities include the operation of the receive site and central computer, data base management, control and management of system access by the user community, software modification and development, and ADP training. A third position, Systems Maintenance Manager, remains unfilled due to budgetary constraints. However, with future additions to the network, sensor add-ons, and increasing primary duties of field staff, this position will become necessary. Essential support is provided from other staff. Program direction is provided by the State Engineer and Deputy State Engineer. The Chief of the Division's Branch of Information Services provides technical support and provides the part-time services of a computer operator. Systems operations and maintenance support is provided by each of the seven Division offices. Each Division has assigned a hydrographer in charge of maintenance of the remote data collection hardware in his Division.

C. System Software

The HYDROMET software package is comprised of a series of programs that provide for transmission receive, raw data processing, data conversions, data archiving, data retrieval in various reports and graphics formats, and system diagnostics. The following is a description of the basic applications programs utilized by the user:

1. DAYFILES maintains and provides access to the real-time data being collected for a given station. This program performs raw data processing, data conversions, shift applications, and archiving of the real-time data. Figure 5 is an example of a DAYFILES report.

2. ARCHIVES computes and stores mean daily values for a given data type for a given station. Figure 6 is an example of an ARCHIVES report.

3. ANNUAL provides a yearly summary of mean daily values for a given data type for a given station. It also summarizes by month the total, mean, minimum, maximum, and any special conversions, i.e. mean daily discharge to acre-feet. The format matches that established by the U. S. Geological Survey-Water Resources Division and accepted by the Colorado Division of Water Resources for publication purposes. Figure 7 is an example of an ANNUAL report.

4. PLOT provides for the development of graphical displays of data values plotted against time. In the case of discharge data, this produces a hydrograph. Figure 8 is an example of a plot of DAYFILES data. FIGURE 9 is an example of a plot of ARCHIVES data. Figure 10 is an example of a plot of ANNUAL data.

5. SCHEMATICS provides for a graphical display of the relative locations of monitoring stations along with the most recent data for each station. Figure 11 represents the lower reaches of the Division 3 monitoring network.

6. DIAGNOSTICS provides a detailed daily summary of the operating characteristics for a network of stations. This includes such things as missed transmissions, parity errors, missing data values, remote battery power, transmission power, and data base quality flags.

Additional programs have been developed internally to supplement the Hydromet software. SMSEQPT provides for a computerized inventory and tracking system for the remote data collection hardware, primarily 166 DCP's and 166 shaft encoders with a replacement cost of $650,000.00. RECORD was developed to facilitate the development of the hydrologic records. It modifies the Hydromet records development programs to better meet the needs and requirements of the Division of Water Resources. Data editing can be performed on either the 15-minute resolution data or the mean daily values. Editing is done on a separate working file duplicated from the original data base. In this fashion, the integrity of the real-time data is maintained. This is necessary since administrative decisions are based on the evaluation of real-time data. LOG was developed to monitor transmission activity on a specified demodulator. This includes scheduled and unscheduled transmissions making it possible to identify unauthorized transmissions that could cause interference problems. Sutron has released a new version of the Hydromet software that the DWR will install by late 1989.

D. System Capabilities

The ability to collect data remotely on a real-time basis is the most fundamental capability of the system. The latest data values are never more than four hours old. Random (emergency) transmissions update the data base at intervals down to two minutes if user defined thresholds at the remote site are surpassed. The remote data collection hardware is easily installed and can be operated in remote locations utilizing portable power packs and solar panels. The hardware can be operated in a wide environmental range from -40°C to +55°C. The DCPs are user programmable in the field. The units are capable of interfacing with up to 16 sensors simultaneously in either analog or digital mode. Very few locations in Colorado do not have a line-of-sight with either GOES-CENTRAL or GOES-WEST. As the GOES spacecraft are in a geostationary orbit, continuous communications can be maintained. The Direct Readout Ground Station can operate in an urban environment with negligible radio frequency interference. The receive site is equipped with eight demodulators allowing the monitoring of eight GOES channels simultaneously. A Sutron developed program was installed in FY 87-88 that allows for programmable operation of the demodulators. Operator input directs the demodulators to switch channels by time. All transmissions through GOES are in the public domain. The state's receive site is thus capable of monitoring all transmissions of interest through either GOES-CENTRAL or GOES-WEST. The system is capable of handling a minimum of 350 DCPs. Data storage capacity is 912 MBytes. Up to 16 users can access the system simultaneously. The system evaluates incoming transmissions and prepare a detailed summary of pertinent operating characteristics.

The Office of the State Engineer operates a computer accessory unit, WATERTALK, that allows data to be output to the user by phone using computer-generated voice-synthesis. The user can dial the WATERTALK unit, located in Denver, and receive up-to-date flow conditions at key gaging stations across the state by input of commands utilizing the keypad of a touch-tone phone. Flow information is automatically up-dated by the central computer in communicating with WATERTALK. Four phone lines are dedicated for WATERTALK user access such that four users can access the unit simultaneously.

Data transmissions are processed in an automated fashion on a real-time basis. Data conversions including analog-to-digital, stage-to-discharge, and mean daily values computations are performed in an automated fashion based on user input. Data are automatically screened and appropriately flagged if they fall outside of a user defined normal range, thus providing a basis for data quality assurance. Data editing routines, with access controlled by user name/password, allow for data base modification in both the real-time data and the archival data base. Data for stations not in the monitoring network may be entered manually, from computer-to-computer transfer, or by computer tape.

The data can be retrieved and output in various reports and graphics formats. The most fundamental output format for the evaluation of flow data is the hydrograph. Data from up to four stations or from four periods of record for a single station can be plotted on a single hydrograph.

The system is capable of providing flood warnings. If river conditions surpass user identified high water levels, the system automatically sends out warning messages to designated personnel by either computer-to-computer communications or by delivering a voice-synthesized message over the phone.

E. Future System Developments

The satellite-linked monitoring system can be both expanded and enhanced to increase its capabilities and effectiveness. The expansion of the state's monitoring network and the enhancement of the system by the addition of other sensor types will be limited by the availability of funds. The cost to purchase and install GOES-linked data collection hardware at an existing shelter is approximately $6,000 per station. Refer to Appendix A. Current funding levels do not provide for capital expenditure beyond hardware replacement costs. There is a large variety of sensor types available over a wide cost range. Sensors are available that can interface with the Sutron DCP and provide valuable data on a real-time basis. These include precipitation, air temperature, water temperature, soil moisture, snow depth, solar radiation, pH, dissolved oxygen, conductivity, wind direction and speed, humidity, and soil temperature. Costs for specific sensors range from $300 to $4,500. Refer to Appendix B. The need for additional data must be coupled with funds from the state of Colorado and from various user groups to cover the costs.
System enhancement cannot become a reality without additional operations and maintenance field support staff.

The Office of the State Engineer, Division of Water Resources, can justify the need for an additional 25 to 30 satellite-linked monitoring stations to assist in water rights administration. This office is also interested in real-time data that can assist in runoff forecasting and in dam safety monitoring. Other state agencies including the Division of Wildlife and the Department of Health identified the need for an additional 20 to 25 stations. The Division of Wildlife is interested in monitoring minimum streamflows and water quality relative to fisheries management. The Department of Health is interested in monitoring basic water quality parameters. The Office of the State Engineer has made the receive site and central computer facilities available to any state agency desiring to get involved in GOES-linked data collection. Technical expertise will also be provided on a cooperative basis.

Numerous non-state water resources management entities are planning on installing and operating additional satellite-linked stations statewide. These include the National Weather Service, Bureau of Reclamation, Northern Colorado Water Conservancy District, City of Colorado Springs, and the City of Aurora. The National Weather Service (NWS) has installed sensors measuring air temperature and precipitation along with stage at 38 stations in the Colorado River basin in Colorado. Through a cooperative agreement, the NWS installed precipitation and air temperature sensors at two state operated stations, Colorado River near Dotsero and the Blue River below Green Mountain Reservoir. The Northern Colorado Water Conservancy District is planning on installing additional GOES-linked meteorological stations for use in runoff forecasting and irrigation planning. The Bureau of Reclamation and the City of Colorado Springs are planning on the installation and operation of real-time monitoring stations for reservoir management and dam safety. The City of Aurora will be increasing its network of stations in South Park for water resources accounting. The stations that are of interest to the user community will be monitored by the state's system.

The input of historic flow data into the system's data base for key gaging stations in Colorado is expected to be completed by early 1990. This will allow for comparisons of recent data with data covering in some cases 100 years of record. Current flow conditions can be compared with normal, wet, and dry periods. Examples of historic flow records available are:

STATION	INITIAL DATE OF RECORD
Arkansas River at La Junta	1889
Arkansas River at Pueblo	1885
Big Thompson River at Mouth of Canyon near Drake	1887
Cache La Poudre at Mouth of Canyon near Fort Collins	1881
South Platte River at Denver	1889
Dolores River at Dolores	1895
Gunnison River near Grand Junction	1894
Rio Grande near Del Norte	1889

It has become evident that there are situations where short-term real-time data collection is necessary. This could include stations for flood warning, dam safety, or for specific water rights administration such as water exchanges. An example of one of these uses took place in May, 1987, when the Cucharas Reservoir (Division 2, Arkansas River basin) showed signs of possible dam failure. The reservoir was at near capacity with 51,000 acre-feet of water. A monitoring station was installed the next day at the reservoir utilizing a pressure transducer to monitor stage elevation. Another station was installed upstream on the Cucharas River to monitor inflow. Both stations remained operational until August 1, 1987. Four sets of remote data collection hardware, portable shelters, and sensors are being pre-packaged to assist in meeting future needs.

The ability to extract information from the enormous amounts of real-time data being collected can be enhanced through the development of more sophisticated software. Currently, several Division offices are developing various water resources accounting programs. Programs in the area of short-term runoff forecasting and automated river call determination are of special interest. Program development will come slow over the next two years but will gradually increase momentum as the monitoring system becomes more integrated into daily water rights administration.

F. Monitoring System Network

The real-time hydrologic data collection network operated by the state of Colorado is comprised of 158 stations. These stations were selected by the State Engineer, Division Engineers, and Water Commissioners with an emphasis on the need for real-time data for water rights administration. The following is a tabulation of the location of these stations by division/river basin:

Division 1 - South Platte River Basin, 37 stations
Division 2 - Arkansas River Basin, 48 stations
Division 3 - Rio Grande Basin, 18 stations
Division 4 - Gunnison River Basin, 11 stations
Division 5 - Colorado River Basin, 22 stations
Division 6 - White/Yampa River Basin, 7 stations
Division 7 - Dolores/San Juan River Basins, 15 stations

A detailed list of these stations is included in Table 1. In the network development, the primary considerations are administrative importance, utility in project management, and the interrelationship of each station to other stations in a subnetwork. The goal is to incorporate those stations that satisfied as many of these requirements as possible in order to obtain maximum benefits from real-time data collection. The most important element in network development is in establishing station interrelationships. Rather than selecting stations, it is more important to incorporate integrated subnetworks. Data collected from one station are not as useful as information extracted from a subnetwork of stations. This is critical for compact administration, project management, developing water resources accounting systems, and in developing water resources management programs. Changes in the network can be made at any time at the discretion of the State Engineer or one of the Division Engineers. Six stations were substituted for in the last 12 months as a result of an evaluation of the utility of real-time data or due to a change in specific water rights administration. The remote data collection hardware is easily removed and installed at a substitute gaging station.

