THE COLORADO SATELLITE-LINKED WATER RESOURCES MONITORING SYSTEM

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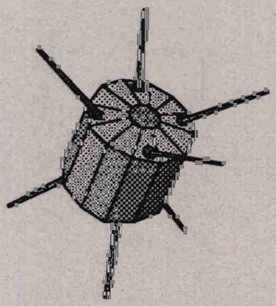

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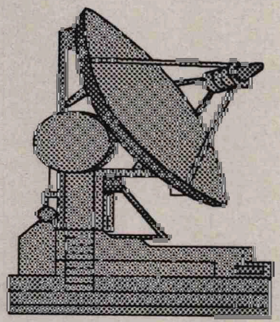

OFFICE OF THE STATE ENGINEER
DIVISION OF WATER RESOURCES

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Governor

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INTRODUCTION

The satellite-linked monitoring system (SMS) provides the Division of Water Resources, other state and federal entities, and the water user community with access to real-time and historic stream-flow data from gaging stations across the State of Colorado. These data and software systems provide for more effective water rights administration, water resource management, computerized hydrologic records development, and flood warning.

The Colorado Water Resources and Power Development Authority provided the system to the State Engineer pursuant to Section 37-95-107(5), C.R.S. (1983), by enactment of Senate Joint Resolution No. 20. A successful two-year pilot project in the Arkansas and Rio Grande River basins demonstrated to the Authority's Board that the system would be an important tool in water resource management. Since the enhancement of water resource 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. On October 4, 1985, the Power Authority turned the system over to the State of Colorado under the jurisdiction of the Office of the State Engineer.

Initially, the State of Colorado operated 150 remote gaging stations linked to the SMS. The Water Resources and Power Development Authority funded an additional expansion of forty stations and an upgrade to the central computer system in 1991. Through that expansion and additional stations funded by various cooperating entities, the Division of Water Resources now operates 210 satellite gaging stations linked to the SMS. Several federal agencies, water conservancy districts, municipalities, and private entities own other stations in Colorado and neighboring states. The Division collects and uses the data from 175 of these stations.

The Colorado satellite-linked water resource 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 the eight top innovative programs instituted by state government in the nation for 1986.

The Satellite Monitoring System provides the primary input data for the South Platte Water Rights Management System (SPWRMS). This is a new project under development by the Division of Water Resources and the Center for Applied Decision Support for Water and Environmental Systems at CU Boulder. This pilot system will allow water commissioners and DWR engineers to more effectively administer and manage the South Platte River. It will be operational in July of 1994.

Funding to begin replacing old Data Collection Platforms, some in their ninth year of operation was obtained from the construction fund of the Colorado Water Conservation Board. A total $113,000 was obtained for FY 93-94. Most of these funds are being used to replace fifteen satellite installations with new electronic equipment. The rest of the funding is to be used to begin a gaging station renovation program. The CWCB recently approved additional $113,000 for FY 94-95 to continue this replacement and renovation program.

I. PROGRAM DESCRIPTION

The Satellite Monitoring System (SMS) allows the Division of Water Resources (DWR) to collect, process, store, and distribute any kind of environmental data transmitted from remote locations. The data set of interest to the Division is the water level at rivers, streams, diversion structures, and reservoirs. The SMS converts these raw water level values into several "products" of use to various "clients". The "products" range from raw data passed on to other computer systems to the official Hydrographic Records of mean daily stream flows. Our "clients" include Division of Water Resources personnel and other water users wanting real-time administrative data, computer systems performing other analyses, and the varied user community of state and federal agencies, municipalities, canal companies, attorneys, and consulting engineers needing access to real-time and historic stream flow data.

A. System Configuration

The Satellite Monitoring System consists of four primary sub-systems: 1) the remote station data measurement, collection, and transmission hardware; 2) the satellite communication links and transmission receive hardware; 3) the computer hardware and software systems; and 4) the computer communication hardware and software

The remote equipment at remote stream, diversion, or reservoir gaging stations includes the on-site sensors, the Data Collection Platform (DCP)and radio transmitter electronics, the power supply, and the radio antenna. 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. Often a temperature sensor and other meteorological sensors are also present. The DCP is a programmable device that collects, processes, and stores data from up to 16 sensors. It also controls the timing of the radio transmissions. Most sites are powered by 12 volt batteries re-charged by solar panels. If available, 120 volt AC power converted to 12 volt DC current for some sites. An environmentally secure enclosure protects the equipment from extreme weather and unauthorized access.

The communications link for data transmissions from the DCPs is a Geostationary Orbital Environmental Satellite (GOES). This is a federal satellite operated by the National Oceanic and Atmospheric Administration-National Environmental Satellite, Data, and Information Service (NOAA-NESDIS). A GOES satellite is in an equatorial, geostationary orbit 22,500 miles in space. This orbit allows a continuous line-of-site to be maintained with both remote DCP transmitters and our Direct Readout Ground Station (DRGS). The DRGS receives data directly from the GOES satellite. This satellite transmits back to earth at relatively low power, requiring a large (5 meter) antenna and a sensitive receiver. There are hundreds of different channels used for GOES transmissions. Although the stations owned by the DWR use only two channels for normal and random alarm transmissions, remote stations operated by other agencies have their own channel assignments. We must have a separate demodulator for each channel. Some of our demodulators are computer scheduled to receive data from different channels at different times. Even with the capability to schedule demodulators, we are limited in our ability to receive all data of interest. To solve this problem, NOAA receives all transmissions at a facility at Wallops Island, Virginia then re-transmits the data over one channel to a domestic communications satellite visible from all of North America. This satellite (DOMSAT) broadcasts back to earth with much more power than the GOES system. The more powerful signal allows us to use a much smaller antenna (1.8) meters and much simpler electronics. Since the DOMSAT uses only one channel we can receive data from all remote sites without additional demodulators. There are no charges for these services.

The DCP's collect data measurements at 15-minute, 30-minute, or 60-minute intervals as needed. In most cases they store 8-hours of data and transmit at 4-hour intervals in the standard transmission mode. This provides replicate data in case of a missed transmission. When the DCPs detect that stream flow conditions exceed programmed levels, they transmit random messages, providing real-time alarm warnings.

The main computer is a Digital Equipment Corporation (DEC) VAX 4000-300. This system gathers data from the DRGS electronics and the DOMSAT receive system running on a PC. Real-time software automatically processes, converts, and stores the incoming data. The conversion calculations use the most up-to-date hydrographic shifts, as determined by actual measurements, to reflect changes in the stream channel characteristics. The system processes meteorological 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. To preserve the integrity of the data, we do not edit the original real-time data. A DWR developed system extracts a subset of the original data for editing and hydrologic record development. The DWR 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. Other programs allow users to access data and to control the system. The central computer hardware is located in the Centennial Building at the Office of the State Engineer.

We support several methods of communications access and data dissemination. Using a PC and a modem, users anywhere in the world, with proper authorization can access our system. In 1993 the DWR replaced the older, low speed (1200 and 2400 baud) modems at the main computer with high speed (14,400 baud) modems. This provides our users with a better level of service through much higher data transfer rates. Newly acquired networking technology allows users to connect to the system through Internet, the "Information Superhighway". Although the Division office personnel are still using modems to connect to the system, they will soon have the opportunity to use the Internet for system access. This technology also connects the SMS to the South Platte Water Rights Management System and other independent systems.

The Division operates a system called WATERTALK that lets users retrieve up-to-date stream flow information from key gaging stations throughout the state by using a touch-tone telephone. WATERTALK uses a computer generated voice synthesis device. This system is very popular with both the public and the Division water commissioners. Originally we dedicated 4 telephone lines to this program. Early this year callers to WATERTALK often got a busy signal. To alleviate this situation the Division installed 4 more WATERTALK units and telephone lines.

The last method of data dissemination is the Alarm system. This is another computer voice synthesized device that alerts the Denver office of the National Weather Service to potential flood conditions. Random alarm messages from the DCPs cause software on the main computer to dial the Weather Service. When they answer their telephone the system tells them the station name and the water level. This program was of great assistance during this years high run-off season.

