REMOTE SENSING BY EVENT AND SATELLITE HYDROMET STATIONS PRESENT AND ANTICIPATED UTILIZATION IN WATER SUPPLY AND SNOW MELT FORECASTING

BY

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INTRODUCTION

The Mid-Pacific Region, United States Bureau of Reclamation (USBR), is responsible for the operation of multi-purpose reservoirs in the State of California. There are five major storage facilities which have extensive snow fields in their respective watersheds. These reservoirs are part of the USBR Central Valley Project (CVP). Clair Engle Lake and Shasta Lake are located in the northern portion of the state to provide controlled water yields from the Trinity river and Sacramento river watersheds in the Cascade Siskiyou mountains. Folsom Lake and New Melones Lake are located in the central portion of the state and provide controlled water yields from the American river and Stanislaus river watershed of the central Sierra Nevada. Millerton Lake is located in the southern Sierra Nevada on the San Joaquin river to provide control of the water from the San Joaquin watershed.

The Mid-Pacific Region is a member of the State of California Cooperative Snow Surveys group. The region provides funding and supports fifty seven remote stations. Of these stations fifty six transmit precipitation data, forty nine transmit temperature data, twenty four transmit snow water content data, and one transmitts river stage information. The twenty four remote snow sensing stations are located in or adjacent to the basins above the project reservoirs. There will be three additional stations installed in the Trinity watershed during this coming summer season.

This year the State of California Snow Surveys office is collecting data from ninety three remote snow sensors in the Sierra Nevada and northern mountains. The information from the stations is telemetered to and stored in computers operated by the National Weather Service River Forecast Center (RFC) and California Department of Water Resources Data Exchange Center (CDEC) whose offices are located in the State Resources Building, Sacramento, California. The data can be retrieved by cooperators as needed. Both the actual reports and forecasts are available.

There are two communications techniques used to transmit from the USBR stations. Event reporting sensors are used on a line of sight communication network where remote data can be transmitted with a minimum use of radio repeaters. Satellite communications are used to transmit information from sites located in areas which otherwise might require a number of radio repeaters. The basic consideration for selecting the communication type to be used for a particular station is the terrain surrounding the site.

BACKGROUND

The storms during the winter seasons of 1966-67 and 1968-69 produced unusually deep and extensive snow fields in the Sierra Nevada. It was extremely difficult, sometimes impossible, to conduct the monthly February through April snow surveys. Subsequent studies indicated that the collection of reliable up to date snow pack information could be based upon automatic telemetering of data from selected sites. In the mid sixties data from four sites in the San Joaquin basin had been observed and transmitted to Fresno State College for analysis as part of a USBR weather modification program.

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In 1969, the USBR Central Valley Operations Coordinating Office (CVOCO) became network manager for the four sites. These sites provided, after extensive modification and station improvement, precipitation, temperature, and snow water content information. The radio transmitted data was logged manually by NWS personnel at Fresno then retransmitted to CVOCO and the RFC at Sacramento.

The expansion of the USBR network to the configuration in use at this time was designed to provide information that could be used for both flood and water supply forecasting. The present system includes fifty one event reporting remote stations, five repeaters, three base receivers, and two computers. Of the fifty one, eighteen provide real time reports on precipitation, temperature, and snow water content, twenty four provide reports on precipitation and temperature, eight provide reports on precipitation, and one provides reports on river stage. There are six satellite USBR remote stations reporting through the California Forestry satellite network to the California Data Exchange Center. Three additional USBR satellite stations will become operational by the fall of 1985.

The computers for the event reporting network are installed at the RFC. The software development and responsibility is the product of and a function of the RFC. The RFC provides both the river flows and reservoir inflow projection during the winter storm conditions to CVOCO. Additionally, the RFC furnishes seasonal water supply forecasts relative the the USBR project operations.

The data from the satellite stations is transmitted two times per day and stored in the CDEC computer. The management of this system is a cooperative effort with California Snow Surveys and CDEC personnel. The Snow Surveys personnel furnishes water supply forecasts to CVOCO.

The information used in the USBR project operation can and is retrieved from the RFC and CDEC computers as necessary to made judgments and decisions related to flood situations and water supply needs through standard 300 or 1200 baud phone terminals.

TYPICAL SNOW SENSOR STATION

The typical station outside wilderness areas which measure snow water content consists of a "A" frame building, snow tanks, and precipitation gauge. The building has a 2.4 by 2.4 meter base with the peak of the roof five plus meters above floor level. There are two doors, one standard size at floor level, and a 61 by 61 centimeter door approximately 3.5 meters above the floor level. The upper door provides access when the snow depth exceeds the height of the lower door. In the interior there are two levels, the upper is 2.4 meters above the lower floor. There are equipment shelves on both levels. The snow sensor stilling well and the precipitation gauge stilling well, if installed, are housed inside the building.

The precipitation guage is strapped to the back, usually south, side of the building. The gauge is a 30.5 centimeters outside diameter aluminum pipe seven to eight plus meters in length. The maximum depth of the snow expected determines the length of the missile pipe. The electronics package is located inside the building. The building provides a shelter for both the equipment and the infrequent winter visitor who may be a snow surveyor taking visual manometer readings or a technician providing service.