Considerable cooperation was necessary in developing this network. One hundred-one (101) of the 158 gaging stations installed with remote data collection hardware by the State of Colorado are owned and operated by non-state entities. Access and installation agreements were negotiated with the following:

ENTITY	NUMBER OF STATIONS
U. S. Geological Survey - Water Resources Division	32
U. S. Bureau of Reclamation	18
Denver Water Board	9
Northern Colorado Water Conservancy District	4
Farmers Reservoir and Irrigation Company	1

ENTITY	NUMBER OF STATIONS
North Sterling Irrigation District	1
Riverside Irrigation Company	1
U. S. Army Corps of Engineers	2
City of Colorado Springs	2
City of Pueblo	5
Highline Canal Company	1
Twin Lakes Canal Company	1
Catlin Canal Company	2
Fort Lyon Canal Company	3
Oxford Farmers Canal Company	1
Rocky Ford Highline Canal Company	1
Colorado Canal Company	1
Holbrook Canal Company	1
Upper Yampa Water Conservancy District	1
Water Supply and Storage Company	2
Lower Latham Ditch Company	1
Lamar Canal Company	1
Union Ditch Company	1
Mutual Irrigation Company	1
Terrace Irrigation Company	1
South Canal Company	1
Grand Valley Water Conservancy District	1
Grand Valley Water Users Association	1
Silt Water Conservancy District	2
MVI Diversion Company	1
La Plata and Cherry Creek Ditch Company	1
Metropolitan Denver Sewage Disposal District #1	1

The cooperation that has been extended to the Office of the State Engineer by these entities is invaluable and demonstrates the interest by the water user community in the satellite monitoring system.

Various entities involved with water resources management and development within the state of Colorado have installed and are operating hydrological real-time data collection hardware in Colorado utilizing the GOES satellite as a communications link. As this is a federal satellite, all resource data transmitted through the satellite data collection system are in the public domain. The State Engineer's Office can schedule its Direct Readout Ground Station to receive and process these raw transmissions. As of July 1, 1988, there were 150 such stations being monitored. The State Engineer's Office is cooperating with these entities in planning network expansion to maximize utility of real-time data collection without redundancy. A list of these stations is included in Table 1.

Twenty-three satellite-linked monitoring stations operated by the state of Colorado are done so on a seasonal basis only. These stations are primarily gages at transmountain diversions and irrigation diversions where actual diversions are not made during the winter months, and at high elevation sites where ice-effects negate a valid record.

TABLE 1

SATELLITE-LINKED DATA COLLECTION NETWORK
MONITORED BY THE STATE OF COLORADO
DIRECT READOUT GROUND STATION

Stations Operated by the State of Colorado
Office of the State Engineer

<u>DIVISION 1</u> (South Platte River Basin)

No.	Station	Data Type
1.	South Platte River at Waterton	S
2.	South Platte River near Kersey	S
3.	South Platte River at Balzac	S
4.	Boulder Creek near Eldorado Springs	S
5.	South Platte River at Julesburg, Channel #4	S
6.	South Platte River at Julesburg, Channel #2	S
7.	South Platte River near Weldona	S
8.	Big Thompson River in the Canyon	S
9.	St. Vrain Creek at Lyons	S
10.	St. Vrain Creek at Mouth near Platteville	S
11.	Cache La Poudre at Mouth of Canyon near Fort Collins	S
12.	Cache La Poudre near Greeley	S
13.	Harold D. Roberts Tunnel	S
14.	Moffat Water Tunnel	S
15.	Alva B. Adams Tunnel	S
16.	Burlington-Wellington Canal at the Headgate	S
17.	North Sterling Canal at the Headgate	S
18.	Riverside Canal at Reservoir Inlet Gage	S
19.	Boulder Creek near Orodell	S
20.	Laramie Poudre Tunnel	S
21.	Grand River Ditch	S
22.	Big Thompson River above Lake Estes	S
23.	Olympus Tunnel	S
24.	Cherry Creek Meteorological Station	P,E
25.	Hoosier Pass Tunnel	S
26.	South Platte River at Fort Lupton	S
27.	Lower Latham Ditch	S
28.	Union Ditch	S
29.	South Platte River below Strontia Springs	S
30.	South Platte River below Chatfield Reservoir	S
31.	Metro Sewage Effluent Outlet Gage	S
32.	Hansen Feeder Canal	S
33.	Cheesman Reservoir	SE
34.	South Boulder Creek below Gross Reservoir	S
35.	Big Thompson River below Lake Estes	S
36.	Clear Creek at Lawson	C,WT,DO,pH
37.	South Platte River at Henderson	C,WT,DO,pH

Division 2 (Arkansas River Basin)

		Data Type
1.	Arkansas River at Portland	S
2.	Arkansas River above Pueblo	S
3.	Arkansas River near Nepesta	S
4.	Arkansas River near Avondale	S
5.	Arkansas River near Wellesville	S
6.	Arkansas River at La Junta	S
7.	Arkansas River at Las Animas	S
8.	Purgatoire River near Las Animas	S
9.	Fountain Creek near Pinon	S
10.	Purgatoire River near Thatcher	S,WT,C
11.	Lake Fork Creek above Turquoise Lake	S
12.	John Martin Reservoir	SE
13.	Arkansas River at Catlin Dam near Fowler	S
14.	Purgatoire River at Ninemile Dam near Higbee	S
15.	Charles H. Boustead Tunnel	S
16.	Homestake Tunnel	S
17.	Busk-Ivanhoe Tunnel	S
18.	Twin Lakes Tunnel	S
19.	Ewing Ditch	S
20.	Kicking Bird Canal	S
21.	Purgatoire River below Trinidad Reservoir	S
22.	Purgatoire River at Madrid	S
23.	Fort Lyon Storage Canal	S
24.	Cheyenne Creek near Stateline	S
25.	Pueblo Water Works Diversion	DM
26.	Lake Creek below Twin Lakes	S
27.	Lake Fork Creek below Sugar Loaf	S
28.	Timpas Creek near Rocky Ford	S
29.	Amity Canal	S
30.	Lamar Canal	S
31.	Crooked Arroyo near Swink	S
32.	Arkansas River at Granada	S
33.	Wurtz Ditch	S
34.	Columbine Ditch	S
35.	Pueblo Reservoir	SE
36.	Larkspur Ditch	S
37.	Arkansas River below John Martin Reservoir	S
38.	Fort Lyon Canal at the Headgate	S
39.	Catlin Canal at Gage Downstream from Catlin Dam	S
40.	Oxford Farmers Ditch at Headgate	S
41.	Rocky Ford Highline Canal at Headgate	S
42.	Colorado Canal at Headgate	S
43.	Holbrook Canal at Headgate	S
44.	Horse Creek at Highway 194	S, WT, C
45.	Cucharas River above Cucharas Reservoir	S
46.	Cucharas Reservoir	SE,pz(2)
47.	Cucharas River below Cucharas Reservoir	S
48.	Cucharas Reservoir Seepage Flume	S

Division 3 (Rio Grande Basin)

		Data Type
1.	Rio Grande near Del Norte	S
2.	Rio Grande near Lobatos	S
3.	Rio Grande at Thirty-Mile Bridge near Creede	S
4.	Conejos River near Mogote	S
5.	Conejos River near La Sauses, North Channel	S
6.	Conejos River near La Sauses, South Channel	S
7.	Los Pinos River near Ortiz	S
8.	San Antonio River at Ortiz	S
9.	Alamosa Creek above Terrace Reservoir	S
10.	Conejos River below Platoro Reservoir	S
11.	Closed Basin Project Outlet	S
12.	Terrace Reservoir	SE
13.	Rio Grande above the Mouth of Trinchera Creek	S
14.	Saguache Creek near Saguache	S
15.	La Jara Creek near Capulin	S
16.	South Fork Rio Grande at South Fork	S
17.	Rio Grande at Alamosa	S
18.	Rio Grande River near Monte Vista	S

Division 4 (Gunnison River Basin)

1.	Surface Creek near Cedaredge	S
2.	Gunnison River below the East Portal of the Gunnison Tunnel	S
3.	Surface Creek at Cedaredge	S
4.	Muddy Creek above Paonia Reservoir	S
5.	Muddy Creek below Paonia Reservoir	S
6.	Cimarron River near Cimarron	S
7.	South Canal	S
8.	Uncompahgre River near Ridgway	S
9.	Dallas Creek near Ridgway	S
10.	Redlands Canal near Grand Junction	S
11.	San Miguel River at Naturita	S

Division 5 (Colorado River Basin)

1.	Blue River below Dillon	S
2.	Dillon Reservoir	SE
3.	Blue River below Green Mountain Reservoir	S
4.	Green Mountain Reservoir	SE
5.	Williams Fork below Williams Fork Reservoir	S
6.	Colorado River at Hot Sulphur Springs	S
7.	Eagle River below Gypsum	S
8.	Fryingpan River near Ruedi	S
9.	Colorado River near Dotsero	S
10.	Williams Fork Reservoir	SE
11.	Colorado River below Lake Granby	S
12.	Lake Granby	SE
13.	Willow Creek Reservoir	SE
14.	Shadow Mountain Reservoir	SE

Division 5 (Colorado River Basin) cont.	Data Type
15. Willow Creek Pump Canal	S
16. Government Highline Canal	S
17. Grand Valley Canal	S
18. Plateau Creek near Cameo	S
19. Rifle Creek below Rifle Gap Reservoir	S
20. Grass Valley Canal	S
21. Fryingpan River near Thomasville	S
22. Willow Creek below Willow Creek Reservoir	S

Division 6 (White/Yampa River Basin)

1. Yamcola Reservoir	SE
2. Illinois River near Rand	S
3. Yampa River above Stagecoach Reservoir	S
5. Michigan River near Gould below the Confluence of the North and South Forks	S
6. Little Snake River near Slater	S
7. Bear Creek near Toponas	S
8. Elk River near Milner at the Mouth	S

Division 7 (Dolores and San Juan River Basins)

1. Lost Canyon Creek near Dolores	S
2. Navajo River below Oso Diversion Dam	S
3. Rio Blanco below Blanco Diversion Dam	S
4. La Plata River at Hesperus	S
5. La Plata River at Colorado-New Mexico Stateline	S
6. Dolores River at Dolores	S
7. Dolores Tunnel	S
8. MVI II Diversion	S
9. Azotea Tunnel Outlet near Chama, NM	S
10. Mancos River near Mancos	S
11. Dolores River below McPhee Reservoir	S
12. Florida River below Lemon Reservoir	S
13. Florida River above Lemon Reservoir	S
14. La Plata and Cherry Creek Ditch	S
15. Pine River below Vallecito Reservoir	S,P,E

Stations Operated by the U. S. Army Corps of Engineers (Omaha District)

Division 1 (South Platte River Basin)	Data Type
1. Bear Creek at Kittredge	P
2. Bear Creek at Morrison	S,P
3. Bear Creek Reservoir	SE,P
4. Bear Creek at Sheridan	S,P

Division 1 (South Platte River Basin cont.)