B. System Operations

Throughout 1992 and the first six months of 1993, the Division of Water Resources used the GOES-Central (GOES-7) satellite, located at 112 degrees west longitude. This satellite has operated 3 years longer than its design life. It has little fuel remaining, and NOAA decided to use what fuel does remain to keep it positioned at 112 degrees. They will no longer make the inclination maneuvers that keep the satellite from moving up and down. This means the satellite's orbit will gradually decay and the inclination will continually increase. Eventually our DRGS will not be able to maintain contact with the satellite 24 hours a day, and we will lose data. We also experience radio frequency interference from cellular telephones and other radio devices. This causes intermittent data loses on the DRGS.

Figure 1 shows a schematic diagram of the DOMSAT receive station. With this system, NOAA's main data acquisition station receives all messages from the GOES satellite and then re-transmits them through a domestic communication satellite (DOMSAT). A small (1.8 meter) dish antenna at our office receives data from the DOMSAT satellite. We acquired the hardware to operate this system during this fiscal year with $19,000 from the SMS operating funds. In July of 1993 we completed the installation of our DOMSAT receive station and connected it to our main computer. This overcame the problems with the DRGS and GOES-7. Our data reception is now better than 98%. Figure 2 shows the changes in the data flow pattern with DOMSAT. These changes are transparent to the end-users. GOES-7 and the current receive system will remain in use as a backup.

The launch date for the next GOES satellite was December 1993. It has been rescheduled for April, 1994. Because of the DOMSAT system, this will not adversely affect our operations.

Maintaining data base integrity is an important operations goal. Real-time data are of no value unless the data are accurate. We expend considerable effort to ensure that the remote hardware and sensors remain in calibration. Other entities operate nearly 65% of the stations in the state's monitoring network. They generally are not using the data to make real-time decisions. This difference in the use of data makes our efforts to keep the equipment calibrated more difficult. Those entities more concerned with historic data do not have the sense of immediacy as the DWR with its interest in water administration. Over time, improved communication has alleviated this problem

Typically hydrographers visit stations at two to four week intervals. They make on-site flow measurements and any necessary adjustments to the equipment. The system compares in-coming data to allowable data ranges for each station and flags outside of range data accordingly. The software that calculates mean values and other statistics does not use these flagged values. Each day the computer reports the number of "data quality" flags for each station.

The system diagnostic report helps in monitoring the operation of the remote data collection hardware. This computer generated report tabulates the transmission characteristics and a data base analysis 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. We can detect remote equipment operating problems before they produce fatal errors.

In January 1993, the Division of Water Resources hired a new employee to repair the electronic equipment, primarily Data Collection Platforms and Shaft Encoders belonging to the SMS. The intent is to repair and recalibrate malfunctioning units and also to establish a program of preventative maintenance. From January 1993 through December 1993, the Maintenance Manager has been a full time employee based in the Denver office. The program has proven to be cost effective. Hardware repair activities were as follows:

	FY 92-93
Data Collection Platforms	38
Shaft Encoders	3

Along with improvements to sites such as improved grounding rods, voltage regulators and new batteries, the maintenance program is proving to be well worth the investment.. Without the maintenance program, the minimum total cost to the state (based upon manufacturers minimum charge of $350.00 plus parts per unit) would have been at least $13,000. Lightning hit two sites, but the improved grounding prevented the electronic equipment from being damaged.

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, it is replaced and sent to our repair facility in Denver. If we cannot repair it, it is then returned to the manufacturer for repair.

We are using monies obtained from the Colorado Water Conservation Board's construction fund to renovate gage houses and replace 15 DCPs per year. Many of the DCPs in the field are approaching ten years of use ,and are nearing the end of their useful life. $113,000 was obtained for these purposes in fiscal year 93-94. Another $113,000 was recently approved by the board for fiscal year 94-95. A source of funds for these purposes on an on going basis is still being developed by this office.

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) has 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 paid by the appropriations for the program, a Systems Analyst/Program Manager and a Senior Telecommunications/Electronic Specialist. The Systems Analyst/Program Manager's responsibilities include the coordination of daily operations, network development, system enhancement, control and management of system access by the user community, software modification, and ADP training. The Senior Tele./Elect. Specialist's responsibilities include preventative maintenance and repair of the system hardware.

Essential additional support is provided by other staff of the Division of Water Resources. The SMS is managed by the Chief of the Hydrographic Branch. His responsibilities include overall management of the program, integration of the SMS into the hydrographic program of the DWR, maintaining communications with the user community, interagency/intra-agency coordination, user fee development, budget management and program direction. Working under the Hydrographic Branch Chief is a computer programmer/operator. The responsibilities of this computer operator include operation of the receive site and central computer, data base management, and data backup. Also, part-time support for western slope preventative maintenance and repair is provided by the Division Engineer's Office for Water Division Three. Overall guidance and direction are provided by the State Engineer and the Assistant State Engineer for Technical Services. Systems operation and maintenance support is provided by the hydrographic staffs of each of the seven Division offices.

C. System Software

The HYDROMET software package consists 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 used 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.

2. ARCHIVES computes and stores mean daily values for a given data type for a given station.

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.

4. SCHEMATICS provides for a graphical display of the relative locations of monitoring stations along with the most recent data for each station.

5. 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 210 DCP's and 210 shaft encoders with a replacement cost of $1,260,000. 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 is altering to fit our system and plans to install by the summer of 1993.

DOMSAT Receive Station (DRS)