The wilderness site uses a satellite type station and has no building or precipitation gauge. The electronics package is located in a metal aluminum box buried in the ground. The sensors are for snow water content and temperature. The electronics unit and pressure transducer are housed in the box. There is an above ground pipe, length depends on snow depth expected, upon which an antenna, solar panel, and temperature sensor is mounted. If winter maintenance is needed it is necessary to remove the snow to gain access to the metal box.

SNOW SENSORS

The sensor used to provide snow water content is comprised of four 1.2 by 1.5 meter twenty six gage stainless steel tanks interconnected with 9.5 millimeter outside diameter copper tubing connected to either a stilling well or a pressure transducer. These tanks are installed over a bed of sand and covered to a depth of three to five centimeters with a natural soil and sand mixture. The tanks are filled with 190 liters of fluid which has a 35% methonal and 65% ethylene glycol mixture. This glycometh mixture has a specific gravity of one. When a event reporting electronics package is used a stilling well is installed for liquid level sensing. The pulley driven liquid level sensor has a beaded cable attached to a float at one end and weight at the other end. As the snow accumulation and depletion process occurs the sensor provides an up or down signal to the logic portion of the electonics package. For each 5 millimeter change in snow water content an accumulator value is transmitted automatically to the RFC computer. The computer logs these values and outputs on call the resulting snow water contents at the time of transmissions.

When the satellite system outside the wilderness is installed the USBR stations have a stilling well and shaft encoder to provide snow water content change to the electronics unit. This provides a sensing technique that is considerably more stable than that provided by a pressure transducer. In the wilderness areas our stations will have pressure transducers to sense the snow water content changes. These satellite stations transmit two times per day via satellite to the receiving station which relays data to the CDEC computer. The data is stored and can be output from the computer when it is needed.

TEMPERATURE SENSORS

The temperature sensors are either mounted in a small louvered wood type shelter or installed in a radiation shield device. The sensing probe is usually located some four to seven meters above ground level. During the winter the sensor height above snow level may be as much as seven meters or as little as one meter. The primary use of temperature data is to make a real time determination of the elevation at which rain turns to snow. This is very important when making storm runoff predictions during potential flood situations.

PRECIPITATION GAUGES

The 30.5 centimeter outside diameter alluminum pipe has become an accepted standard for providing precipitation measurements in California. The USBR stations all have Alter type windshields mounted on the pipe. The length of the pipe depends on the maximum depth of snow that is anticipated at a particular site. During a recent winter season the surveyors at the Mammoth Pass station reported snowshoeing to and looking down into a gauge which was over eight meters in length. At this same location in the winter of 1969 the top of the seven plus meter gauge installed at that time was observed to be about 30 centimeters below the snow level.

There are two types of precipitation gauges in use by the region, one type being an overflow into a tipping bucket associated with the event reporting system, and the other type a fluid storage to stilling well associated with the satellite system. Both types are charged with a 60% methonol, 40% ethylene glycol mixture. This glycometh has a specific gravity of 0.93 and snow will dissolve at a low temperature of -40 degrees Celsius (Mayo, 1972). Each summer the gauges are recharged with a fresh mixture, 95 liters for the event type, and 45 liters for the satellite type. When either rain or snow occurs the resulting water will sink and mix with the fluid. This mixture has proven to be a very satisfactory solution to the problems associated with rain and snow water layering and freezing on top of the fluid in a gauge.

The event type gauge uses a thermo-compensator to prevent excessive dumping of the fluid as a result of expansion and contraction associated with thermal changes. The gauges are painted black to provide radiational heating during the winter season.

This heating of the pipe will usually cause the snow which may adhere to the inside of the pipe during storms to melt when the sun is shining. If the snow depth is above the top of fluid level in the pipe, melting will likely be delayed until the spring season. This is one of the accepted phenomena in operating at remote high elevation locations. The catch for the season is still the true catch by that particular gauge.

The event reporting gauge uses a tipping bucket to send a signal to the electronics unit which transmitts the accumulator number stored by the logic unit to the RFC computer. Each tip represents one millimeter of precipitation. The computer logs the values received and upon request will provide the timing of the tips and print out the six hour totals. As mentioned before the satellite information is transmitted two times a day.

EVENT ELECTRONICS PACKAGE

The radio, battery, and logic units are the major components in the electronics package. These components are contained in either a twenty five centimeter diameter by forty centimeter length or a twenty one centimeter diameter by fifty two centimeter length cylindrical open top alluminum can. The top plate has terminals for connecting the sensors and antenna. There is a seal between the top plate and the outer shell of the can. The electronics are all mounted to a frame which is attached to the top plate.

The logic unit counts and accumulates the precipitation and snow events. Whenever and if a down time occurs at the repeater or the base station the remote unit will continue to function and log the events. When the network is operational the latest event value will be transmitted. Precipitation and snow values are transmitted twice per day with or without a storm, these transmissions are clock controlled. Temperature values are clock controlled and can be set for transmissions every 3.6 minutes and in other increments up to once each twenty four hour. The radio transmitts on an approved frequency with six to eight watts of power. There is an optional power amplifier which can be used to increase power output up to twenty to twenty four watts.