		Data Type
5.	Chatfield Reservoir	SE,P
6.	Cherry Creek at Parker	P,AT
7.	Clear Creek at Blackhawk	P
8.	Clear Creek at Derby	S,P
9.	Clear Creek at Georgetown	P,AT
10.	Clear Creek near Golden	S,P
11.	Conifer	P
12.	South Platte River below Cheesman Reservoir	S,P
13.	South Platte River at Denver	S
14.	North Fork South Platte River at Grant	S,P,AT
15.	South Platte River above Elevenmile Reservoir	S,P,AT
16.	South Platte River at Henderson	S,P
17.	South Platte River at South Platte	S,P
18.	Plum Creek at Larkspur	P
19.	Cherry Creek Reservoir	SE,P

Division 2 (Arkansas River Basin)

1.	Purgatoire River at Trinidad	S

Stations Operated by the
National Weather Service, Colorado River Forecast Center
(Salt Lake City)

Division 3 (Rio Grande Basin)

1.	Rio Grande Reservoir	P,AT

Division 4 (Gunnison River Basin)

1.	Blue Mesa Reservoir	P,AT,SE
2.	Crested Butte	P,AT
3.	Gunnison River at Delta	S,P,AT
4.	East River at Almont	S,P,AT
5.	Gunnison River near Grand Junction	S,AT
6.	Ouray	P,AT
7.	Paonia	P,AT
8.	San Miguel River near Placerville	S,P,AT
9.	Sargents	P,AT
10.	North Fork Gunnison River near Somerset	S,AT
11.	Taylor River at Almont	S,AT
12.	Gunnison River near Gunnison	S,P,AT
13.	Dolores River near Bedrock	S,P,AT
14.	Taylor Park Reservoir	P,SE
15.	Uncompahgre River near Colona	S,P

Division 5 (Colorado River Basin)

		Data Type
1.	Breckenridge	P,AT
2.	Colorado River near Cameo	S
3.	Colorado River below Glenwood Springs	S,P,AT
4.	Colorado River near Kremmling	S
5.	Colorado River near Colorado-Utah Stateline	S,AT
6.	Dillon	P,AT
7.	Grand Lake	P,AT
8.	Meredith	P,AT
9.	Roaring Fork River near Aspen	S,P,AT
10.	Roaring Fork River at Glenwood Springs	S
11.	Ruedi Reservoir	SE,P,AT
12.	Winter Park	P,AT
13.	Eagle River at Redcliff	AT,P,S
14.	Piney River near State Bridge	AT,P,S
15.	Crystal River near Avalanche Creek	AT,P,S
16.	Eagle River near Redcliff	AT,P,S

Division 6 (White/Yampa River Basin)

1.	White River near Meeker	S,P,AT
2.	Yampa River near Maybell	S,AT
3.	Little Snake River near Lily	S,P
4.	Little Snake River near Dixon, WY	S,P,AT

Division 7 (Dolores and San Juan River Basins)

1.	Animas River at Durango	S,P,AT
2.	San Juan River at Pagosa Springs	S,P,AT
3.	Vallecito Reservoir	SE,P,AT

Stations Operated by the
National Weather Service, Central Forecast Office
(Denver)

Division 1 (South Platte River Basin)

1.	Clear Creek at Lawson	S, P
2.	Big Thompson River North Fork near Drake	S,AT

Division 6 (White/Yampa Basin)

1.	North Platte River near Northgate	S

Stations Operated by the
U. S. Geological Survey - Water Resources Division

Division 1 (South Platte River Basin)

1.	Boulder Creek at Boulder	S
2.	Cache La Poudre at Fort Collins	S
3.	Clear Creek at Golden	C,WT

Division 2 (Arkansas River Basin)

		Data Type
1.	Arkansas River near Coolidge, KS	S
2.	Frontier Ditch near Coolidge, KS	S
3.	Trinidad Reservoir	SE
4.	Fort Lyon Canal near Cornelia	S
5.	Fort Lyon Canal near Big Bend	S
6.	Arkansas River near Nathrop	S
7.	Arkansas River near Parkdale	S
8.	Monument Creek at Pikeview	S,P
9.	St. Charles River at Vineland	S

Division 6 (White/Yampa River Basin)

1.	Yampa River near Oak Creek	S,WT,C
2.	Yampa River near Deer Lodge	S,WT,C
3.	White River below Boise Creek near Rangley	S
4.	Yampa River at Steamboat	S

Division 7 (Dolores and San Juan River Basins)

1.	Animas River near Cedar Hill, NM	S
2.	San Juan River at Farmington, NM	S
3.	Lemon Reservoir	SE

Stations Operated by the U. S. Bureau of Reclamation

Division 3 (Rio Grande Basin)

1.	Platoro Reservoir	SE,P

Division 4 (Gunnison River Basin)

1.	Silverjack Reservoir	SE
2.	Paonia Reservoir	SE
3.	Ridgway Reservoir	SE

Division 5 (Colorado River Basin)

1.	Lincoln Creek below Grizzly Reservoir	S,P,SR,AT
2.	Roaring Fork River above Lost Man Creek	S,P,SR,AT
3.	Mormon Control House	DM,P,SR,AT
4.	Chapman Control House	DM,P,SR,AT

Stations Operated by the Northern Colorado Water Conservancy District

Division 5 (Colorado River Basin)

1.	Upper Fraser River above Winter Park	S
2.	Lower Fraser River near Winter Park	S

Division 5 (Colorado River Basin cont.)

	Station	Data Type
3.	St. Louis Creek above Fraser	S
4.	Ranch Creek above Tabernash	S
5.	Crooked Creek at Tabernash	S
6.	Ten Mile Creek near Granby	S
7.	Strawberry Creek near Granby	S
8.	Vasquez Creek at Winter Park	S
9.	Berthoud Pass Meteorological Station	SW,ST,SMU,SML,P,AT,SR
10.	Arrow Meteorological Station	SW,ST,SMU,SML,P,AT
11.	Fraser Meteorological Station	SW,ST,SMU,SML,P,AT
12.	Meadow Creek Meteorological Station	SW,ST,SMU,SML,P,AT
13.	Cottonwood Pass Meteorological Station	SW,ST,SMU,SML,P,AT
14.	Granby Meteorological Station	SW,ST,SMU,SML,P,AT
15.	Fraser River near Windy Gap	S
16.	Upper Blue River	S

Stations Operated by the City of Aurora

Division 1 (South Platte River Basin)

1.	Michigan River near Jefferson	S
2.	South Platte River above Spinney	S
3.	Fourmile Creek near Hartsel	S
4.	Middle Fork at Santa Maria	S
5.	Fourmile Creek at Highcreek	S
6.	Middle Fork at Prince	S
7.	South Fork above Antero	S
8.	Jefferson Creek above Jefferson	S
9.	Ohler Gulch above Jefferson	S
10.	Tarryall Creek near Como	S

Stations Operated by the City of Colorado Springs

Division 2 (Arkansas River Basin)

1.	Fountain Creek at Fountain	S
2.	Fountain Creek at Pueblo	S
3.	Fountain Creek at Security	S
4.	Lake Creek above Twin Lakes	S
5.	Bob Creek at Colorado Canal	S,AT,P, BPE,H, WS,WD
6.	Fountain Creek at Colorado Springs	S
7.	Fountain Creek at Monument	S
8.	Lake Henry Reservoir and Outflow Gage	SE,S
9.	Meredith Reservoir	SE
10.	Meredith Reservoir Inflow	S
11.	Sugar City Flume	S

Station Operated by the
Santa Maria Reservoir Company

Division 3 (Rio Grande Basin)

		Data Type
1.	Continental Reservoir	SE

Station Operated by the
Rio Grande Reservoir Company

Division 3 (Rio Grande Basin)

1.	Rio Grande Reservoir	SE

Station Operated by the
Rio Grande Water Users Association

Division 3 (Rio Grande Basin)

1.	Rio Grande Canal	S

Station Operated by the
Division of Wildlife

Division 3 (Rio Grande Basin)

1.	Tabor Transmountain Diversion	S

Stations Operated by the
Colorado-Ute Electric Association, Inc.

Division 4 (Gunnison River Basin)

1.	Trout Lake	SE
2.	Trout Lake Outflow	S

Division 7 (Dolores and San Juan River Basins)

1.	Electra Lake Outflow	S
2.	Electra Lake Diversion	S
3.	Electra Lake	SE

Station Operated by the
Aspen Consolidated Sanitation District

Division 5 (Colorado River Basin)

1.	Roaring Fork River below Maroon Creek near Aspen	S

Stations Operated by the Southwestern Water Conservation District

Division 7 (Dolores and San Juan River Basins)

		Data Type
1.	Cherry Creek near Red Mesa	S
2.	Long Hollow Creek at the Mouth Near Red Mesa	S

Data Type Abbreviations

S	Stage
SE	Stage Elevation (Reservoir)
DM	Discharge Meter
P	Precipitation
AT	Air Temperature
SR	Solar Radiation
SW	Snow Water
ST	Snow Temperature
SMU	Soil Moisture Upper
SML	Soil Moisture Lower
V	Voltage Metering
C	Conductivity
WT	Water Temperature
E	Evaporation
PZ	Piezometer
DO	Dissolved Oxygen
pH	pH
WS	Wind Speed
BP	Barometric Pressure
WD	Wind Direction
H	Humidity

II. SYSTEM APPLICATIONS

A. Water Rights Administration

The primary utility of the Colorado satellite-linked monitoring system is for water rights administration. The availability of real-time data from a network of key gaging stations in each major river basin in Colorado provides an overview of the hydrologic conditions of the basin that was previously not available. By evaluating real-time data for upstream stations, downstream flow conditions can typically be predicted 24 to 48 hours in advance. This becomes an essential planning tool in the hands of the Division Engineers and Water Commissioners. The "river call" can be adjusted more precisely to satisfy as many water rights as possible. Access to real-time data makes it possible to adjust the "river call" to match dynamic hydrologic conditions. If additional water supplies are available, more junior rights can be satisfied. On the other hand, if water supplies decrease, then water use can be curtailed to protect senior rights.

The administration of water rights in Colorado is becoming increasingly more complex due to increased demands, implementation of augmentation plans, water exchanges, transmountain diversions, and minimum streamflow requirements. The number of water rights increased by 23% from 1982 to 1988, from 102,028 to 124,994. Plans for water rights transfers approved by the water courts are becoming increasingly complex. This is especially evident where agricultural water rights are transferred to municipal use. One point that must not be overlooked is that Colorado is coming out of a wet cycle. Historical and statistical evidence strongly indicate that Colorado can expect to experience a downturn in this cycle. As the availability of water decreases, the necessity of the system for water rights administration increases.

There is considerable interest in monitoring transmountain diversions, both by western slope water users and the eastern slope entities diverting the water. Transmountain diversion water is administered under different laws than water originating in the basin. In general, this water may be claimed for reuse by the diverter until it is totally consumed. Fourteen transmountain diversions are monitored by the system.

Water exchanges between water users are becoming increasingly frequent. These exchanges can provide for more effective utilization of available water resources in high demand river basins, but can be difficult to administer. The satellite-linked monitoring system has proven to be an integral component in monitoring and accounting of these exchanges.

Many municipalities and major irrigation companies have reservoir storage rights. Generally, these entities can call for release of stored water on demand. The Division Engineer must be able to delineate the natural flow from the storage release while in the stream. He then must track the release and ensure that the proper delivery is made. The system has demonstrated to be effective in this area.

The utility of the system in the administration of interstate compacts is an especially important application. The State Engineer has the responsibility to deliver defined amounts of water under the terms of the various interstate compacts, but not to over-deliver and deprive Colorado of its entitlement. Fifteen stations incorporated in the statewide monitoring network are utilized for the effective administration of these interstate compacts.

The majority of the large, senior water rights in Colorado belong to irrigation companies. These rights are often the calling right in the administration of a water district. The direct diversion rights exercised can affect significantly the hydrology of the river. Twenty-one major irrigation diversions are monitored by the system.

Water rights have been acquired by federal and state agencies to guarantee minimum streamflow for both the recreational and fisheries benefits. The availability of real-time data is essential in ensuring that these minimum streamflows are maintained.

B. Hydrologic Records Development

Specialized software programs provide for the processing of raw hydrologic data on a real-time basis. Conversions such as stage-discharge relationships and shift applications are performed on a real-time basis as the data transmissions are received. Mean daily values are computed automatically each day for the previous day. Data values that fall outside of user defined normal or expected ranges are flagged appropriately. Flagged data values are not utilized in computing mean daily values. Missing values can be added and invalid data values corrected by the respective hydrographer for that station using data editing functions. The records development software was significantly modified to allow for progressive records development. Computations are carried out by the computer alleviating the chance for human error.

Data can be retrieved and displayed in various formats including the standardized U. S. Geological Survey-Water Resources Division annual report format adopted by the Colorado Division of Water Resources for publication purposes. An advantage of real-time hydrologic data collection is in being able to monitor the station for on-going valid data collection. If a sensor or recorder fails, the hydrographer is immediately aware of the problem and can take corrective action before losing a significant amount of data.