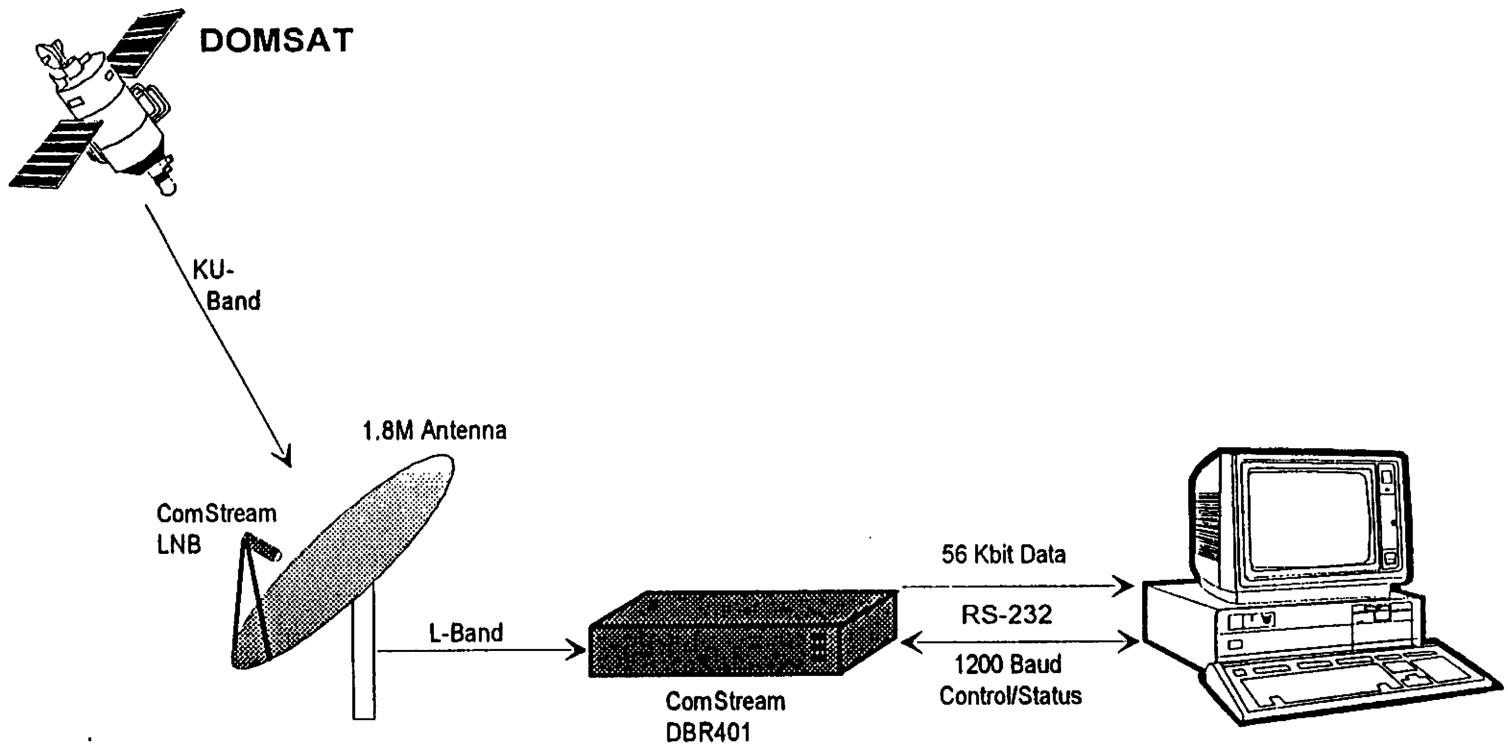

FIGURE 1

NOAA Sponsored Data Collection System (DCS)

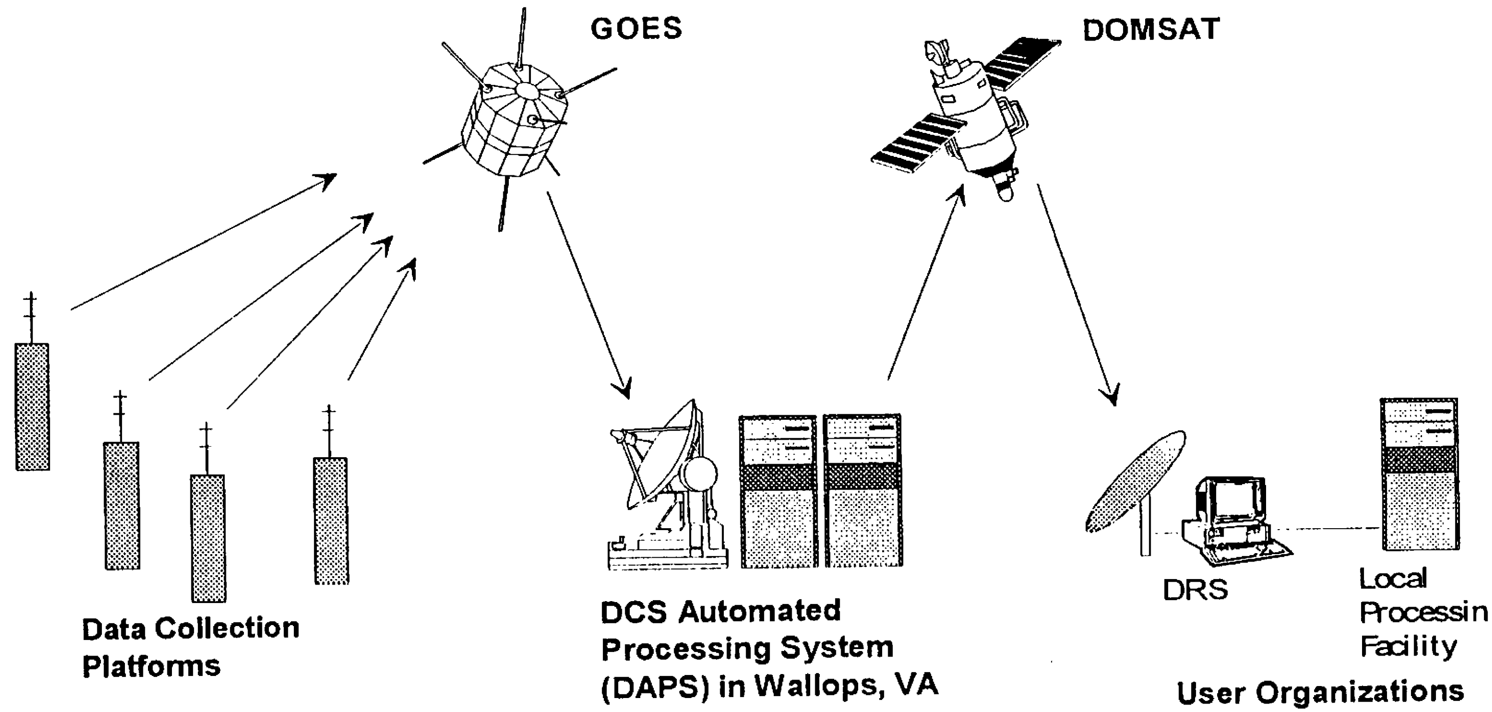

FIGURE 2

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 using portable power packs and solar panels. The hardware can be operated in a wide environmental range from -40 degrees C to +55 degrees C. The DCPs are user programmable in the field. The units can interface 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. 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 can thus monitor all transmissions of interest through either GOES-CENTRAL or GOES-WEST. The system can handle a minimum of 350 DCPs. Data storage capacity is 912 MBytes. Up to 12 users can access the system simultaneously. The system evaluates incoming transmissions and prepares 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 using the keypad of a touch-tone phone. Flow information is automatically updated 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 automatically on a real-time basis. Data conversion including analog-to-digital, stage-to-discharge, and mean daily values computations are performed based on user input. Data are automatically screened and appropriately flagged if they fall outside 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.

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 1994. 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	1881
Cache La Poudre at Mouth of Canyon near Ft. 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

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
It has become evident that there are situations where short-term real-time data collection is necessary.
acre-feet of water. A monitoring station was installed the next day at the reservoir using 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 have been prepackaged to assist in meeting future needs.

Another example occurred this past spring when west slope rivers and streams crested at their highest levels since 1984. The SMS was used to monitor the flow at selected sites. Each morning the staff prepared a report of the hydrograph of the selected streams for the past couple weeks. This report was made available to the Governor's Office, the CWCD, and various county emergency agencies along with the NWS. Thanks to the SMS this report was completed by 9:00 a.m. each day throughout the affected period.

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 water resource accounting programs. Programs in the area of short-term runoff forecasting and automated river call determination are of special interest. Over the next couple years the SMS will become an integral part of the Upper South Platte Management Support System and the Colorado River Decision Support System. These two programs use SMS data, GIS, water rights tabulations, etc. to assist the Division Engineer in making administration decision using computer technology on a real-time basis.

E. Monitoring System Network

The real-time hydrologic data collection network operated by the state of Colorado is comprised of approximately 387stations. 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. 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 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 any time at the discretion of the State Engineer or one of the Division Engineers. The remote data collection hardware is easily removed and installed at a substitute gaging system.

Cooperation is necessary in maintaining this network. One hundred-twelve (112) of the locations 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	44
U.S. Army Corps of Engineers	36
National Weather Service	36
City of Aurora	18
U.S. Bureau of Reclamation	11
National Park Service	4
Denver Water Department	9
Northern Colorado Water Conservancy District	4
Farmers Reservoir and Irrigation Company	1
North Sterling Irrigation District	1
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. The State Engineer's Office is cooperating with these entities in planning network expansion to maximize utility of real-time data collection without redundancy.