There are different types of antennas in use with the system. These vary from single di-pole unity gain to ten DB gain directional types. The antenna is mounted on a fifty millimeter diameter pipe which is attached to the front side of the building. Radio path tests and studies are accomplished to determine the type antenna best suited for each station.

The battery used to operate the electronics package is a rechargeable gel cel twelve volt eight ampere hour unit. There are no solar panels used with the USBR event stations. This feature is available if it is desired. Each battery is removed, recharged, and returned to service during the summer season. The average life of the batteries is three to four years.

Some configerations differ somewhat from that described as design improvements have been incorporated since the original installations. The most recent electronics units are considered to be fourth generation.

SATELLITE ELECTRONICS PACKAGE

The radio, battery, and logic units are the major components in the electronics package. The container is a rectangle alluminum box, approximately twenty five by thirty five centimeters. All terminal connections can be made without opening the lid to the box. The lid has a dust moisture seal installed.

The logic unit has a minicomputer to control the recovery, storage, and transmission of data through the GOES satellite then to the base receiving system. The unit can be programmed at the remote site using a briefcase size programming kit. If a power interrupt occurs at the unit it must be reprogrammed.

The battery is a rechargeable twelve volt twenty ampere hour. The battery is charged on site with a solar panel. The solar panel is mounted below the satellite antenna on a fifty millimeter pipe which is secured to the front of the building or set in concrete base if it is a wilderness type station.

CLIMATOLOGY

The length of the histories at each station vary from one year to twelve years. The historical information for one of the older stations has been analyzed and in Figure one shows the information from Mammoth Pass, 2900 meters elevation, in the Sierra Nevada. The solid line is the twelve year normal snow pack water content for the winter season. During this period there were two extremely dry years and two extremely wet years. The dashed line is the snow water content for the 1982-83 season, the wettest year during the period. The dash-dot line is the snow water content for the 1976-77 season, the driest year. The dotted line is the accumulated precipitation for 1982-83. The peak normal water content, 139 centimeters, occurs on April 10th. The peak in the extreme years was 229 centimeters on May 10th and 30 centimeters on March 30th for the wet and dry years, respectively. The values for this year, 1984-85, are shown by the "X" plots. At a glance it is possible to determine what the snow pack water content for the present year is in relation to the normal and extremes. With this knowledge from a number of stations it is possible to arrive at a reasonable water supply projection for the watershed which the stations represent.

The information from the Huysink station, 2070 meters elevation, in the Sierra Nevada, is presented in Figure two. The solid line is the four year normal snow pack water content. The dashed line is the water content for the 1982-83 extremely wet year. The dotted line is the accumulated precipitation for 1982-83. The "X" plots are the water content values for the present year, 1984-85. The 1982-83 precipitation and water content values are in close agreement through January 31st. After that time snow apparently adheres to the inside of the missile gauge with only a little melting occurring through April 20th. Beginning in May the snow in the gauge melts rather rapidly with some 79 centimeters being recorded. It is of interest to note the peak pack water content and precipitation accumulation are 248 and 252 centimeters, respectively. At this particular site the two values are of similiar magnitudes in the other years. This is not necessarily true at all high elevation sites. At Mammoth Pass the precipitation accumulation during the snow season falls far short of the peak water content, e.g., in 1982-83, it was only 61% of the peak water content. At Kaiser Point, 2900 meters, for the same year the observed precipitation was 72%.

The location of the site and the resulting wind patterns are the single most likely cause for not measuring the true precipitation at high elevations during the winter season in the Sierra Nevada. Huysink is located in a sheltered forested small open area where wind effect appears to be minimal. Mammoth Pass is as the name implies is a windy pass, even though there is some shelter provided by the forest it apparently has little effect on winds at that location.

In applying either precipitation or snow water content values from the same station for purposes of water supply forecasting it is not necessary that the two measurements be in close agreement. The history of the station and the climatological phenomenon must be analyzed rather extensively to gain useful information. The data from the stations located at mid-elevations in the Sierra Nevada where the snow pack accumulates and melts frequently during the winter season has uses that differ from those at high elevations. High elevation stations are definitely water supply oriented while mid-elevation stations are both flood and water supply oriented.