It is essential to understand that real-time records can be different from the final record for a given station. This can be the result of editing raw data values because of sensor calibration errors, sensor malfunctions, analog-to-digital conversion errors, or parity errors. Discharge conversions can be modified by the entering of more current rating tables and shifts. Corrections to the data are sometimes necessary to compensate for hydrologic effects such as icing. Human error can also result in invalid data. The final record for those gaging stations operated by non-state entities, such as the U. S. Geological Survey-Water Resources Division, is the responsibility of that entity. Modifications to the real-time records for these stations are accepted by the state of Colorado.

C. Water Resources Accounting

There is a growing need for the ability to perform automated water resources accounting. Currently, the satellite-linked monitoring system is being utilized for such accounting for the Colorado-Big Thompson Project, the Dolores Project, and the Fryingpan-Arkansas Project Winter Water Storage. The ability to input real-time data into these accounting programs allows for current and on-going tabulations. Since the computations are performed on a computer, the accuracy is increased significantly.

D. Dam Safety

Dam safety monitoring has developed in recent years into a major issue. Numerous on-site parameters are of interest to the State Engineer in assessing stability of a dam. At this time, the system monitors seven reservoirs in Colorado. Currently, the parameters monitored are limited to inflow, outflow, and stage elevation. These data do, however, provide a basis for evaluating current operating conditions as compared to specific operating instructions. The installation and operation of additional sensor types could provide essential data on internal hydraulic pressure, vertical and horizontal movement, and seepage rates.

E. Automated Flood Warning System

The Office of the State Engineer, Division of Water Resources, in cooperation with the National Weather Service-Central Forecast Office (NWS-CFO) in Denver, operates a statewide flood warning system utilizing 78 stream gaging stations that are part of the Colorado satellite-linked water resources monitoring network operated by the State Engineer. The NWS-CFO, which operates on a 24-hour basis, is alerted to changing flow conditions. If conditions warrant, either a flood WATCH or a flood WARNING is issued.

Table 2 lists the incorporated stream gaging stations with the designated alert levels used to flag high water conditions. A synopsis of how the system operates follows:

1. Remote Data Collection/Data Transmission

Stream stage levels are measured and recorded every fifteen minutes for transmission at standard 4-hour intervals. If stage alert levels are surpassed, emergency transmissions are made at random intervals of from 2-10 minutes. All transmissions are sent via the Geostationary Operational Environmental Satellite. Transmissions are received and processed at the receive site located in Denver operated by the State Engineer.

2. Flagging High Water Levels

Data are screened in an automated fashion by the system's central computer to flag high water levels. The central computer automatically contacts the NWS-CFO by phone giving a voice-synthesized message that relays pertinent information. The transmission is not completed until the message is received and verified. A file is generated in the computer that lists all stations reporting high water levels during the last hour.

3. Hydrologic Conditions Assessment

The NWS-CFO OFFICIAL-IN-CHARGE (OIC) immediately accesses by computer terminal the satellite monitoring system data base to further evaluate overall upstream and downstream flow conditions for the effected watershed. Sophisticated software including color graphics capability allows the user to effectively evaluate the data. The OIC follows up by consulting with the NWS regional offices of Pueblo, Grand Junction, Colorado Springs, and Alamosa. Radar coverage is utilized to identify and determine the intensity of precipitation events. The appropriate county sheriff offices and official spotters are contacted for verification of hydrologic conditions.

4. Watch/Warning Dissemination

If flooding is considered a possibility, a WATCH is issued. If flooding is considered to be imminent, a WARNING is issued. The National Warning System (NAWAS), utilizing the Colorado State Highway Patrol and the Colorado Division of Disaster Emergency Services' (DODES) communications networks, is utilized to contact the various law enforcement agencies and county emergency preparedness offices. These agencies in turn provide a "fanout" to secondary points of contact including hospitals, schools, etc. Public announcements are made over the National Weather Service designated VHF-FM radio frequencies, known as the National Weather Radio (NWR), and through the news media via the Automation of Field Operations and Services (AFOS) national weather wire. In the Denver metropolitan area, the Metropolitan Emergency Telephone System (METS) is utilized.

It is important to comprehend inherent limitations of the satellite monitoring system relative to its utilization as a warning system. There are no absolute safeguards against false alarms. Sensor malfunctions are an obvious cause for such false alarms. However, the computer can be programmed to ignore data values that are not plausible. For example, stage values greater than 10 to 15 feet are not physically possible at most stream gaging stations. In the event of a flash flood in a narrow, confined canyon, the remote data collection hardware would be washed away. This is especially the case for a station operating downstream of a failed dam. Ice jams on a river can cause the upstream stage to increase and consequently provide invalid discharge conversions. There is always a time lapse from the time a hydrologic event occurs to when the system identifies that it has occurred and when a random (emergency) transmission is sent. If an event occurs at 1410 hours, the system is not aware of the condition until 1415 hours since the DCP is programmed to activate at even 15-minute intervals to record a data measurement. The DCP then computes a transmit interval utilizing a random number generator. This interval is between 2 and 10 minutes. If a 6-minute interval is utilized, the random transmission will be made at 1421 hours. The elapsed time from event occurrence to transmission of data is 13 minutes. Scenarios could be given which would give a minimum elapse time of two minutes or a maximum elapse time of 24 minutes. In addition, a random transmission occurring on channel 118W has approximately a 20% chance (with current channel load levels) of not being received due to interference with another random transmission being sent at the same time.

F. Future Applications

Any data that can be collected remotely can be monitored by the satellite-linked monitoring system. Future applications, based primarily on current sensor capabilities, are likely to be in the areas of runoff forecasting, water quality monitoring, and in irrigation planning. Runoff forecasting will require the addition of sensor configurations capable of monitoring liquid and frozen precipitation, air temperature, solar radiation, and soil moisture. Water quality monitoring covers an extremely wide spectrum but would likely consist of a sensor configuration capable of monitoring conductivity (total dissolved solids), water temperature, dissolved oxygen, and turbidity. Irrigation planning would require a sensor configuration capable of monitoring humidity, precipitation, soil moisture, soil temperature, air temperature, wind velocity and azimuth, evaporation rates, and solar radiation.

TABLE 2

SATELLITE MONITORING SYSTEM
FLOOD WARNING NETWORK

		ALERT LEVEL (FEET)	DISCHARGE (CFS)
Division 1 - South Platte River Basin			
1.	Bear Creek at Morrison	5.50	345
2.	Clear Creek at Golden	4.00	345
3.	Boulder Creek near Orodell	3.50	590
4.	St. Vrain Creek at Lyons	5.60	1,610
5.	North Fork Big Thompson near Drake	4.60	172
6.	Cache La Poudre at Canyon Mouth near Fort Collins	4.50	2,000
7.	South Platte River at Denver	6.00	3,930
8.	South Platte River at Henderson	9.00	4,450
9.	South Platte River near Kersey	7.00	6,560
10.	South Platte River near Weldona	7.00	4,200
11.	South Platte River near Balzac (Channel-South)	7.00	2,230
12.	South Platte River near Julesburg (Channel-Right)	7.00	4,280
13.	Cache La Poudre at Greeley	7.00	2,500
14.	Big Thompson River at Mouth of Canyon	5.00	2,400
Division 2 - Arkansas River Basin			
1.	Arkansas River near Wellesville	7.90	5,000
2.	Fountain Creek near Pinon	6.53	5,020
3.	Arkansas River near Avondale	5.00	5,000
4.	Arkansas River below Catlin Dam	7.70	10,000
5.	Purgatoire River near Thatcher	11.30	10,040
6.	Purgatoire River at Las Animas	8.00	2,910
Division 3 - Rio Grande Basin			
1.	Alamosa Creek above Terrace Reservoir	3.50	1,480
2.	Conejos River below Platoro Reservoir	3.75	1,085
3.	Conejos River near Mogote	5.25	2,970
4.	La Jara Creek near Capulin	4.05	211
5.	Los Pinos River near Ortiz	6.25	1,840
6.	Rio Grande near Del Norte	5.10	7,060
7.	Rio Grande at Thirty-Mile Bridge	4.70	2,700
8.	South Fork Rio Grande at South Fork	6.60	3,280
9.	Saguache Creek near Saguache	4.50	540
10.	San Antonio River at Ortiz	5.00	1,000
11.	Rio Grande at Alamosa	8.00	3,000
12.	Conejos River near La Sauses (North Channel)	6.00	1,550
13.	Rio Grande near Monte Vista	7.50	5,000

	ALERT LEVEL (FEET)	DISCHARGE (CFS)
Division 4 - Gunnison River Basin		
1. Cimarron River near Cimarron	5.40	1,050
2. East River at Almont	7.00	3,000
3. Gunnison River at Delta	11.30	18,500
4. Gunnison River near Grand Junction	12.85	20,540
5. Gunnison River near Gunnison	5.00	5,760
6. Kannah Creek near Whitewater	2.50	660
7. Leroux Creek near Lazear	4.50	910
8. Muddy Creek above Paonia Reservoir	7.90	2,680
9. Muddy Creek below Paonia Reservoir	7.20	2,580
10. North Fork Gunnison River near Somerset	7.25	7,000
11. Surface Creek at Cedaredge	3.20	590
12. San Miguel River at Naturita	7.00	4,600
13. San Miguel River near Placerville	6.00	
14. Smith Fork near Crawford	8.00	1,140
15. Surface Creek near Cedaredge	3.40	630
16. Taylor River at Almont	4.25	2,015
17. Uncompahgre River at Colona	5.00	2,970
18. Uncompahgre River near Ridgway	4.95	1,550
19. Dallas Creek near Ridgway	5.20	540
Division 5 - Colorado River Basin		
1. Willow Creek below Willow Creek Reservoir	5.30	1,260
2. Colorado River at Hot Sulphur Springs	4.65	4,200
3. Williams Fork below Williams Fork Reservoir	5.90	1,950
4. Blue River below Dillon	3.80	1,840
5. Blue River below Green Mountain Reservoir	9.10	2,820
6. Eagle River below Gypsum	8.80	5,850
7. Colorado River near Dotsero	11.70	16,120
8. Fryingpan River near Ruedi	3.70	1,240
9. Fryingpan River near Thomasville	4.20	1,290
10. Rifle Gap below Rifle Gap Reservoir	2.60	90
11. Colorado River near Kremmling	10.00	3,800
Division 6 - Green River Basin		
1. Elk River at Clark	5.90	4,500
2. Yampa River near Oak Creek	4.60	1,500
3. Yampa River at Steamboat Springs	6.00	4,500
4. Yampa River near Maybell	7.00	7,000
5. White River near Meeker	3.90	4,150

	ALERT LEVEL (FEET)	DISCHARGE (CFS)
Division 7 - Dolores & San Juan River Basins		
1. Rio Blanco below Blanco Diversion Dam	4.37	1,000
2. Navajo River below Oso Diversion Dam	4.80	1,200
3. Dolores River at Dolores	6.40	4,050
4. Lost Canyon Creek near Dolores	6.10	500
5. La Plata River at Hesperus	3.88	800
6. La Plata River at Colorado-New Mexico Stateline	3.60	800
7. Mancos River near Mancos	4.00	900
8. Florida River above Lemon Reservoir	3.90	1,000
9. Florida River below Lemon Reservoir	5.00	970
10. San Juan River at Pagosa Springs	8.00	7,620
11. Animas River at Durango	6.50	6,120

III. OPERATING BUDGET

A. FY 89-90 Operating Costs

The actual operating cost of the satellite-linked monitoring system for FY 89-90 was $209,613. The projected budget was $228,124. Available funds amounted to $222,013. A detailed breakdown of expenditures is given in Table 3. Spending was held down to adjust for uncertain year-end revenue receipts and to attempt to build-up a fund reserve. A summary of the major spending variances is as follows:

UNDER VARIANCES

	ITEM	UNDER EXPENDITURES
FIXED EXPENSES		
II-D.	Scheduled Maintenance	$ 7,800
	This basically involves preventive maintenance and calibration of remote data collection hardware and sensors.	
F-I.	Personnel Costs	$ 5,636
	A full-time summer intern was not employed.	
III.	Indirect Cost Assessment	$ 4,000
	The Department of Natural Resources applies an assessment against cash funds to cover administrative overhead.	
VARIABLE EXPENSES		
I-A.	Travel and Per Diem	$ 1,397
	Out-of-state travel and travel related to training were reduced.	