Approximately twenty-five 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

Division 1 (South Platte River Basin)

1	SOUTH PLATTE RIVER AT WATERTON, CO.
2	SOUTH PLATTE RIVER NEAR KERSEY, CO
3	SOUTH PLATTE RIVER NEAR WELDONA, CO.
4	BIG THOMPSON RIVER BELOW LAKE ESTES
5	SOUTH PLATTE RIVER AT COOPER BRIDGE, NEAR BALZAC
6	SOUTH PLATTE RIVER AT JULESBURG, CO. LEFT CHANNEL
7	SOUTH PLATTE RIVER AT JULESBURG, CO. RIGHT CHANNEL
8	SAINT VRAIN CREEK AT LYONS, BOULDER COUNTY, COLO
9	ST. VRAIN CREEK AT MOUTH, NEAR PLATTEVILLE, CO
10	CACHE LA POUDRE AT CANYON MOUTH, NEAR FORT COLLINS
11	CACHE LA POUDRE NEAR GREELEY, COLORADO, WELD COUNTY
12	BIG THOMPSON AT MOUTH, NEAR LA SALLE, CO, WELD COUNTY
13	BOULDER CREEK NEAR ORODELL, CO, BOULDER COUNTY
14	BURLINGTON-WELLINGTON CANAL AT HEADGATE, ADAMS COUNTY
15	RIVERSIDE CANAL AT RESERVOIR INLET GAGE, WILD COUNTY
16	NORTH STERLING CANAL AT HEADGATE, MORGAN COUNTY
17	ROBERTS TUNNEL AT EAST PORTAL NEAR GRANT, COUNTY
18	ALVA B. ADAMS TUNNEL AT EAST PORTAL, NEAR ESTES
19	MOFFAT WATER TUNNEL, GILPIN COUNTY, COLORADO
20	LARAMIE POUDRE TUNNEL
21	GRAND RIVER DITCH AT LA POUDRE PASS
22	BIG THOMPSON RIVER ABOVE LAKE ESTES
23	OLYMPUS TUNNEL (ESTES FOOTHILLS CANAL) AT LAKE ESTES
24	BIG THOMPSON RIVER AT MOUTH OF CANYON, NEAR DRAKE
25	HOOSIER PASS TUNNEL AT MONTGOMERY RES., NEAR ALMONT
26	SOUTH PLATTE RIVER AT FORT LUPTON
27	LOWER LATHAM CANAL, NEAR LASALLE, COLORADO
28	SOUTH BOULDER CREEK BELOW GROSS RESERVOIR, BOULDER
29	S. PLATTE RIVER BELOW STRONTIA SPRINGS
30	CHARLES HANSEN FEEDER CANAL WASTEWAY TO BIG THOMPSON
31	METRO SEWER EFFLUENT AT DENVER, COLORADO
32	CHEESMAN RESERVOIR
33	SOUTH SAINT VRAIN CREEK AT WARD
34	NORTH FORK BIG THOMPSON RIVER AT DRAKE, CO.
35	CLEAR CREEK NEAR LAWSON
36	BUTTON ROCK RESERVOIR
37	FORT MORGAN CANAL HEADGATE NR WIGGINS, COLORADO
38	NORTH FORK SOUTH PLATTE RIVER AT BAILEY, COLORADO
39	SAND CREEK AT COLORADO-WYOMING STATE LINE
40	BOREAS PASS DITCH AT BOREAS PASS NR COMO, COLORADO
41	CHERRY CREEK EVAPORATION
42	SOUTH BOULDER CREEK NEAR ELDORADO SPRINGS, COLORADO
43	STERLING NO 1 DITCH NR STERLING COLORADO
44	SOUTH PLATTE RIVER BELOW 11-MILE RES., NEAR LAKE
45	SOUTH PLATTE RIVER BELOW ANTERO RESERVOIR

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

Division 2 (Arkansas River Basin)

1	ARKANSAS RIVER NEAR WELLSVILLE, CO.
2	ARKANSAS RIVER AT PORTLAND, CO.
3	PUEBLO RESERVOIR NEAR PUEBLO, COLORADO
4	ARKANSAS RIVER ABOVE PUEBLO, CO.
5	FOUNTAIN CREEK NEAR PINON, COLORADO
6	ARKANSAS RIVER NEAR AVONDALE, CO.
7	ARKANSAS RIVER NEAR NEPESTA, CO.
8	ARKANSAS RIVER AT CATLIN DAM NEAR FOWLER, CO.
9	ARKANSAS RIVER AT LA JUNTA, CO.
10	ARKANSAS RIVER AT LAS ANIMAS, CO.
11	PURGATOIRE RIVER NEAR THATCHER, COLORADO
12	PURGATOIRE RIVER AT NINEMILE DAM, NEAR HIGBEE, CO
13	PURGATOIRE RIVER NEAR LAS ANIMAS, COLORADO
14	ARKANSAS RIVER BELOW JOHN MARTIN RESERVOIR, CO.
15	LAKE FORK CREEK ABOVE TURQUOISE RESERVOIR, COLORADO
16	JOHN MARTIN RESERVOIR AT CADDOA, COLORADO
17	CHARLES H. BOUSTEAD TUNNEL, COLORADO
18	HOMESTAKE TUNNEL
19	BUSK-IVANHOE TUNNEL, COLORADO
20	TWIN LAKES TUNNEL, COLORADO
21	EWING DITCH, COLORADO
22	WURTZ DITCH NEAR TENNESSEE PASS, CO
23	COLUMBINE DITCH, COLORADO
24	COTTONWOOD CREEK NEAR BUENA VISTA, CO
25	FORT LYON CANAL, COLORADO
26	CATLIN CANAL AT CATLIN DAM, NEAR FOWLER, COLORADO
27	OXFORD FARMERS DITCH COMPANY
28	ROCKY FORD HIGHLINE CANAL AT MILE 4.9 NEAR BOONE
29	COLORADO CANAL AT MILE 3.8, NEAR BOONE, COLORADO
30	HOLBROOK CANAL AT MILE 3.4, NEAR ROCKY FORD, CO
31	PURGATORIE RIVER BELOW TRINIDAD RESERVOIR CO.
32	PURGATORIE RIVER AT MADRID CO.
33	FT. LYON STORAGE CANAL
34	CHEYENNE CREEK NEAR COLORADO,KANSAS STATELINE,CO
35	PUEBLO WATER WORKS DIVERSION
36	LAKE CREEK BELOW TWIN LAKES
37	LAKE FORK CREEK BELOW SUGAR LOAF
38	TIMPAS CREEK NEAR ROCKY FORD CO.
39	AMITY CANAL
40	LAMAR CANAL CO.
41	CROOKED ARROYO NEAR SWINK CO.
42	ARKANSAS RIVER AT GRANADA CO.
43	HORSE CREEK AT HIGHWAY 194
44	HUERFANO RIVER AT BADITO, NEAR WALSENBURG, CO.
45	ARKANSAS RIVER AT CANYON CITY, CO.
46	CUCHARAS RESERVOIR
47	CUCHARAS RIVER BELOW CUCHARAS RESERVOIR
48	CLEAR CREEK DAM
49	ARKANSAS RIVER AT GRANITE, CO.
50	GRAPE CREEK NEAR WESTCLIFFE, CO
51	ARKANSAS RIVER AT SALIDA, CO.
52	CUCHARAS RIVER AT BOYD RANCH NEAR LA VETA, CO.
53	WURTZ EXTENSION
54	ARKANSAS RIVER NEAR ROCKY FORD, COLORADO

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

Division 3 (Rio Grande Basin)