In order to gain an insight to the accuracy of the measuring techniques Figures three through six were plotted. They provide a presentation of the relationship between the computer information, the snow tube control sampling, and the stilling

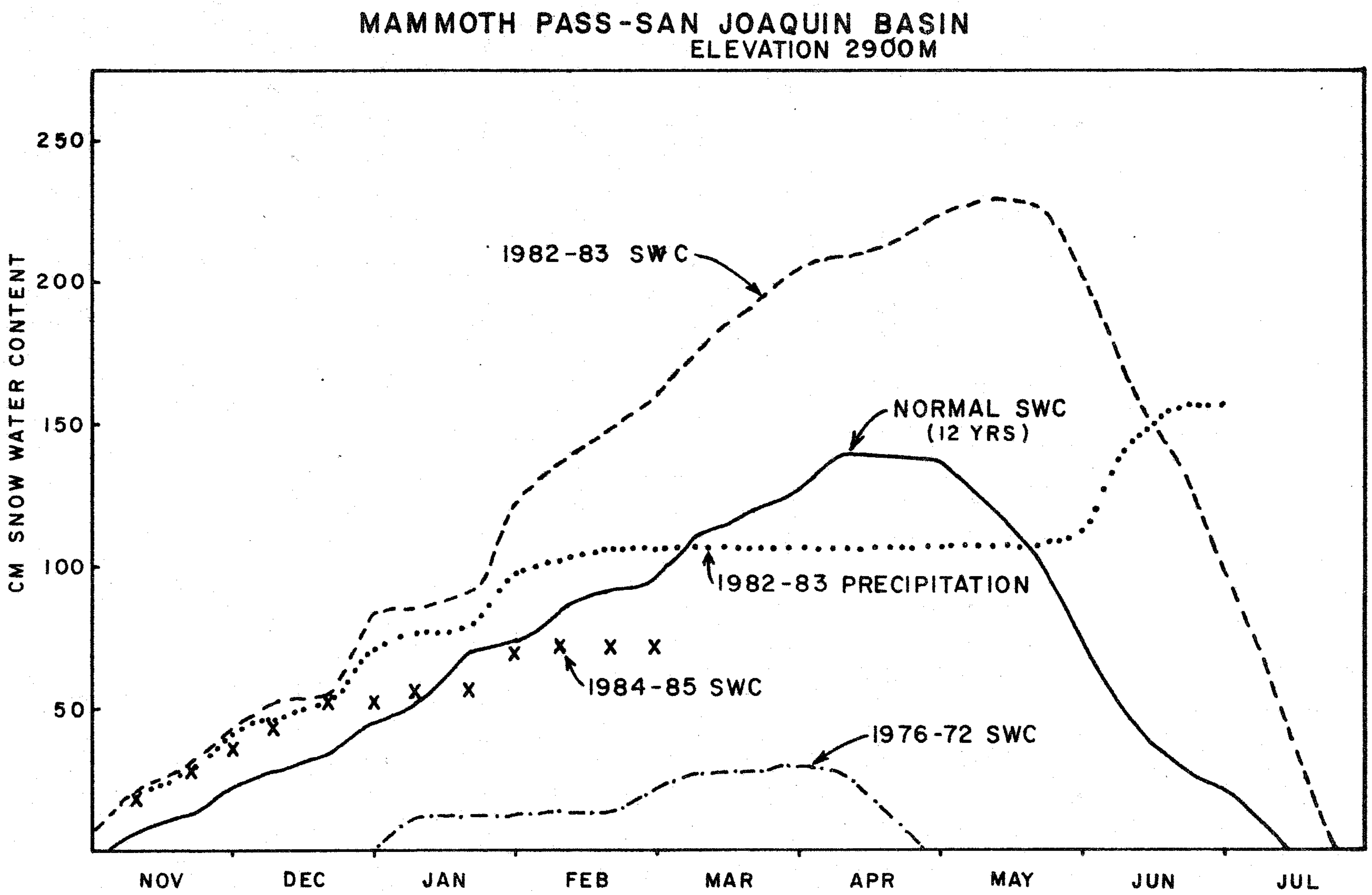

Figure 1. Snow Water Content and Precipitation Patterns.