OVER VARIANCES

ITEM	OVER EXPENDITURES
VARIABLE EXPENSES	
II-A Hardware Maintenance Contracts	$ 1,337
Increased costs and increased coverage resulted in an over expenditure.	

It is necessary to point out that certain indirect costs in operating the system are also realized. These indirect costs are absorbed by the Division of Water Resources. These indirect costs, amounting to an estimated $86,240 per year, are as follows:

1. Manpower to maintain the monitoring network 7 divisions/30 hours per month @ $12 per hour	$30,240
2. Travel costs to maintain remote data collection hardware	$14,000
3. Office space and secretarial support for 2 FTE's $1,000 per month	$12,000
4. Computer room and utilities for VAX 11/750 computer $1,000 per month	$12,000
5. Support from the Information Services Branch $1,000 per month	$12,000
6. Administrative costs $500 per month	$ 6,000

B. FY 90-91 Budget

The projected operating cost of the system for FY 90-91 is $238,124. A detailed breakdown of these costs is given in Table 4.

C. Future Budget Considerations

There are indications that in the future user fees will be charged by NOAA-NESDIS to offset the costs of operating the GOES DCS. These user fees may be assessed as early as 1992, coinciding with the launch of the next generation of GOES spacecraft. There is no estimate as to the possible range of user fees.

The new generation of GOES spacecraft may utilize transmission relay rates of 300 bits per second (bps) over the present rate of 100 bps. This would require modifications to the existing DCP transmitters. If the modification cost were to range from an estimated $200 to $400 per unit, the total cost to modify the 166 units operated by the state of Colorado would amount to $33,200-$66,400.

There is a concern over short-term and long-term hardware replacement costs. On the short term (24 to 48 months), replacement will be primarily due to damaged/vandalized hardware. Current replacement cost for the GOES-linked data collection hardware installed at a single station is approximately $6,000. If 5% of the hardware had to be replaced in a given year, the cost would be $48,000. This exceeds current budgeted amounts by $43,000. On the long-term (48 to 72 months), consideration must be given to blanket replacement of hardware. The effective lifetime of a DCP is expected to be between 6 to 8 years (as per the manufacturer, the Sutron Corporation). DCPs operated by the state of Colorado will reach this in the 1990 to 1992 period. The cost to replace 166 DCPs is currently $581,000.

An additional FTE should be seriously considered to work on the program. The position, System Maintenance Manager, would be responsible for both coordinating and carrying-out the sustained operation and maintenance of the remote data collection network. As the system becomes more integrated into real-time water rights administration, there develops a greater need to maintain the operation of the monitoring network on a continuous and consis- tent basis. Demands on designated Division staff to maintain the remote data collection hardware have become a burden as their primary hydrographic duties have increased dramatically. This position would add an estimated $40,000 to the budget.

TABLE 3

SATELLITE MONITORING SYSTEM
FY 89-90 BUDGET

ITEM	FY 89-90 (projected)	FY 89-90 (actual)
FIXED EXPENSES		
I. PERSONNEL COSTS	$105,316	$ 99,680
II. OPERATING COSTS	$ 83,255	$ 75,896
A. Hardware Maintenance Contracts	$ 22,735	$ 24,072
B. Telecommunications	$ 38,697	$ 38,454
C. Computer Operations	$ 1,827	$ 1,174
D. Scheduled Maintenance	$ 19,996	$ 12,196
III. INDIRECT COST ASSESSMENT	$ 8,429	$ 4,429
	$197,000(87%)	$180,005 (86%)
VARIABLE EXPENSES		
I. OPERATING COSTS	$ 17,575	$ 15,895
A. Travel and Per Diem	$ 7,626	$ 6,229
B. Training	$ 4,060	$ 4,658
C. Hardware Service	$ 2,350	$ 1,735
D. Other Operating Costs	$ 3,539	$ 3,273
II. CAPITAL OUTLAY	$ 13,549	$ 13,713
A. Hardware Replacement	$ 7,049	$ 7,023
B. System Enhancement	$ 6,500	$ 6,690
	$ 31,124 (13%)	$ 29,608 (14%)
TOTALS	$228,124	$209,613

TABLE 4

SATELLITE MONITORING SYSTEM
FY 90-91 BUDGET

ITEM	FY 90-91 (projected)
FIXED EXPENSES	
I. PERSONNEL COSTS	$120,444
II. OPERATING COSTS	$ 80,758
A. Hardware Maintenance Contracts	$ 23,552
B. Telecommunications	$ 39,108
C. Computer Operations	$ 1,800
D. Scheduled Maintenance	$ 16,298
III. INDIRECT COST ASSESSMENT	$ 2,660
	$203,862 (86%)
VARIABLE EXPENSES	
I. OPERATING COSTS	$ 19,890
A. Travel and Per Diem	$ 8,289
B. Training	$ 2,158
C. Hardware Service	$ 1,353
D. Other Operating Costs	$ 8,090
II. CAPITAL OUTLAY	$ 14,372
A. Hardware Replacement	$ 4,806
B. System Enhancement	$ 9,566
	$ 34,262 (14%)
TOTALS	**$238,124**

IV. FUNDING SOURCES

A. FY 89-90 Funding

One hundred thousand dollars ($100,000) was appropriated from the General Fund for the operation of the satellite-linked monitoring system in FY 89-90. A total of $228,124 was approved for total program expenditures. The remaining $128,124 was to be collected from user fees and contributions, pursuant to Section 37-80-111.5(c), C.R.S. (1985 Supplement).

In FY 89-90, fees and contributions amounting to $106,033 were collected as compared to $103,350 in FY 88-89. User fees amounted to $40,884. Contributions amounted to $65,150. The following is a summary of the fees and contributions collected in FY 89-90:

Southeastern Colorado Water Conservancy District	$35,000	c
Arkansas River Compact Commission	8,000	uf
Colorado River Water Conservation District	7,500	c
Southwestern Water Conservation District	7,200	c
Dolores Water Conservancy District	6,500	uf
Colorado-Ute Electric Association	5,400	uf
City of Aurora	4,200	uf
Aspen Consolidated Sanitation District	3,200	uf
Animas-La Plata Water Conservancy District	3,000	c
City of Denver	2,400	uf
City of Thornton	2,400	c
Colorado Division of Wildlife	2,300	uf
Bureau of Reclamation (San Juan Chama Project)	1,800	uf
Bureau of Reclamation (Durango Projects Office)	1,200	uf
Central Colorado Water Conservancy District	1,200	c
City of Westminster	1,200	c
Denver Metropolitan Sewage Disposal District #1	1,200	uf
Farmers Reservoir and Irrigation Company	1,200	c
Lower South Platte Water Conservancy District	1,200	c
Rio Grande Canal Water Users Association	1,200	uf
Rio Grande Reservoir Company	1,200	uf
Urban Drainage & Flood Control District	1,200	uf
Henrylyn Irrigation District	1,000	c
Conejos Water Conservancy District	1,000	c
Santa Maria Reservoir Company	983	uf
Florida Water Conservancy District	600	c
Mancos Water Conservancy District	600	c
City of Durango	600	c
Pine River Irrigation District	600	c
Uncompahgre Valley Water Users Association	600	c
West Divide Water Conservancy District	250	c
Enoctech, Inc.	100	uf
TOTAL	$106,033	

c = contribution
uf = user fee

Total funds available for FY 89-90 were $222,013. A summary of the funding is as follows:

Fund balance remaining from FY 88-89		$ 6,087
General Fund with POTS		$107,962
User Fees/Contributions		$106,033
Interest on Cash Funds		$ 1,931
	TOTAL	$222,013

Actual expenditures for FY 89-90 amounted to $209,613 leaving a fund balance of $12,400. The fund balance is an accumulation of unspent year-end funds going back to FY 85-86. The amount of fees that are collected in any given year varies. Fees are also received throughout the fiscal year rather than at the beginning of the fiscal year. Efforts are maintained so as not to overspend against available funds. In addition, a fund of $25,000 to $35,000 is considered desirable to handle possible emergency expenditures.

B. FY 90-91 Funding

Two hundred thousand dollars ($200,000) was appropriated from the General Fund for the operation of the satellite-linked monitoring system for FY 90-91. A total of $238,124 was approved for FY 90-91 program expenditures. A total of $38,124 in user fees will be required to meet the projected budget. Contributions are expected to cease with the increase in General Fund support. This excludes use of the existing fund balance of $12,400. Fee collections are projected to be adequate in FY 90-91.

C. FY 91-92 Funding

A budget request was submitted to the Joint Budget Committee of the General Assembly to maintain the General Fund appropriation for the operation of the monitoring system in FY 91-92 at $200,000.

D. Future Funding Considerations

The water user community has expressed the opinion that the administration of the state's water resources is a public responsibility. The satellite monitoring system is effectively being utilized in daily water rights administration, hydrologic records development, flood monitoring, water resources accounting, and in the administration of interstate compacts. All of these tasks are carried out for the benefit of the public. The FY 90-91 funding mix is 84% general funding and 16% user fees. This is considered to be workable and balanced.

The satellite monitoring system represents a $1,800,000 investment by the state of Colorado to apply space-age technology to the administration and management of the state's most valuable natural resource. The allocation of General Funds to operate the system will provide all interested users the opportunity to directly utilize the system's capabilities, which is a primary objective of the Office of the State Engineer. Non-Colorado water users, i.e. the state of Kansas, will be provided access only on a user fee basis. Users being provided with special services, i.e. the receiving and processing of data transmissions from privately operated data collection hardware, will still be required to pay for the actual cost of those services.

V. COST-BENEFIT CRITERIA

It is estimated that the Colorado satellite-linked water resources monitoring system provides benefits to the state of Colorado amounting to between $1,337,000 and $1,505,000 per year. These benefits will increase as the system becomes further assimilated into the statewide administration and management of water resources. Benefits will also increase dramatically during periods of water shortages. Since the cost to operate the system in FY 89-90 was $295,853 ($209,613) in direct costs and $86,240 in indirect costs), the net benefit to the state of Colorado is between an estimated $1,041,000 and $1,209,000. If the original capital cost of the system of approximately $1,500,000 is amortized simply over a 7-year period, net benefits realized are between an estimated $826,000 and $994,000 per year.

Direct and indirect benefits are calculated as follows:

1. Approximately $5,300,000 per year is budgeted by the Office of the State Engineer for statewide water rights administration. If the operation of the satellite-linked monitoring system conservatively increases effectiveness by 10%, that equates to a benefit of $530,000 per year. Direct benefits are attained by water commissioners having more time for water administration and reduction in overtime to accomplish ever increasing workloads. Indirect benefits relate to the ability to be more effective in water rights administration. This leads to greater cooperation among water users and fewer legal problems.

   Despite the fact that the number of water rights increased from 102,028 in 1982 to 124,994 in 1988 (increase of 23%), the number of water commissioners decreased from 94 to 93. These statistics indicate that based strictly on the number of water rights, the number of water commissioners should have increased by twenty-three. We must also consider the increased workload due to the growing complexity being incorporated into water rights administration. The monitoring system cannot be expected to replace the need for twenty-three additional water commissioners, but can compliment a moderate increase in water commissioners. If the system can potentially eliminate the need for ten additional water commissioners, savings may be an estimated $350,000 to $400,000 annually. The responsibility of water rights administration is a statutory responsibility given to the State Engineer. The necessary personnel and tools to carry out this responsibility must also be provided.