1	RIO GRANDE AT THIRTY MILE BRIDGE
2	RIO GRANDE NEAR DEL NORTE, CO.
3	ALAMOSA CREEK ABOVE TERRACE RESERVOIR,CO CONEJOS
4	CONEJOS RIVER BELOW PLATORO RESERVOIR, CO CONEJOS
5	CONEJOS RIVER NEAR MOGOTE, CO.
6	SAN ANTONIO RIVER AT ORTIZ, CO.
7	LOS PINOS RIVER NEAR ORTIZ, CO.
8	NORTH CHANNEL CONEJOS RIVER NEAR LASAUSES, CO.
9	SOUTH CHANNEL CONEJOS RIVER NEAR LASAUSES, CO.
10	RIO GRANDE NEAR LOBATOS, CO.
11	NORTON DRAIN DITCH NEAR LASAUSES, CO.
12	CONTINENTAL RESERVOIR NEAR CREEDE, CO.
13	RIO GRANDE CANAL NEAR DEL NORTE, CO.
14	RIO GRANDE RIVER ABOVE THE MOUTH OF TRINCHERA CR
15	SAGUACHE CREEK NEAR SAGUACHE, CO.
16	LAJARA CREEK AT GALLEGOS RANCH NEAR CAPULIN, CO.
17	SOUTH FORK RIO GRANDE RIVER AT SOUTH FORK
18	NORTH CLEAR CREEK BELOW CONTINENTAL RESERVOIR,CO
19	CLOSED BASIN PROJECT CANAL NEAR ALAMOSA, CO
20	TERRACE RESERVOIR IN CONEJOS COUNTY, COLORADO
21	DIVISION 3 TEST CHANNEL
22	TABOR DITCH AT SPRING CREEK PASS,CO
23	MOUNTAIN HOME RESERVOIR IN COSTILLA COUNTY,COLORADO
24	RIO GRANDE RESERVOIR NEAR CREEDE,CO
25	PINOS CREEK NEAR DEL NORTE, CO
26	SAN ANTONIO RIVER NEAR MANASSA, CO
27	ALAMOSA CREEK BELOW TERRACE RESERVOIR, CO.
28	SANGRE DE CRISTO CREEK NEAR FORT GARLAND, CO.
29	RIO GRANDE AT MONTE VISTA, CO
30	BEAVER RESERVOIR
31	TRINCHERA CREEK AB. TURNER'S RANCH CO
32	RIO GRANDE RIVER AT ALAMOSA, COLORADO
33	UTE CREEK NEAR FORT GARLAND CO
34	SAND CREEK AT GREAT SAND DUNES NAT. MON.
35	RIO GRANDE RIVER AT COUNTY LINE, CO.

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

Division 4 (Gunnison River Basin)

1	SURFACE CREEK NEAR CEDAREDGE,CO DELTA COUNTY
2	GUNNISON RIVER BELOW E. PORTAL GUNNISON TUNNEL
3	SURFACE CREEK AT CEDAREDGE, COLORADO, DELTA COUNTY
4	MUDDY CREEK ABOVE PAONIA RESERVOIR, CO - GUNNISON
5	MUDDY CREEK BELOW PAONIA RESERVOIR, CO - GUNNISON
6	CIMARRON RIVER NEAR CIMARRON, CO - GUNNISON COUNTY
7	SOUTH CANAL NR MONTROSE, CO - MONTROSE COUNTY
8	REDLANDS CANAL NR GRAND JUNCTION, CO
9	DALLAS CREEK NEAR RIDGWAY,CO - OURAY COUNTY
10	UNCOMPAHGRE R. nr RIDGWAY, CO - OURAY COUNTY
11	UNCOMPAHGRE RIVER NR OLATHE, CO
12	KANNAH CK AT JUNIATA ENLARGED DIVERSION

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

Division 5 (Colorado River Basin)

1	BLUE RIVER BELOW DILLON, CO SUMMIT COUNTY
2	DILLON RESERVOIR SUMMIT COUNTY
3	BLUE RIVER BELOW GREEN MOUNTAIN RESERVOIR, CO
4	GREEN MOUNTAIN RESERVOIR SUMMIT COUNTY
5	WILLIAMS FORK BELOW WILLIAMS FORK RES. ELEVATION
6	COLORADO RIVER AT HOT SULPHUR SPRINGS, CO GRAND
7	EAGLE RIVER BELOW GYPSUM, CO EAGLE COUNTY
8	FRYINGPAN RIVER NEAR RUEDI, CO EAGLE COUNTY
9	COLORADO RIVER NEAR DOTSERO, CO EAGLE COUNTY
10	COLORADO RIVER NEAR GRANBY,CO GRAND COUNTY
11	GRANBY RESERVOIR
12	WILLOW CREEK RESERVOIR GRAND COUNTY CO
13	SHADOW MOUNTAIN RESERVOIR GRAND COUNTY CO
14	WILLOW CREEK PUMP CANAL GRAND COUNTY CO
15	GOVERNMENT HIGHLINE CANAL
16	GRAND VALLEY CANAL
17	PLATEAU CREEK NEAR CAMEO COLORADO
18	RIFLE GAP RESERVOIR
19	GRASS VALLEY CANAL
20	FRYINGPAN RIVER NEAR THOMASVILLE, COLORADO
21	WILLOW CREEK BELOW WILLOW CREEK RESERVOIR
22	ROARING FORK RIVER BELOW MAROON CREEK NEAR ASPEN

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

Division 6 (White/Yampa River Basins)

1	ILLINOIS RIVER NEAR RAND, COLORADO
2	YAMCOLA RESERVIOR ELEVATION ABOVE YAMPA, COLORADO
3	YAMPA RIVER ABOVE STAGECOACH RESERVIOR
4	ELK RIVER NEAR MILNER, COLORADO
5	YAMPA RIVER NEAR CRAIG, COLORADO
6	MICHIGAN RIVER NEAR GOULD, COLORADO
7	LITTLE SNAKE RIVER NEAR SLATER, CO. ROUTT COUNTY
8	NORTH PLATTE RIVER NEAR NORTHGATE, COLORADO

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

Division 7 (Dolores and San Juan River Basins)

1	DOLORES RIVER AT DOLORES,CO MONTEZUMA COUNTY
2	LOST CANYON CREEK DOLORES CO. MONTEZUMA COUNTY
3	NAVAJO RIVER BELOW OSO DIVERSION DAM NEAR CHROMO
4	RIO BLANCO BELOW BLANCO DIVERSION DAM NEAR PAGOSA
5	LA PLATA RIVER AT HESPERUS, CO LA PLATA COUNTY
6	LA PLATA RIVER AT THE COLORADO/NEW MEXICO LINE
7	HERMOSA CREEK NEAR HERMOSA, CO
8	PINE RIVER BELOW VALLECITO RESERVOIR NEAR BAYFIELD
9	DOLORES TUNNEL OUTLET NEAR DOLORES,CO.
10	LONE PINE CANAL AT GREAT CUT DIKE NEAR DOLORES,CO.
11	AZOTEA OUTLET TUNNEL NEAR CHAMA,NEW MEXICO
12	MANCOS RIVER NEAR MANCOS,COLORADO
13	DOLORES RIVER BELOW MCPHEE RESERVOIR,CO.
14	FLORIDA RIVER BELOW LEMON RESERVOIR,CO.
15	FLORIDA RIVER ABOVE LEMON RESERVOIR NEAR DURANGO
16	LA PLATA AND CHERRY CREEK DITCH NEAR HESPERUS,CO
17	VALLECTIO CREEK NEAR BAYFIELD, CO
18	LONG HOLLOW AT THE MOUTH NEAR RED MESA, CO.
19	CHERRY CREEK AT THE MOUTH NEAR RED MESA, CO.
20	CASCADE CANAL ABOVE ELECTRA LAKE
21	NAVAJO RIVER AT BANDED PEAKS RANCH NEAR CHROMO,C
22	ENTERPRISE DITCH NEAR THE COLORADO-NEW MEXICO ST
23	U LATERAL CANAL BELOW GREAT CUT DIKE NEAR DOLORE
24	PIONEER DITCH AT THE COLORADO-NEW MEXICO STATELINE
25	HAY GULCH ABOVE RED MESA WARD RESERVOIR

Stations Operated by Other Entities
and
Monitored by the Division of Water Resources

Division 1 (South Platte River Basin)