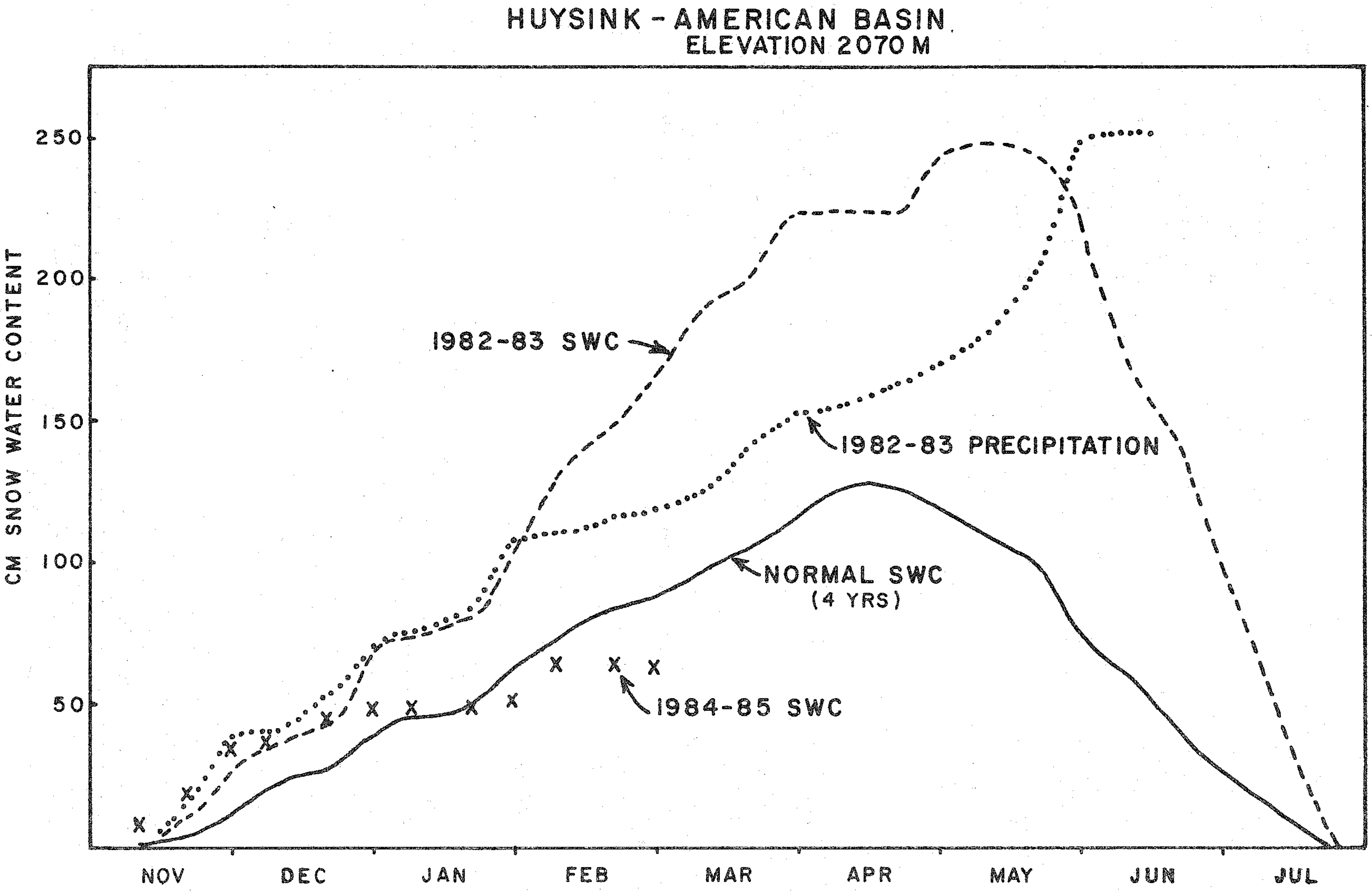

Figure 2. Snow Water Content and Precipitation Patterns.

well manometer readings. The control measurements were corrected using the curve presented by Peterson and Brown (1975).

The 0.998 correlation coefficients computed from the data plotted in Figures four and six indicate an excellent relationship between the snow water content manometer visual readings and the computer readouts. It is apparent that the hardware and software used to sense, transmit, and analyze the snow water content information meet accuracy requirements. When a comparison is made of the manual snow water content control data and the computer readout, reference Figures three and five, the correlation coefficient decreases somewhat. There are a number of reasons for the decrease, one is the snow tube measurement problems discussed by Peterson and Brown (1975), a second is the experience level of the snow surveyor, a third is the snow tanks-control sample area site condition, and a fourth a probable limited capability of the four tanks to measure the water content when the snow depth and water content is greater than four meters and 120 centimeters of water, respectively. An evaluation of the three different tank installations is being conducted at Mammoth Pass at this time. These are a six tank stilling well, a four tank stilling well, and a four tank transducer installation. The one absolute necessity for these tests is an extremely deep snow pack. Another few years like 1982-83 would meet the criteria for the tests and evaluation. The results of this project will hopefully be presented at the Western Snow Conference sometime in the future.

DATA EDITING

The computer read out of the data from the remote stations will quite frequently contain erroneous values. The source of these errors is seldom caused by the remote logic unit and subsequent transmission. It is usually caused by a spike, from an unknown and unidentifiable source, that interfers with the signal as it passes through the receiver, decoder, and computer electronics logic maze. If the source of error is identifiable, experience has proven that these interferences can be eliminated. One of the necessary functions on these systems is to provide for data editing. The errors, few as they may be, must be identified and removed. If not, as the history builds the data can become questionable and of little value to the user. The software has been written to allow for an edit function. Routinely, at least once per week, the stored information is reviewed and the erroneous data is purged from the files.

WATER SUPPLY FORECASTS

Development of the history of each station is necessary to gain an insight to the relativeness of the data as it evolves with each passing year. Data from even one year can be of some limited value in arriving at decisions related to operations. As each new year of record becomes available the value increases and broader applications can be used in arriving at operational decisions.

Water supply forecasts which accurately predict the availability of water that will runoff into the reservoirs are necessary. The CVOCO personnel use the snow course reports collected by the California Cooperative Snow Surveys program to apply in forecast procedures and arrive at projections of water yield during the spring runoff.

In California, data from a few courses are available around January 1st. The scheduled number of courses to be taken increases February 1st and by April 1st data is available from all active courses, weather permitting. The types of travel to obtain snow samples vary from skiing to over snow vehicles to helicopters. When there are extended storm periods during the months of February through April it is not likely that all course schedules will be accomplished. These are usually the years which have the larger water yields. This, as discussed previously, has resulted in the installation of remote sensing stations.