2. It is calculated that in an average year, between 42,000 and 56,000 acre-feet of water can be saved for use in Colorado through utilization of the system. At a conservative price of $12.00 per acre-foot of water, this amounts to between $504,000 and $672,000 per year. In years of water scarcity, the amount that is actually saved for consumption may vary but the value of the water would naturally be higher.

3. Cost savings in the area of hydrologic records development are calculated to be $69,600 per year.

   a. Automated data processing and data entry
      150 stations/2 hours per month @ $12 per hour — $43,200

   b. Data archiving and retrieval
      $1,000 per month — $12,000

   c. Cost of lost data
      150 stations/8 hours per year @ $12 per hour — $14,400

4. Water resources accounting programs utilizing the system have been set up for the Dolores Project, the Colorado-Big Thompson Project, and the Fryingpan-Arkansas River Project. Savings are estimated to be 40 hours per month @ $12 per hour or $5,760 per year.

5. The benefits attributed to the system from flood warning are calculated to be $175,000 per year. If a real-time flood monitoring network of 50 stations is considered essential, and the operating cost for each station is $3,500 per year, this amounts to $175,000 per year.

6. An estimated $53,400 per year is saved in reduced manpower and travel costs in manually reading stream gages.

   a. Manpower savings
      150 stations/8 hours per month @ $12 per hour — $14,400

   b. Travel savings
      150 stations/1 trip per week
      25 miles per trip @ $0.20 per mile — $39,000

VI. EFFECTS OF LOSS OF FUNDING FOR FY 90-91

The satellite-linked water resources monitoring system, without adequate funding, would not be able to function satisfactorily and would likely be deactivated within eighteen months. The system is an integration of various essential components that cannot function with the loss of any one of those components. This would effectively mean the loss of a $1.5 million investment by the state of Colorado.

The FY 90-91 budget of $238,124 is broken down into two categories; fixed expenses amounting to $203,862, and variable expenses amounting to $34,262. The variable expense items are 14% of the budget and would be the first cuts made. These cuts would mean curtailment of:

1. Long-distance phone access by the water commissioners.
2. Repair of malfunctioning remote data collection hardware.
3. Replacement of damaged, vandalized, or stolen remote data collection hardware.
4. Timely maintenance and calibration of remote data collection hardware.
5. Training for system users relative to data base access and software utilization.
6. Travel to Division offices, system users, and cooperating Federal agencies.

Fixed expense items would be the second area for budget cuts. The effects of these cuts would be as follows:

1. Personnel eliminations

   Two full-time employees would be eliminated from the program, the Program Manager and the System Analyst. The effects of the elimination of the Program Manager position would include the following:

   a. The loss of statewide interagency coordination.
   b. The loss of intraagency coordination.
   c. The loss of coordination with system users.
   d. The loss of coordination in network expansion.
   e. The loss of coordination in system enhancement.
   f. The loss of coordination in system operation and utilization.

   The effects of the elimination of the System Analyst position would be as follows:

   a. The loss of coordination in central computer and Division personal computer utilization.
   b. The loss of coordination in data base management.
   c. The loss of coordination of data base access and software utilization.
   d. The loss of coordination in software development.

2. Elimination of system maintenance contracts.

3. The elimination of telecommunications access to the system.

The resultant cumulative effects on the general operations of the system would be as follows:

1. During the first twelve months, an estimated 20%, or thirty of the remote data collection stations, would be taken off-line due to malfunctioning, damaged, or stolen hardware. There would be a deliberate effort to maintain subnetworks that have received operations and maintenance subsidies (user fees).

2. As a result of the above, the state of Colorado would have thirty transmission slots on GOES revoked by the NOAA-NESDIS due to inactivity.

3. Maintenance of remote data collection hardware would face 2-3 week delays.

4. Data quality would deteriorate.

5. Down-time of the Direct Readout Ground Station and central computer would be in excess of six weeks per year.

6. As the system became less dependable, it would be utilized less and less.

7. Hydrologic records would cease to be developed on the system requiring manual records development.

8. Real-time data would not be available requiring additional staff and travel to manually read remote gages.

VII. SYSTEM USERS

The following is a list of users of the satellite-linked water resources monitoring system:

A. Office of the Colorado State Engineer

1. Division of Water Resources
   a. Division 1, Greeley
   b. Division 2, Pueblo
   c. Division 3, Alamosa
   d. Division 4, Montrose
   e. Division 5, Glenwood Springs
   f. Division 6, Steamboat Springs
   g. Division 7, Durango
   h. Central Office, Denver
2. Water Commissioners

B. Water Conservancy Districts/Irrigation Districts

1. Southeastern Colorado Water Conservancy District
2. Lower South Platte Water Conservancy District
3. Colorado River Water Conservation District
4. Southwestern Water Conservation District
5. Dolores Water Conservancy District
6. Animas-La Plata Water Conservancy District
7. Florida Water Conservancy District
8. Northern Colorado Water Conservancy District
9. Rio Grande Water Conservation District
10. North Sterling Irrigation District
11. Central Colorado Water Conservancy District
12. Henrylyn Irrigation District
13. Mancos Water Conservancy District
14. Pine River Irrigation District
15. Aspen Consolidated Sanitation District

C. Municipalities

1. Denver Board of Water Commissioners
2. Pueblo
3. Colorado Springs
4. Durango
5. Alamosa
6. Westminster
7. Aurora
8. Thornton
9. Metropolitan Denver Sewage Disposal District #1

D. State Agencies

1. Division of Disaster Emergency Services
2. Colorado Water Conservation Board
3. Colorado Water Resources and Power Development Authority
4. Division of Wildlife

5. Department of Health
6. Division of Parks
7. Department of Highways

E. Federal Agencies
   1. Bureau of Reclamation
      a. Loveland
      b. Denver
      c. Grand Junction
      d. Albuquerque
      e. Montrose
   2. USGS - Water Resources Division
      a. Denver
      b. Pueblo
      c. Grand Junction
      d. Meeker
      e. Durango
   3. National Weather Service
      a. Denver
      b. Salt Lake City
      c. Washington, D.C.
   4. Corps of Engineers
      a. Omaha
      b. Albuquerque
   5. Soil Conservation Service
   6. Colorado-Kansas Arkansas River Compact Commission

F. Associations
   1. Rio Grande Water Users Association
   2. Urban Drainage District
   3. Arkansas River Rafters Association
   4. Trout Unlimited

G. Private Entities
   1. Fort Lyon Canal Company
   2. Santa Maria Reservoir Company
   3. Mutual Reservoir and Irrigation Company
   4. Farmers Reservoir and Irrigation Company
   5. Colorado-Ute Electric Association
   6. Rio Grande Reservoir Company

H. WATERTALK
   Users estimated at 500-600.

VIII. UTILITY OF THE SATELLITE-LINKED MONITORING SYSTEM WITHIN THE COLORADO DIVISION OF WATER RESOURCES

A. Division 1, Greeley, Colorado, South Platte River Basin
Alan Berryman, Division Engineer

The satellite-linked monitoring system has become an integral tool in daily water rights administration in Division 1. With increasing complexity in the administration of the South Platte River basin, the system provides the key to effective decision making.

In past years, streamflow data needed for river administration was slow, if not difficult, to acquire because of the remote location of key gaging stations. Administration was inefficient and frustrating to the water commissioner and to downstream water users. With the satellite monitoring system, comprehensive river data are available to the water commissioner allowing him to administer water rights on a timely and accurate basis. This ability allows the water users to adjust more quickly to the changing conditions of the river system and expand the number of water rights able to divert and use water. The system allows the water commissioner to determine the river conditions largely on his own, not having to rely as much on data supplied by water users. This results in closer administration of water rights, potentially benefiting all water users of the area by assuring that the available supply of water is being diverted by the correct water right. Another advantage of the satellite monitoring system is that the water commissioner can release water downstream knowing that the amounts released reflect actual river conditions and won't have to be adjusted at a later date. The efficiency afforded to the water commissioner allows him to attend to more of his other duties which are ever increasing with the growth of the water rights system such as ground water administration.

With the satellite monitoring system data, the water commissioner can immediately evaluate river conditions both upstream and immediately above the senior rights. Subsequently, he can adjust diversions in his own district to satisfy the more senior rights or send a demand (call) to the upstream districts for more water to satisfy those rights early in the day. This is especially critical in administering water exchanges.

The river can be run more efficiently simply as a result of the increased knowledge of the river conditions provided by the satellite monitoring system. The readily available knowledge of river conditions also provides the water commissioner with "evidence" that can be beneficial when interacting with water users that question administrative practices. The system makes it easier for the water commissioners to interact with other district water commissioners in receiving or passing water through his district. The ability to monitor diversions by some of the major irrigation diversions including the Burlington-Wellington Canal, the Union Ditch, the North Sterling Canal, the Lower Latham Ditch, and the Riverside Canal, is essential since the large amounts diverted can have a significant effect on the flow of the South Platte River below Denver.

B. Division 2, Pueblo, Colorado, Arkansas River Basin
Steve Witte, Division Engineer

The satellite monitoring system has become essential for water rights administration throughout Division 2. This includes the administration of direct diversion rights, storage rights, transmountain diversion water, the Arkansas River Winter Water Storage Program, and the Arkansas River Interstate Compact. Division 2 covers a large and diverse geographical area with a number of major senior rights. It is an arid, water thirsty area that typically dries up the Arkansas River at several locations during the late irrigation season.

Division 2 staff use the satellite monitoring system to keep an accounting of transmountain diversions that are delivered to storage, storage by exchange, and routed to ditches in the Lower Arkansas River Valley. The system has been valuable in determining daily diversions in a timely manner for accurate accounting and delivery. An example involves the exchange of Colorado Springs' transmountain diversion water discharged into Fountain Creek for storage in Twin Lakes Reservoir.

The capability to monitor inflows and outflows of reservoirs with accuracy in a timely manner has helped in the administration and accounting of reservoirs in the division. The routing of natural streamflow and reservoir releases to storage or through a reservoir is difficult and takes constant attention to maintain proper discharge and storage. The system also helps in keeping close watch on reservoir releases so that we can determine the section of the river the release is in and prevent any diversion of these releases except by the ditch or ditches calling for the water. The Division Engineer routinely utilizes the system to track reservoir releases from Clear Creek Reservoir, Pueblo Reservoir, and John Martin Reservoir.

Another success of the satellite monitoring system is the real-time monitoring of exchanges of water. These exchanges allow irrigators, through the use of reservoir water, to irrigate when not in "priority" and are also vital for large municipalities such as Colorado Springs and Aurora to move water upstream in the Arkansas River Basin to a point where the water can be diverted to these cities. This use of the satellite monitoring system permits the maximum beneficial use of exchange water, which in both of the above cases, translates into real dollars for the water users.

Division 2 personnel have found the system to be an essential tool in setting the "river call." Flow conditions can vary dramatically in the period of hours rather than days due to diurnal effects of spring runoff, major tributary inflow, flash flooding from summer precipitation events, the effects of major irrigation diversions, and a high volume of imported water (transmountain diversions). The basinwide overview provided by the system on a real-time basis is a valuable tool for both short-term and long-term planning. This allows for maximum efficiency in putting Colorado water to beneficial use in Colorado. The system has been especially effective in setting the "river call" in the lower Arkansas River basin from Pueblo Reservoir to the stateline.

The WATERTALK feature of the satellite monitoring system is a valuable and time saving tool. In addition to its main purpose of allowing public phone access to water flow and storage levels, in Division 2, WATERTALK is also used to publish the current "river call." This aspect of WATERTALK allows water users phone access to the current river call which saves Division 2 personnel time and provides much improved communication to water users which probably prevents some water disputes.