1	TARRYALL CREEK AT BORDEN DITCH
2	PLUM CREEK NR LOUVIERS, COLORADO
3	SOUTH PLATTE RIVER AT UNION ST. BRIDGE AT ENGLEW
4	NORTH FORK OF SAINT VRAIN CREEK, NEAR ALLENSPARK
5	FOUR MILE CREEK NEAR HARTSEL, CO
6	SOUTH PLATTE RIVER ABOVE SPINNEY RESERVOIR
7	TROUT CREEK AT CONFLUENCE
8	OHLER GULCH NEAR JEFFERSON, COLORADO
9	JEFFERSON CREEK NEAR JEFFERSON
10	MICHIGAN CREEK ABOVE JEFFERSON, COLORADO
11	TARRYALL CREEK AT US 285 NR COMO, COLORADO
12	MIDDLE FORK AT PRINCE
13	MIDDLE FORK SANTA MARIA, CO
14	FOUR MILE AT HIGH CREEK
15	SOUTH FORK PLATTE ABOVE ANTERO
16	DIXON FLUME ON HOLLTHUSEN GULCH
17	FRENCH CREEK ABOVE CONFLUENCE WITH MICHIGAN CREE
18	JEFFERSON CREEK BELOW SYNDER CREEK
19	ROCK CREEK ABOVE CONFLUENCE WITH TARRYALL CREEK
20	SCHATTINGER FLUME ABOVE CONFLUENCE WITH MICHIGAN
21	SPRING BRANCH ABOVE CONFLUENCE WITH MID FORK S.
22	TROUT CREEK NEAR GARO

Stations Operated by Other Entities
and
Monitored by the Division of Water Resources

Division 2 (Arkansas River Basin)

1	PURGATOIRE RIVER AT ROCK CROSSING NEAR TIMPAS, C
2	ARKANSAS RIVER NEAR PARKDALE, CO
3	MONUMENT CREEK AT PIKEVIEW
4	FRONTIER DITCH, KANSAS
5	ARKANSAS RIVER NEAR COOLIDGE,KANSAS
6	APISHAPA RIVER NEAR FOWLER, CO.
7	FOUR MILE CREEK NEAR CANON CITY, CO.
8	ARKANSAS RIVER NEAR NATHROP, CO.
9	HUERFANO RIVER NEAR BOONE, CO.
10	BEAVER CREEK ABOVE UPPER BEAVER CEMETERY, NEAR P
11	BEAVER CREEK ABOVE HIGHWAY 115, NEAR PENROSE, CO
12	TELLER RESERVOIR NEAR STONE CITY, CO.
13	ARKANSAS RIVER AT LAMAR, CO.
14	ST. CHARLES R. AT VINELAND, CO
15	ARKANSAS RIVER AT BUENA VISTA, CO.
16	LEADVILLE 2SW, CO
17	ROCKY FORD DITCH NEAR MANZANOLA

Stations Operated by Other Entities
and
Monitored by the Division of Water Resources

Division 3 (Rio Grande Basin)

1	RIO GRANDE NEAR WAGON WHEEL GAP, CO.
2	RIO GRANDE RESERVIOR WEATHER STATION
3	PLATORO RESERVOIR
4	HERON RESERVOIR ON WILLOW CREEK
5	EL VADO RESERVOIR, NM.
6	RIO GRANDE FLOODWAY AT SAN ACACIA
7	SAN MARCIAL CONVEYANCE CHANNEL ON RIO GRANDE, NM
8	SAN MARCIAL FLOODWAY ON RIO GRANDE, NM
9	RIO GRANDE BELOW CABALLO RESERVOIR, NEW MEXICO
10	RIO GRANDE BELOW ELEPHANT BUTTE RESERVOIR, NM
11	RIO CHAMA NEAR LA PUENTA, NM.
12	LOWER WILLOW CREEK ABOVE HERON, NM.
13	RIO CHAMA BELOW EL VADO, N. MEXICO

Stations Operated by Other Entities
and
Monitored by the Division of Water Resources

Division 4 (Gunnison River Basin)

1	PAONIA RESERVOIR NR BARDINE, CO
2	SILVERJACK RESERVOIR NR CIMARRON, CO
3	UNCOMPAHGRE RIVER AT COLONA, COLORADO, MONTROSE
4	RIDGWAY RESERVOIR, OURAY COUNTY
5	UNCOMPAHGRE RIVER BELOW RIDGWAY RESERVOIR
6	TAYLOR RIVER AT TAYLOR PARK RESERVOIR (INFLOW)
7	BLUE MESA RESERVOIR, GUNNISON COUNTY, COLO.
8	TAYLOR PARK RESERVOIR, GUNNISON COUNTY, COLO
9	TAYLOR RIVER AT ALMONT, CO
10	N.F. GUNNISON R. nr. SOMERSET, CO
11	GUNNISON RIVER AT DELTA, COLORADO, DELTA COUNTY
12	GUNNISON R. nr. GRAND JUNCTION, CO
13	DOLORES RIVER NEAR BEDROCK, CO - MONTROSE COUNTY
14	EAST RIVER AT ALMONT, CO
15	SAN MIGUEL RIVER NR. PLACERVILLE, CO
16	GUNNISON RIVER NEAR GUNNISON, COLORADO, GUNNISON
17	OURAY, CO (CLIMATOLOGICAL)
18	CRESTED BUTTE, CO (CLIMATOLOGICAL)
19	PAONIA, CO (CLIMATOLOGICAL)
20	SARGENTS, CO (CLIMATOLOGICAL)

Stations Operated by Other Entities
and
Monitored by the Division of Water Resources

Division 5 (Colorado River Basin)

1	COLORADO RIVER NEAR CAMEO CO
2	COLORADO RIVER NEAR KREMMLING CO
3	PINEY RIVER NEAR STATE BRIDGE COLORADO
4	ROARING FORK RIVER AT GLENWOOD SPRINGS CO
5	MUDDY CREEK NEAR KREMMLING, CO.
6	MUDDY CREEK ABOVE ANTELOPE CREEK
7	COLORADO RIVER NEAR PALISADE
8	RUEDI RESERVOIR NEAR BASALT CO
9	GRAND LAKE, CO (CLIMATOLOGY)
10	DILLON 1 E, CO (CLIMATOLOGY)
11	COLORADO RIVER NEAR COLORADO-UTAH STATE LINE
12	EAGLE RIVER AT RED CLIFF, COLORADO
13	COLORADO RIVER BELOW GLENWOOD SPRINGS CO
14	ROARING FORK RIVER NEAR ASPEN, CO
15	BRECKENRIDGE 5S, CO (CLIMATOLOGY)
16	CRYSTAL RIVER ABOVE AVALANCHE CREEK NEAR REDSTON
17	WINTER PARK, CO (CLIMATOLOGY)
18	MEREDITH, CO (CLIMATOLOGY)

Stations Operated by Other Entities
and
Monitored by the Division of Water Resources

Division 6 (White/Yampa River Basins)

1	YAMPA RIVER AT DEER LODGE PARK
2	YAMPA RIVER BELOW STAGECOACH RESERVOIR
3	WHITE RIVER BELOW BOISE CREEK NEAR RANGLEY
4	YAMPA RIVER AT STEAMBOAT
5	YAMPA RIVER AT MAYBEL,CO.
6	LITTLE SNAKE RIVER NEAR LILLY ,CO
7	GREEN RIVER NEAR JENSEN, UTAH
8	WHITE RIVER NEAR MEEKER, CO
9	LITTLE SNAKE RIVER NEAR DIXON, WY

Stations Operated by Other Entities
and
Monitored by the Division of Water Resources

Division 7 (Dolores and San Juan River Basins)

1 SAN JUAN RIVER AT FARMINGTON, NM.
2 ANIMAS RIVER NEAR CEDAR HILL, NM .
3 ANIMAS RIVER AT SILVERTON, CO.
4 LEMON RESERVOIR NEAR DURANGO, CO.
5 VALLECITO RESERVOIR, CO.
6 ANIMAS RIVER AT DURANGO,COLORADO
7 SAN JUAN RIVER AT PAGOSA SPRINGS, CO.
8 DOLORES RIVER NEAR RICO, CO

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 stream flow requirements. For example, the number of water rights increased by 23% from 1982 to 1988, from 102,028 to 124,994. This increase in the number of water rights has continued through 1992. 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 stream flow for both the recreational and fisheries benefits. The availability of real-time data is essential in ensuring that these minimum stream flows 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 (GOES). 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 b 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 11 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 118 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.