Since the length of the USBR station histories range from one to twelve years the data use varies considerably. Analysis similiar to that illustrated in Figures

MAMMOTH PASS-SAN JOAQUIN BASIN
ELEVATION 2900M

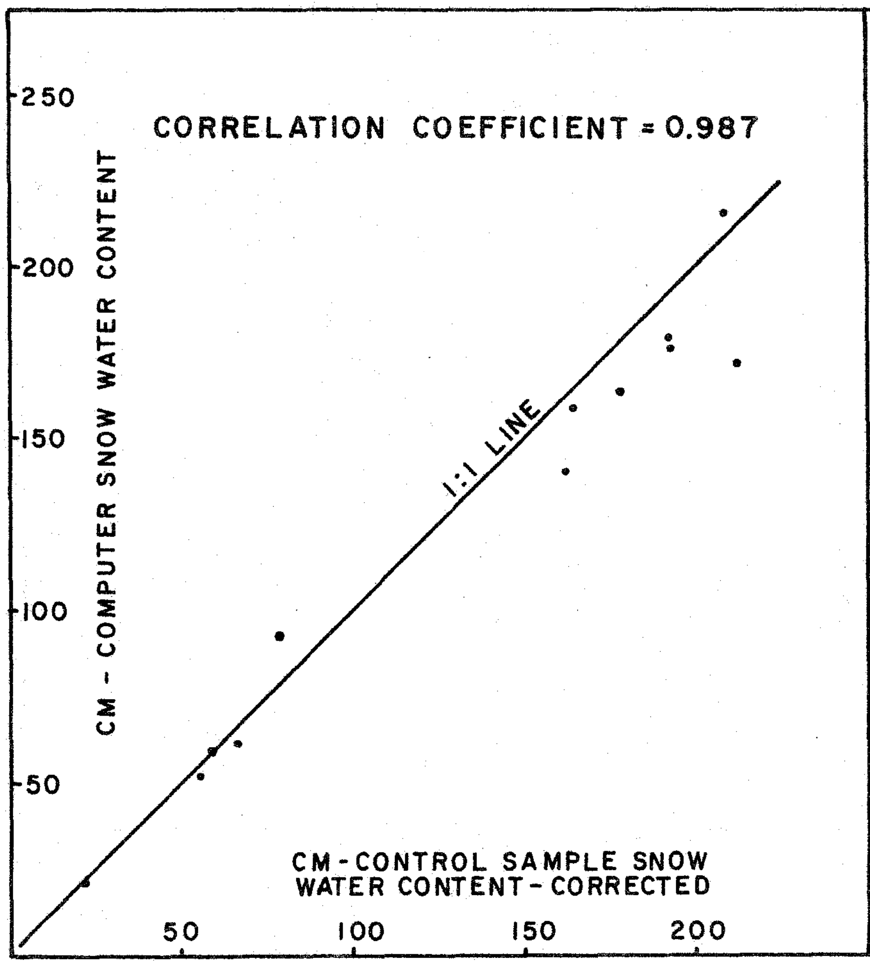

Figure 3. Snow Tube Controls (corrected) Versus Computer Readout.