During the 1987 water year, releases were made from the flood pool in John Martin Reservoir from March 24 to July 7, 1987. The Corps of Engineers determined that the safe channel capacity below the reservoir was 3,000 cfs. The monitoring system was used successfully to control releases in order to avoid exceeding channel capacity. The inflow stations above John Martin Reservoir are all incorporated into the system's monitoring network. In addition, the major irrigation diversions are in the network. Similar operating procedures were utilized for Pueblo Reservoir. This capability gives valuable lead time in order to make administrative decisions concerning streamflow routing through the reservoirs relative to standard operating procedures, which in turn affects the operation of the entire basin.

Within the past two years, several temperature sensing instruments and precipitation gages have been installed and are monitored by the satellite system. New precipitation gages, air temperature instruments, snow pillows and pyranometers are to be installed. Data from these instruments is used to warn of flood peaks, monitor snowpack, calculate snowmelt, assist in computing flow records, etc. The system is being used at one site to monitor streamflow velocity.

Cooperation between Division 2 and other agencies, municipalities, and the public has steadily increased the past three years. At numerous streamflow stations, Division 2 shares instruments, shelters, and the hydrologic data collection effort with the U.S. Geological Survey (USGS). Daily streamflow reports are given to the USGS and U.S. Bureau of Reclamation. At several locations, Division 2 and the City of Colorado Springs cooperate in instrument operation and in hydrologic data and collection. The Southeast Colorado Water Conservancy District and some of the Federal agencies continue to observe and use the information provided by the system. Daily satellite monitoring system information is given to some of the southeast Colorado newspapers and radio stations.

The satellite monitoring system is used to collect basic data for use in developing hydrologic records. The data is analyzed to provide streamflow quantities for annual publications and for daily, monthly, and other time periods. Annual maximum and minimum flows, base flows, travel time, and means are but a few of the other hydrographic statistics which can be determined through the system's use. The system is also used to indicate problems at streamflow stations so that records are improved through more timely maintenance and repair.

C. **Division 3, Alamosa, Colorado, Rio Grande Basin**
Steve Vandiver, Division Engineer

Due to the complexity of the administration of the Rio Grande Compact, the San Luis Valley was the first drainage basin in Colorado to receive satellite-linked monitoring sites during the summer of 1984. During the time the system has been in place, the annual runoffs in the Rio Grande Basin have gone from one extreme to the other; therefore, the utilization of satellite-linked monitoring system has also varied considerably. Water years 1985-87 were high runoff years and the satellite system was used extensively to monitor flooding conditions on the Rio Grande and Conejos rivers. Water years 1988-1990 have been low runoff years and have created drought conditions in the basin. Due to the spill of Elephant Butte Reservoir in New Mexico during water years 1985-88, Colorado was exempt from some of the tough constraints imposed by the Rio Grande Compact. Drought conditions forced Division III personnel to return to strict Compact administration during the 1989 and 1990 irrigation seasons. The satellite monitoring system has become an integral part of daily water rights administration, and is a valuable tool to ensure compliance of the interstate compact.

Division 3 currently maintains twenty-three satellite sites. These included sixteen stream gaging stations, four reservoirs, two canals, and one transmountain diversion. Of the twenty-three gaging stations, seventeen are owned by the Colorado Division of Water Resources, four by private irrigation companies and water users, one by the Colorado Division of Wildlife, and one by the United States Bureau of Reclamation.

In addition to these stations, the Trinchera Conservancy District has purchased satellite monitoring equipment for Mountain Home Reservoir near Fort Garland, Colorado. This station will become operational in the fall of 1990. The Conservancy District plans to install additional sites as funds become available. We are also hopeful that funding will be made available for three additional sites on streamflow gaging stations owned by the Division of Water Resources to increase administration efficiency on the San Antonio River, Pinos Creek, and Alamosa Creek.

The main use of the satellite monitoring system in fiscal year 1989-90 was to aid Division personnel in the daily administration of the Rio Grande Compact and decreed water rights in the San Luis Valley.

The Rio Grande Compact requires Colorado to deliver a specific percentage of the annual flows recorded at the upper index gages on the Rio Grande and Conejos rivers to the New Mexico/Colorado stateline. Even though the Conejos is tributary to the Rio Grande, the Compact requires a separate delivery schedule for each river, which adds to the complexity of the administration. The satellite monitoring system enables our staff to monitor the flows and major diversions on a daily basis which helps minimize the amount of overdelivery at the stateline for each river system. The Rio Grande and Conejos systems are also each credited with a portion of the water introduced to the river by the Bureau of Reclamation's Closed Basin Project. The Closed Basin Project deliveries are measured using a twelve-foot concrete Parshall flume which is also tied into the satellite-linked monitoring system. By accurately crediting each river system with flows delivered to the lower index gaging stations, the water users are able to help meet their Compact obligations with Closed Basin Project water which enables them to use more native streamflow for irrigation on the upper reaches of their systems. The station on Platoro Reservoir (Bureau of Reclamation) and the gaging station below Platoro Reservoir (Division of Water Resources) on the Conejos River are used on a daily basis to account for water purchased by the Conejos water users from the Conejos Water Conservancy District.

The satellite monitoring stations have become an integral part of the daily administration of water rights in Division III. Of the eight water districts in Division III, five have installations utilizing the satellite monitoring system. Each morning the water commissioners access data from the computer in Denver to determine how much water is available for delivery to decreed water rights. The availability of this data via personal computers or from WATERTALK has had a profound effect on how our commissioners make daily administrative decisions. The ability to monitor reservoir releases and changing river conditions on a real-time basis results in better management and utilization of the resource.

Once again, the streamflow record development system was utilized extensively for 1989-90 water year records. All of the annual flow records for the sixteen stream gages, Tabor Ditch (transmountain diversion), and the Closed Basin Project Canal were computed by our hydrographic section using the record development system. Eleven of these records are published by the United States Geological Survey. In addition to the annual streamflow records, the record development system is used on a 10-day and monthly basis to monitor compliance with the Rio Grande Compact.

Additional uses for the system have become apparent. For example, we regularly use the system to answer questions about flows at particular gages or reservoir contents. These inquires are from private citizens, federal agencies, and state agencies. Also, historic data stored in Denver can be retrieved and plotted in the Division office to give visual representations of flows. These plots are extremely useful for public meetings, studies, and presentations. Likewise, air temperature probes installed last year on selected sites have been a very useful tool for estimating winter flows at stream gaging stations.

Not a day goes by that the data collected by the satellite monitoring system isn't used. Whether its monitoring river flows, reservoir contents, Compact administration, or the development of hydrographic records the satellite monitoring system has increased productivity and has made data more readily available to the public and to our staff.

D. Division 4, Montrose, Colorado, Gunnison River Basin
Keith Kepler, Division Engineer

The satellite monitoring system has become an extremely useful tool in the daily administration of water rights in Division 4. The water supply for the past irrigation season was extremely short, making 1990 the third dry year in a row. Flows in the various drainages were from 35% to 70% of average. The system provides the real-time data necessary for meaningful water resources accounting, flood monitoring, dam safety and hydrologic records development.

The availability of real-time data provides for administering direct flows to maximize beneficial use. This is critical in Division 4 where the senior water rights are generally downstream of junior water rights. A timely knowledge of the amount of water available allows delivery to junior water rights while assuring senior users of their entitlement. During the runoff season with large diurnal variations in flow, real-time knowledge of the water supply allows serving a maximum number of users.

Real-time data is useful in separating natural flow from reservoir releases at a point in the stream system. Examples of this application exist at the reservoirs on Muddy Creek and the Uncompahgre River. Satellite-linked gaging stations above and below each reservoir monitor inflows, storage and outflows. This information allows the Division Engineer and his staff to regulate the operation of the reservoirs and differentiate reservoir water from direct flow for proper deliveries.

A computerized accounting spreadsheet was implemented this year on the Uncompahgre River. Essentially all inflow into Ridgway Reservoir was categorized as to location and amount. The inflow was then compared with reservoir evaporation and outflow in relation to direct flow and change in storage. The releases were monitored while delivered to decreed points of diversion. The satellite monitoring system is the fundamental tool in accounting procedures and in administration of waters to vested water rights.

Division 4 enjoyed an adequate supply of water for the first three years of operation of the satellite monitoring system; thus, the utilization of the data was minimal. The below average water supply of the past two irrigation seasons has demonstrated the necessity of real-time data allowing the Division Engineer, division staff and water commissioners to be more effective under these conditions. Additional stations monitoring the storage and outflows of Ridgway Reservoir were installed by the Bureau of Reclamation at the request of the Division Engineer. The data is being used by many different entities, government and private, to facilitate planning and for accounting and administration of our water resources. Division 4 has requested satellite equipment for four additional stations to further exploit the utility of this new technology.

A benefit of the satellite monitoring system is in operations cost reduction. Like water, operating funds are in short supply. The real-time data provided by the satellite system has served to hold down man hours and travel costs associated with the administration of a growing and complex set of water rights.

The flood warning capability of the satellite network was used this year. Rainfall caused flash flooding at Delta, Colorado. The early warning capability of the system allowed the Division Engineer to implement relief procedures immediately.

E. Division 5, Glenwood Springs, Colorado, Colorado River Basin
Orlyn Bell, Division Engineer

The utility of the satellite monitoring system in the Colorado River basin is developing at a rapid rate. As the only major river basin in Colorado that has significant amounts of unappropriated water, the system is becoming a powerful planning tool in the area of water resources development. The Colorado Front Range has several transmountain diversions from the Colorado River basin currently operating, with several others on the drawing board. The inevitable resurgence of the oil shale industry will definitely put added demand on the available supplies.

The Colorado River accounting system is a necessary tool for the administration of a mainstem call. It can determine which structures are in and/or out of priority, which owe the river, and what reservoir releases should be made for transmountain diversions, west slope depletions, and augmentation replacement. Key components of the real-time monitoring network include stations that monitor the operations of Green Mountain Reservoir and the Adams Tunnel.

The initial step in this process is the assimilation of data for direct diversions, streamflows, reservoir contents, evaporation, and precipitation. Once the data are entered into a spread sheet, needed diversion or storage adjustments can be made. Some of the data are obtained from the water commissioners on site checks and phone calls. The remainder are obtained from the satellite monitoring system. Although a small percentage of a water commissioner's structures are monitored by the system, those monitored are the majority of the ones most critical to a mainstem call, the largest, and the most likely to change from day to day. The real-time data allow us to track the river and anticipate an upward or downward trend in the river. We can reduce the lag time between a shortage or rise in flow and the corresponding adjustment to the river call. This increases the effectiveness and the efficiency of administration and saves water during critical periods.

Administration of the Blue River involves tracking a paper fill in Green Mountain Reservoir, accounting for transmountain diversions and power interference, out-of-priority replacement from a separate basin, and upstream exchanges. The Blue River shares a water commissioner with the Eagle River and, therefore, is very short-handed. Because of the lack of man-power in this area, the system is valuable not only for its real-time data, but also for the daily, monthly, and annual data stored in the archives.

F. **Division 6, Steamboat Springs, Colorado, White/Yampa River Basin**
Ed Blank, Division Engineer

The administration of water rights in Division 6 is complicated not as much by demand as by limited manpower resources and geographic diversity. As such, the satellite monitoring system allows this office to become increasingly effective with limited staffing. Division 6 personnel use the system to obtain streamflows for daily water right administration purposes. The system improves administrative efficiency and effectiveness by providing real-time data when administrative requirements are critical. In addition, data received from the system is monitored to determine compliance with the Colorado River and Upper Colorado River Compacts.

A total of 506 additional water rights were decreed in Division 6 during FY 1989-90. Although not all of these water rights require administration, administrative demands are increasing. Tracking of storage releases has also added to administration requirements.

No network expansion needs are anticipated at this time. Much of the data in the Division comes from USGS equipped monitoring stations. The data has been extremely valuable. System enhancement is needed only in the area of data recovery. Changes made during the last month appear to have resolved much of the lost data problem.