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 Rive 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 nr. Balzac So. Channel	7.00	2,230
12.	So. Platte River nr. Julesburg R. Channel	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 River 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.	Conejos River nr. La Sauses North Channel	6.00	1,550
12.	Rio Grande near Monte Vista	7.50	5,000

DIVISION 4 (Gunnison River Basin)

		ALERT LEVEL (FEET)	DISCHARGE (CFS)
1.	Cimmaron River near Cimmaron	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.	Muddy Creek above Paonia Reservoir	7.90	2,680
7.	Muddy Creek below Paonia Reservoir	7.20	2,580
8.	North Fork Gunnison River near Somerset	7.25	7,000
9.	Surface Creek at Cedaredge	3.20	590
10.	San Miguel River near Placerville	6.00	
11.	Surface Creek near Cedaredge	3.40	630
12.	Taylor River at Almont	4.25	2,015
13.	Uncompahgre River at Colona	5.00	2,970
14.	Uncompahgre River near Ridgway	4.95	1,550
15.	Dallas Creek near Ridgway	5.20	540

DIVISION 5 (Colorado River Basin)

		ALERT LEVEL (FEET)	DISCHARGE (CFS)
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 Res.	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)

		ALERT LEVEL (FEET)	DISCHARGE (CFS)
1.	Yampa River at Steamboat Springs	6.00	4,500
2.	Yampa River near Maybell	7.00	7,000
3.	White River near Meeker	3.90	4,150

DIVISION 7 (Dolores and San Juan River Basins)

		ALERT LEVEL (FEET)	DISCHARGE (CFS)
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 CO/NM State line	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

SATELLITE MONITORING SYSTEM
FY 92-93

		Budget	Actual
I.	Personnel Costs	$ 84,775	$ 83,532
II.	Operating Costs		
	A. Hardware & Software Maint. Contracts	$ 3,317	$ 3,317
	B. Telecommunications	41,114	36,960
	C. Computer Operations	2,500	4,593
	D. Hardware Service	3,500	3,312
	E. Required Maintenance	26,700	28,368
	F. Travel and Per Diem	9,500	6,282
	G. Training	9,750	4,243
	H. Other Operating Costs	2,053	1,651
III.	Indirect Cost Assessment	$ 6,500	$ 6,500
IV.	Capital Outlay		
	A. Hardware Replacement	$ 16,930	$ 25,097
	B. System Enhancement	13,530	22,534
	C. DRS Hardware	25,000	23,154
	Total	**$ 245,169**	**$ 250,043**

Notes:

1. The cost of the maintenance contract on the new VAX 4000-300 computer (installed in July, 1991) is incorporated into the purchase price, providing coverage for five years with a total savings of $75,480 over that period.

2. This amount exceeds the spending authority of $238,669 by $11,374. This was offset by additional appropriations, including POTS of $2630 and Capital Outlay of $5355, which are not added to the spending authority limit. In addition, the Indirect Cost Assessment ($6500) is also not included in the spending authority limit.

SATELLITE MONITORING SYSTEM
FY 93-94 (PROPOSED)

I.	Personnel	$ 104,000	$ 104,000
II.	Operating		$ 101,691
	A. Computer Operation and Maintenance	$ 8,000	
	B. Telecommunications	40,000	
	C. Required Maintenance	27,000	
	D. Travel and Per Diem	12,000	
	E. Training	10,000	
	F. Capital Complex Lease	2,600	
	G. Other	2,091	
III.	Capital Outlay		$ 40,000
	A. Hardware Replacement	$ 15,000	
	B. System Enhancement	25,000	
	Total		$ 245,691

Indirect costs:

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 costs for FY 93-94 are estimated as follows:

1.	Manpower to Maintain the monitoring network 7 Divisions/30 hrs. per mo. @ $14 per hr.	$35,280
2.	Travel costs to maintain remote data collection hardware	$14,000
3.	Office space and secretarial support @ $1,000 per month	$12,000
4.	Computer room and utilities for VAX 4000-300 @ $1,000 per month	$12,000
5.	Administrative costs 1.35 FTE	$59,370
	Total	$132,650

IV. FUNDING SOURCES

A. FY 92-93 FUNDING

One hundred ninety-five thousand three hundred fifty-eight dollars ($195,358) was appropriated from the General Fund for the operation of the satellite-linked monitoring system for FY 92-93. A total of $238,669 was approved for total program expenditures. The remaining $43,311 was to be collected from user fees, pursuant to Section 37-80-111.5 (c), C.R.S. (1985 Supplement).

In FY 92-93, user fees amounting to $57,074.50 were collected as compared to $43,489 collected in FY 91-92 and $45,050 collected in FY 90-91. Interest on cash funds amounted to $1,902. The following is a summary of the fees collected in FY 92-93:

Arkansas River Compact Commission		$8,000
City of Aurora		7,600
Dolores Water Conservancy District		6,500
Tri-State Generation & Trans		3,600
Aspen Consolidated Sanitation District		3,500
Pueblo Board of Water Works		2,400
Denver Water Department		2,400
Southwestern Water Conservancy District		2,400
U.S. Fish & Wildlife Service		2,000
U.S.B.R. San Juan/Chama Project		1,800
Santa Maria Reservoir Company		1,200
City of Thornton		1,200
Farmers Reservoir and Irrigation Company		1,200
Urban Drainage and Flood Control District		1,200
Denver Metro Sewage Disposal District #1		1,200
Central Colorado Water Conservancy District		1,200
Centennial Water & Sanitation District		1,200
Trinchera Irrigation Co.		1,200
Public Service Co.		1,200
Colorado-Ute Electric Association		1,174.50
Rio Grande Canal Water Users Association		700
Other Revenue		4,200
	Total	$57,074.50

Total funds available for FY 92-93 amounted to $256,964. A summary of the funding is as follows:

Fund Balance remaining from FY 90-91		$ 24,803
General Fund Appropriation		$195,358
Users Fees		57,074
Interest on Cash Funds		1,902
Other Appropriations (including POTS)		2,630
	Total	$281,767

Actual expenditures for FY 92-93 amounted to $250,043 leaving a fund balance of $31,724. The fund balance is an accumulation of un-spent year-end funds going back to FY 85-86. The amount of fees 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 made so as to not overspend against available funds.

V. 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
    i. 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. Westminister
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 Dev. 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. Tri-State Generation & Transmission Ass., Inc
6. Rio Grande Reservoir Company
7. Public Service Company

H. WATERTALK
    Users estimated at 1500-3000

VI. 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. The system provides critical flow data that is needed daily to make effective decisions related to the allocation and distribution of water. Engineers, water commissioners, water right holders, and other water users such as rafters and fishermen use information provided by the satellite-linked monitoring system. The readily available flow information is so useful that water commissioners generally feel that the satellite system is the one tool that is most important to their job.

Prior to implementation of the satellite-linked system, stream flow data was much more difficult to obtain and many times required a trip and visual inspection to verify flow at a given location. Especially in remote mountain areas this constituted a major effort in order to obtain the data needed for daily water administration. The satellite-linked system provides comprehensive flow data on a continual basis and allows water administrators and water users to have up-t0-date knowledge of flow conditions at critical locations without having to travel to a remote location to get the data. This time savings is used by water administrators to administer more water rights and allocate water more timely. The quick access to such comprehensive data means that water resources are able to be allocated more efficiently and accurately and that problems can be resolved more quickly. Because demands on the water resources are increasing each day, the satellite system allows water users and administrators a better chance to keep up with those demands.

The information provided by the satellite-linked system improves water administration by allowing more responsive adjustments of diversions under changing flow conditions, by making it easier to monitor flow conditions related to exchanges, by allowing water commissioners to better track releases of reservoir water through the river system, and by providing warning and data regarding flood events. Water commissioners can determine what activities are occurring upstream of them and give them time to react to changing conditions. The division engineer can better coordinate operation between water districts with the information provided by the system. Hydrographers also use the satellite system to accumulate water flow information at key gaging stations for subsequent publication as flow information for each station. This information is particularly valuable in water project planning.