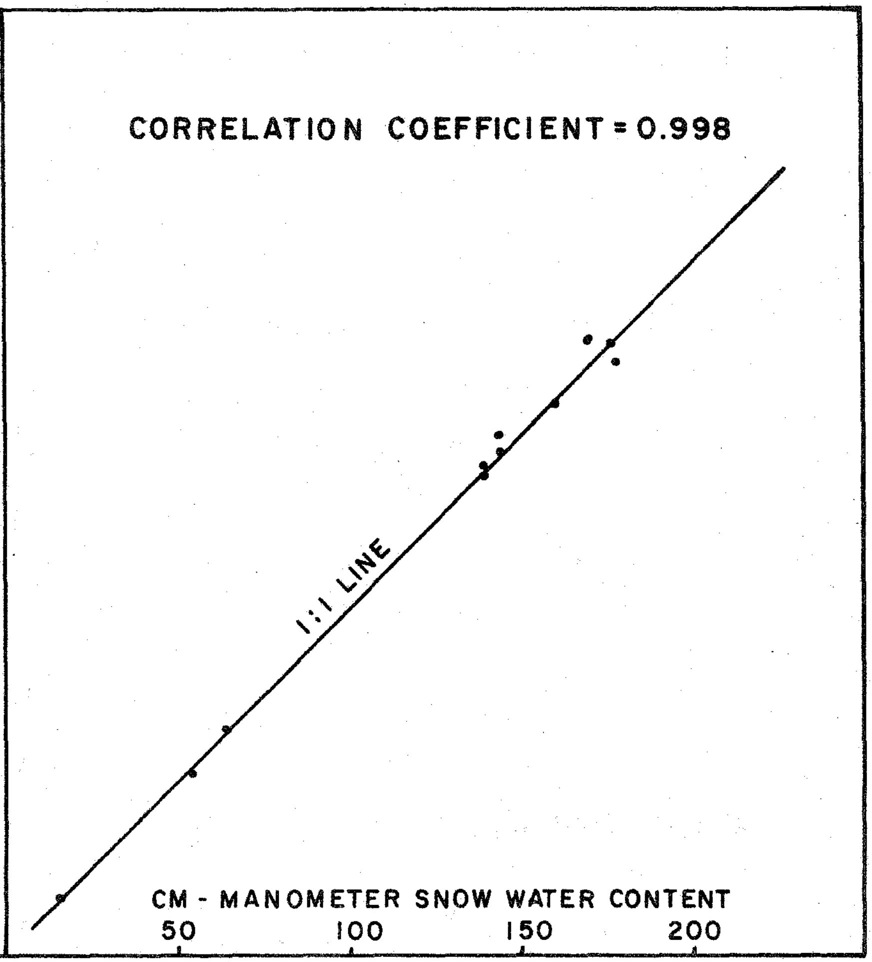

Figure 4. Manometer Visual Reading Versus Computer Readout.

HUYSINK - AMERICAN BASIN
ELEVATION 2070 M

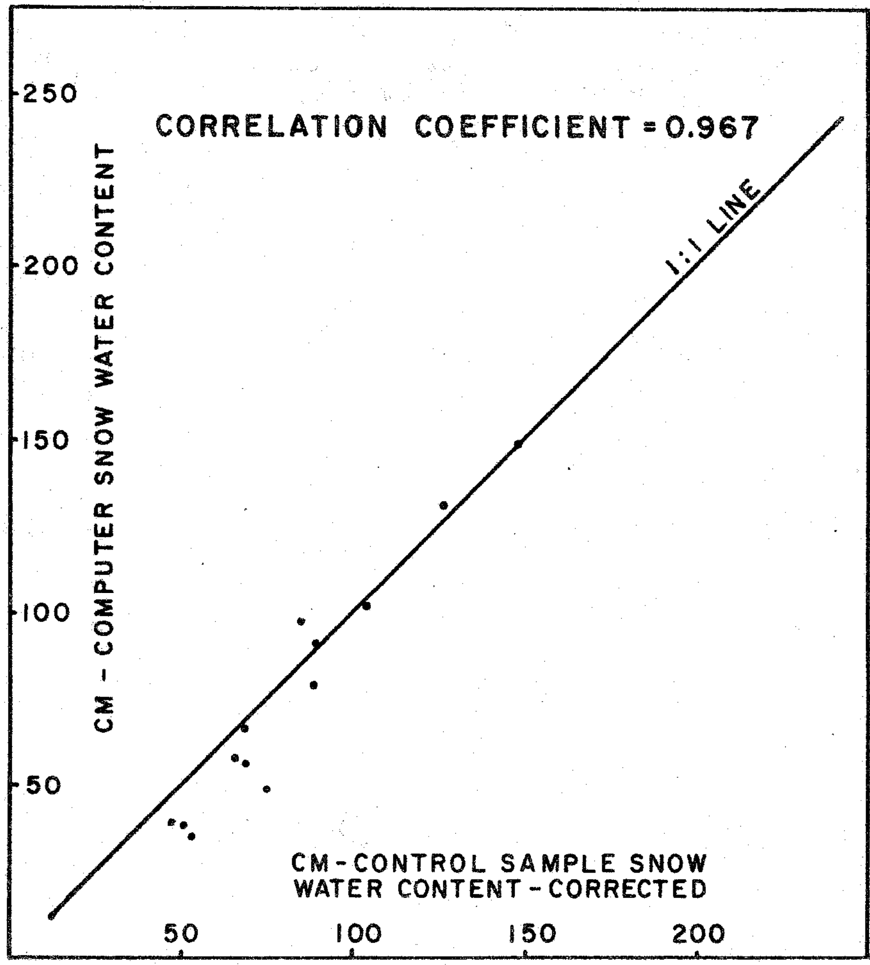

Figure 5. Snow Tube Controls (corrected) Versus Computer Readout.