There appears to be limited use of the monitoring system by the water users. WATERTALK has been used by the water commissioners within the Division and by some water users.

Recovery of real-time data from a long-distance telephone call rather than expending water commissioner travel time and budget provides a monetary benefit in savings that is estimated to be approximately $4,000 per year for the Division.

Although system utilization and benefits may not match that for the Front Range Divisions, the day-to-day operation of Division 6 would be severely hampered if the system were to be lost.

G. Division 7, Durango, Colorado, San Juan and Dolores River Basins Chuck Lile, Division Engineer

The satellite monitoring system is being effectively utilized in Division 7 for water rights administration, reservoir management, water resources accounting, and flood monitoring. The benefits of the system have reached the majority of water users in this division. Our monitoring network is unique in that the stations are located in a stream drainage which consists of separate and individual but large streams which exit the state without becoming a single administrative unit as in the other divisions.

The McPhee Reservoir and Dolores Project administration is not as yet totally functional since the project is not complete, although there are five monitoring stations in operation. The La Plata River Compact is probably our best present use and example since it is being used on a daily basis. The San Juan-Chama Project subnetwork has been effective in monitoring the Bureau of Reclamation operations, and the Lemon Reservoir subnetwork was quite helpful this past season to adjust reservoir releases.

The satellite monitoring system is being utilized for daily water rights administration relative to the Dolores Project. This includes administering allocations to the Montezuma Valley Irrigation District, Mountain Ute Indian Tribe, City of Cortez, and the Dove Creek Canal. The Division Engineer and the manager of the Dolores Water Conservancy District utilize the system in the operation of McPhee Reservoir. A water resources accounting system for the Dolores Project incorporates real-time data from five satellite monitoring stations.

The La Plata River Compact is administered on a daily basis by the Division Engineer and the District 33 water commissioner utilizing the satellite monitoring system. The water commissioner is able to access the system's data base at any time utilizing a portable computer terminal. An upstream station provides streamflow data necessary for advance planning. These conditions are typically dynamic. Early morning flows can be used to predict anticipated daily flows. Diversions are adjusted to allow for maximum daily usage yet meeting compact requirements. Dry conditions experienced in late summer and early fall required precise and prompt delivery of irrigation water to Colorado users. A station at the Colorado-New Mexico stateline gives data on actual deliveries.

Through the use of the satellite monitoring system, the water commissioner can operate the La Plata River on a real-time basis. He can observe the changes occurring at Hesperus and the stateline, and in turn, direct the diversions or curtailment of ditches in Colorado to meet the compact needs. We have found that the real-time data have greatly enhanced our ability to administer the La Plata River and are of the opinion that there has been an increase in the amount of water available to Colorado users through the prompt administration of the stream. This office has realized significant savings in travel and manpower relative to this task.

Three monitoring stations are being operated for the benefit of administering the San Juan-Chama Project and the associated interstate compact. The compact provides for the diversion of up to 1000 cfs into New Mexico. The network includes a monitoring station on the Azotea Tunnel outlet near Chama, New Mexico. The Division Engineer and the San Juan-Chama Project Manager coordinate the operation of the project utilizing real-time data. Both have access to the system's data base.

The satellite monitoring system is being utilized in the daily administration of Lemon Reservoir on the Florida River. Two monitoring stations, one above the reservoir and one below the reservoir, provide real-time data used to account for storage, delineating natural flow from storage releases, and for flood control. Diurnal inflow conditions are flattened through controlled releases.

We were able to utilize the historic data records to make tabular and graphical presentations to public groups showing effects of various water right's demands on the La Plata and Florida Rivers. These data were assembled using the Hydromet applications software.

In June, the plotted flows of the Hesperus and Stateline gages were compared using software developed for the VAX. With this we were able to see significant losses through the system where the stream channel was affecting the flow. We were able to respond by June 19 and 20 to get the Compact back into an administration credit situation.

Based on the predicted runoff from the Colorado Water Supply Outlook of 46,000 A.F. and 160,000 A.F. inflow on the Florida and Pine Rivers, we were able to look at storage capacity and the predicted use to determine that nearly 80% of our storage would be required. This information was then passed along to various ditch companies to alert them of the potential draft of their supplies. Thus warned, they were able to closely monitor their Project users.

System improvements have been made at several locations with the installation of air temperature gages and three precipitation gages. An evaporation pan was installed below Vallecito Reservoir. It has functioned well; however, the data generated is showing marked discrepancies with a nearby check station, and is leading to questions about the reliability of the depth monitoring sensor on the pan, as well as our confidence in evaporation data from any source. It is recommended that we not rely upon evaporation pan data until calibration and accuracy evaluations are made.

Additional stations were added on the system within Division 7 on the La Plata River at Cherry Creek and Long Hollow. They enable us to develop a historical record of return flows on the La Plata River as well as to determine real time stream flow characteristics in situations such as described above.

IX. DEFINITION OF TERMS

NOMENCLATURE FOR STATION NAMES

Station names have been abbreviated to eight characters. The first three characters identify the river basin, the second three characters identify the station location, the last two characters identify the state. Example: The monitoring station, Colorado River near Dotsero, Colorado, is abbreviated COLDOTCO.

DIVISIONS

The Office of the Colorado State Engineer, Division of Water Resources, is divided statutorily into seven divisions for purposes of water rights administration. The seven divisions coincide with the seven major drainage basins in Colorado. Each division has a central office administered by a Division Engineer.

Division 1, Greeley, Colorado, South Platte River Basin
Alan Berryman, Division Engineer

Division 2, Pueblo, Colorado, Arkansas River Basin
Steve Witte, Division Engineer

Division 3, Alamosa, Colorado, Rio Grande Basin
Steven Vandiver, Division Engineer

Division 4, Montrose, Colorado, Gunnison River Basin
Keith Kepler, Acting Division Engineer

Division 5, Glenwood Springs, Colorado, Colorado River Basin
Orlyn Bell, Division Engineer

Division 6, Steamboat Springs, Colorado, White/Yampa River Basin
Ed Blank, Division Engineer

Division 7, Durango, Colorado, Dolores and San Juan River Basins
Daries Lile, Division Engineer

DISTRICTS

The Office of the State Engineer, Division of Water Resources, divided the state of Colorado into eighty districts for purposes of water rights administration on a smaller geographic area than a division. District administration is carried out directly by the designated water commissioner.

RIVER CALL

The "river call refers to a date in the water rights appropriation records where water rights senior to that date may be exercised. Water rights junior to that date may not be exercised. The "river call" reflects the availability of water to satisfy those senior water rights for a district or districts. A call is placed by a water right owner when his or her right is not receiving the water to which they are entitled.

FREE RIVER

A "free river" designation exists when the availability of water exceeds the demand of active water rights.

INDEX STATION

A key gaging station that determines the availability of water for establishing the "river call" or determines the water to be delivered under a compact agreement.

FLOW AND VOLUME CONVERSIONS

Real-time discharge values, as listed in DAYFILES, are instantaneous values in cubic feet per second (cfs).

Daily discharge values, as listed in ARCHIVES, are mean values computed from 96 real-time measurements, and are in cubic feet per second (cfs).

Daily content values, as listed in ARCHIVES, are mean values computed from 96 real-time measurements, and are in acre-feet.

COMMON WATER CONVERSION FACTORS

1 cubic foot per second equals 1 cubic foot of water passing a point in one second of time.

1 acre-foot equals the quantity of water required to cover 1 acre of land 1 foot deep.

VOLUME

1 acre-foot = 325,851 gallons
1 acre foot = 43,560 cubic feet
1 cubic foot = 7.4805 gallons
1 cubic foot/second = 448.8 gallons/minute
1 cubic foot/second = 646,317 gallons/day
1 cubic foot/second = 86,400 cubic feet/day
1 cubic foot/second = 1.9835 acre-feet/day

VOLUME cont.

1 cubic foot/second = 723.96 acre-feet/year
1 million gallons/day = 1.547 cubic feet/second
1 million gallons/day = 3.07 acre-feet/day

TIMES

Times given are local time based on a 24-hour clock.

APPENDIX A

GOES-LINKED REMOTE DATA COLLECTION HARDWARE AND ACCESSORIES

Data Collection Platform	$3,500 - $4,000
Incremental Shaft Encoder	450 - 1,100
Yagi antenna	200 - 250
Antenna cable	50 - 75
12-volt power supply	50 - 175
Power supply cable	25 - 50
Environmental enclosure	200 - 300
Solar panel	250 - 350
Solar panel cable	25 - 50
Programming terminal	750 - 1,250
Grounding package	50 - 75
Float/tape/counterweight	100 - 200

Installation costs (pre-existing structure) range from $200 - $700.

VENDORS

Handar, Inc.
1380 Borregas Avenue
Sunnyvale, CA 94089
Telephone: (408) 734-9640

Sutron, Inc.
2190 Fox Mill Road
Herndon, VA 22071
Telephone: (703) 471-0810

Synergetics, Inc.
P. O. Box E
Boulder, CO 80306-1236
Telephone: (303) 530-2020

APPENDIX B

SENSORS THAT CAN BE UTILIZED IN GOES-LINKED REMOTE DATA COLLECTION

Water Level Measurement Sensors

Type:	Shaft encoder/float
Cost:	$500 - $1,200
Output:	Analog-to-digital
Requirements:	Stilling Well
Advantages:	Accurate to ±.01 foot; easy to install and operate
Limitations:	Requires a stilling well, difficult to operate with ranges greater than 10 feet; ice effected

Type:	Acoustic echo-ranging
Cost:	$650 - $850
Output:	0-5 VDC or 4-20 MA
Requirements:	Stable platform installation
Advantages:	Non-contact sensor; not effected by water conditions
Limitations:	Accuracy ±.05% of range; range 2-14 feet

Type:	Pressure transducer (strain gauge)
Cost:	$700 - $1,500
Output:	0-5 VDC or 4-20 MA; can be converted to BCD to allow for analog-to-digital output
Requirements:	Stable sensor position
Advantages:	No stilling well required; easy to install and operate; wide range available; portable; can position sensor at considerable distance from transmitter
Limitations:	Accuracy ±0.1% of range; power consumption 175 MA from 12 VDC

Precipitation Measurement Sensors

Type:	Tipping bucket
Cost:	$500 - $700
Output:	Analog incremental counter
Requirements:	Unimpeded rain catchment
Advantages:	Easy to install and operate
Limitations:	Liquid precipitation only

Type:	Weighing bucket
Cost:	$1,600 - $2,200
Output:	0-5 VDC or 4-20 MA
Requirements:	Unimpeded rain catchment
Advantages:	Both liquid and frozen precipitation
Limitations:	Scheduled maintenance necessary; measures cumulative precipitation minus evaporation

Water Quality Sensors

Type:	Multipurpose including water temperature, conductivity, pH, redox, and dissolved oxygen
Cost:	$4,500 - $5,000
Output:	Digital
Requirements:	Proper site selection and data analyses
Advantages:	Portable, multipurpose unit
Limitations:	Scheduled maintenance necessary

Temperature Measurement Sensors

Type:	Air
Cost:	$200 - $300
Output:	0-5 VDC or 4-20 MA
Requirements:	Shield from solar radiation effects
Advantages:	Easy to install and operate
Limitations:	None

Type:	Water
Cost:	$200 - $300
Output:	0-5 VDC or 4-20 MA
Requirements:	Stable position in water
Advantages:	Easy to install and operate
Limitations:	Water temperature varies with depth

Snow Depth Measurement Sensors

Type:	Snow pillow
Cost:	$1,500 - $2,000
Output:	0-5 VDC or 4-20 MA
Requirements:	Controlled snowcourse
Advantages:	Delineates current snowpack water equivalence
Limitations:	Installation must be protected from rodents