Presently, the Division of Water Resources, in cooperation with many of the metropolitan water users is increasing the utility and access of information provided by the satellite system. The South Platte Water Rights Management System effort will incorporate satellite data into a water information and management tool that will provide satellite system data, flow information for major diversions, and water call information to water administrators and water users. This information will make all water users more aware of river operations and will allow more efficient transfer of data between users and administrators.

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 flow diversion rights, storage rights, transmountain imports, exchanges, reuses, successive used, terms and conditions applicable to changes of water rights, and the Arkansas River Interstate Compact. The system also enhances our ability to efficiently develop hydrographic records and to collect and distribute various types of data.

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 basin wide 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 state line.

The WATERTALK features 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 communicate 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 in turn prevents water disputes.

During periods of high stream flow and high storage in the reservoirs, the satellite monitoring system is used to control releases to avoid exceeding channel capacity. Reservoir inflow stations are in the system's monitoring network, as are major canal diversions. This capability provides valuable lead time so that administrative decisions can be made concerning stream flow routing through reservoirs relative to standard operating procedures. These decisions affect water administration in the entire basin.

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 stream flow 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 from Clear Creek Reservoir, Pueblo Reservoir, and John Martin Reservoir.

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.

Another success of the satellite monitoring system is the realtime 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. An example involves the exchange of Colorado Springs' transmountain return flow water discharged into Fountain Creek for storage in Twin Lakes Reservoir.

Remote, and realtime sensing of streamflow facilitates management of waters subject to the Arkansas River Compact by helping to ensure that the water users below John Martin Reservoir in Colorado and Kansas are supplied with water in accord with their compact entitlements.

The satellite monitoring system is used to collect basic data for use in developing hydrologic records. The data is analyzed to provide stream flow 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 stream flow stations so that records are improved through more timely maintenance and repair.

Within the past several years, temperature sensing instruments and precipitation instruments were installed at some locations, and are monitored by the satellite system. More are to be installed in the future. Data from these and other instruments are used to warn of floods, monitor snowpack, assist in computing flow records, and calculate snow melt. Water quality parameters data, sediment samples, wind speed data, and other information is being collected at some sites.

Within the past year to 18 months, satellite monitoring equipment has been installed by the Colorado Division of Water Resources at these stations:

Cucharas River below Cucharas Reservoir
Huerfano River at Badito

Cooperation between Division 2 and other agencies, municipalities, and the public has steadily increased the past 5-6 years. At numerous stream flow stations, Division 2 shares instruments, shelters, and the hydrologic data collection effort with the U.S. Geological Survey (USGS). Daily stream flow reports are given to the USGS and U.S. Bureau of Reclamation. At several locations, Division 2 and the City of Colorado Springs, City of Aurora, Pueblo Water Works, 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.

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 1988-91 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 3 personnel to return to strict Compact administration during the 1989-91 irrigation seasons. The Rio Grande Compact obligation was met early during the 1991-92 irrigation season due to an above average snow pack on the valley floor. The satellite monitoring system was extensively utilized to administer senior water rights on the lower end of the system while minimizing over delivery to the state line. 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 35 satellite sites. These included 26 stream gaging stations, 6 reservoirs, 2 canals, and one transmountain diversion. Of the 35 satellite stations, 26 are owned by the Colorado Division of Water Resources, 6 by private irrigation companies and water users, 2 by the Colorado Division of Wildlife, and 1 by the Great Sand Dunes National Monument.

The main use of the satellite monitoring system in fiscal year 1992-93 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 state line. 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 over delivery at the state line 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 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 stream flow 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 stream flow record development system was utilized extensively for 1992-93 water year records. All of the annual flow records for the 26 stream gages, Tabor Ditch (transmountain diversion), and the Closed Basin Project Canal were computed by our hydrographic section using the record development system. Fourteen of these records are published by United States Geological Survey. In addition to the annual stream flow 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 inquiries 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 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 it's 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 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, and 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 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.

Currently, Division 4 is participating in developing daily accounting spreadsheets for the Gunnison River in cooperation with the Colorado River Water Conservation District, Colorado Water Conservation Board, U.S. Bureau of Reclamation, Upper Gunnison Water Conservancy District, Uncompahgre Valley Water Users Association, and Tri County Water Conservancy District. One of the anticipated outcomes of this effort will be to better identify real-time data requirements for flows on the Gunnison River in light of need for increased water management and administration resulting from new demands for instream flows, endangered fish flows, reserved water rights, hydro-electric power, sophisticated augmentation and exchange plans, etc.

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 still developing. 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 numerous transmountain diversions from the Colorado River Basin currently operating, with several others on the drawing board. The resurgence of the oil shale industry could 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 gages at the key calling points on the Colorado River.

The initial step in this process is the assimilation of data for direct diversions, stream flow, reservoir contents, evaporation, and precipitation. Once the data are entered into a spread sheet, needed diversion or storage adjustments can be made. 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 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 work force resources and geographic diversity. The increasing number of complex changes to old water rights and many new water rights, has forced us to find more efficient ways of using our limited labor resources. Use of the satellite monitoring system has provided a valuable increase in the efficiency of administration. Division 6 personnel use the system to obtain real-time stream flow data for critical water rights administration. It is also used to monitor compliance with the Colorado River and Upper Colorado River Compacts, to track storage releases from Stagecoach and Steamboat Reservoirs, and to monitor compliance with the Supreme Court Decree in Nebraska v. Wyoming and Colorado.

In cooperation with Colorado Division of Parks and Outdoor Recreation, and U.S. Fish and Wildlife Service, a new station is under construction on Willow Creek below Steamboat Lake to monitor releases for the endangered fish in the lower Yampa River. The stilling basin and shelter are complete, but the DCP and shaft encoder have not arrived. Additional changes in the historic use of water within the Division may require installation of more stations.

WATERTALK is an economical way for water commissioners to obtain information from the system. An estimated $4,000 per year in travel expenses is saved by obtaining real-time data by telephone. WATERTALK access by water and recreational users enable our personnel to spend more time on administrative responsibilities. Although system utilization and benefits may not match that of the Front Range Divisions, our day-t0-day operations would be hindered without the system. Much of the data in the Division is from stations owned and operated by the U.S.G.S. Recent modifications to the system has resolved a lot of lost data problems. Intermittent data loss problems still exist.

Division 6 will soon receive new DCPs and shaft encoders to upgrade our system. Old equipment has been pulled from four stations for a project in Division 5.

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

Ken Beegles, 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 6 monitoring stations in operation. The La Plata River Compact is probably our most extensive present use of the system. The satellite system is being monitored on a daily basis at several sites. 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 6 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 stream flow 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 state line gives data on actual deliveries. Additional stations were added to the Pioneer Ditch at the Colorado-New Mexico state line and to the Enterprize Ditch near the Colorado-New Mexico state line to aid in the administration of the La Plata River compact. The flow at both stations is added to the flow at the La Plata River at the Colorado-New Mexico state line to determine the total flow delivered to New Mexico as required by the compact. Another station was installed on Hay Gulch above Red Mesa Ward Reservoir. The water commissioner utilizes this real time data to determine both direct flow and storage releases from the reservoir in an effort to maximize Colorados' use of its compact entitlement.

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 state line, 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.

Four 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. Currently an upstream gage is being operated at Banded Peaks Ranch on the Navajo River. Both the downstream release to bypass requirements and the tunnel diversions are monitored at a single telemetry site.

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.

System improvements were made in the replacement of several DCP setups with new equipment. Temporary stations were operated to provide flood information on Vallecito Creek and Hermosa Creek. These were removed early in July. The system provided great assistance during floods which occurred on August 25-26. Water talk was utilized by local officials extensively to determine the latest reported flows.

VII. 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, 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
Ken Beegles, 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 continue to divert their water rights. 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

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

one acre foot equals the quantity of water required to cover one acre of land one 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
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.