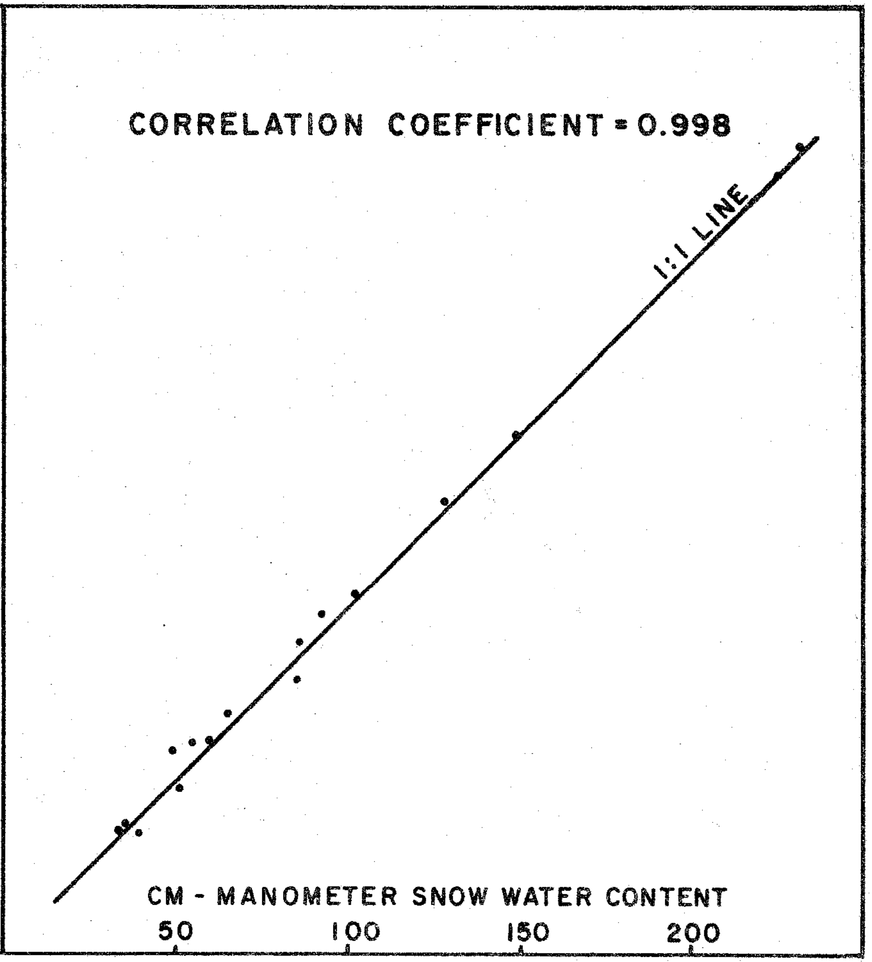

Figure 6. Manometer Visual Reading Versus Computer Readout.

one and two has and is being used by CVOCO personnel to keep abreast of the snow pack water content as the season progresses. After a particular storm or series of storms the watershed sensor data can be checked and the changes in water content observed. It is possible with experience and knowledge of the basin characteristics to apply the observed changes to the water supply forecasts made at an earlier time and determine the effect the storm sequence had on the projected water supply. The equations which are used by CVOCO for water supply forecasting are multi-regression type which use the 1st of the months February through May snow course data to compute the projected runoff from the watershed above the CVP reservoirs. The snow sensor data is currently used to update the forecast at mid-month or after a storm period. This is accomplished by selecting the applicable equation for the particular watershed. All information needed for the equation is updated to the date selected. It is possible using the actual snow sensor reports to make realistic estimates of the changes for each source used in the equation. Until sufficient history for a station is acquired a direct application of the computer accumulated snow water content is not possible. Since the equations use snow course data a correlation must be made to adjust one set of data to the other. On the other hand, it is quite reasonable to use snow water content data over a short period, a few days, to arrive at an updated forecast between the usual monthly forecast times.

At present there has been no attempt by CVOCO to develop a water supply forecast scheme using the snow sensor data directly. It is anticipated that this step will be taken watershed by watershed as the station histories lengthen sufficiently. This will be accomplished for the San Joaquin watershed within the next two or three years. Four stations of the six in this basin have twelve years of record. The ultimate goal is to develop a computer model for each on the major reservoirs which collect, store, and analyze all information needed to produce a daily or as needed update of the water supply forecast as the winter snow accumulates and spring snow melt occurs. With the snow sensing equipment installed or to be installed and a computer available this is certainly a realistic goal that can be achieved.

CONCLUSIONS

The installations of hydrometeorological stations within the USBR Mid-Pacific Region has provided real time data which has and can be used to predict high water flood flows and make water supply forecasts.

The event type and satellite equipment have both been utilized successfully to relay information from low to high elevation locations. The event system is being used where line of sight communications are possible. The satellite system is used from locations where line of sight is not feasible. Both types of equipment have proven reliable and capable of operating under very adverse conditions.

The liquid level float type sensor with a stilling well connected to the four snow tanks is recommended as the sensing method. It has proven considerably more stable than the transducer to tanks sensing method.

The catchment characteristics of the four snow tanks and the missile precipitation gauge can be considerably different. Wind caused drifting and scalping of the snow can influence the true snow water measurements. Wind effects at the precipitation gauge does influenece the true precipitation measurements. Careful site selection can minimize these effects. Even with these notable differences the measured snow water content and precipitation may and likely will be good indexes to the runoff from the watershed.

The snow sensor data can be used during the first year of operation to make adjustments in the water supply forecasts between the routine forecast times. When there are a number of stations in the watershed at different elevations within the snow zone an improvement in the adjusted forecasts will be observed.

There will be direct use of the snow sensor data to provide real time water supply forecasts as the station climatology periods lengthen. Equations can and will be developed for real time forecasting.

While remote sensing, radio data transmissions, computers, and associated equipment are very reliable, it is and will continue to be necessary to eliminate erroneous values by continual data editing. The historical information must be free of questionable values.

The remote sensing systems provide for new insights and new techniques to be developed as relates to the California snow fields, however, the snow surveyor will continue with his efforts and use snow tubes to provide valuable and irreplaceable information.

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