THE IMPACT OF AUTOMATED HYDROMETEOROLOGICAL INSTRUMENTATION UPON DATA QUALITY FOR THE FEATHER RIVER BASIN, CALIFORNIA [1]

By

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INTRODUCTION

The California Department of Water Resources (DWR) operates an extensive network of hydrometeorological instrumentation for flood forecasting and water supply forecasting. The instrumentation includes precipitation gauges, snow sensors, temperature sensors, and water stage sensors. The network has grown steadily over the years, both in size and sophistication.

The system has been extremely valuable for flood monitoring and real time flood forecasting, but in order to realize the system's full potential for water supply forecasting it is essential to build a consistent, error free data base from the telemetered data records.

This paper analyzes the problems of building such a data base from the telemetered data archives for the Feather River basin in California (Fig. 1 and 2). Although the study focuses on the specific problems and possible solutions for this system, the findings may be of general interest to others developing, expanding, or managing a telemetered hydrometeorological instrumentation system.

BACKGROUND

In the wake of severe and widespread flooding throughout Northern California in December, 1964, the California State Legislature authorized the Department of Water Resources (DWR) to collect hydrologic data and to make flood forecasts.

In cooperation with the National Weather Service and other agencies, the Department has developed a hydrometeorological data telemetry system for Northern California, with particular emphasis on the North Coast. The backbone of this data system was an existing statewide microwave repeater network (Fig. 1), called the Public Safety Microwave System (PSMS).

The PSMS was originally developed to serve as a highly reliable statewide public safety communication system for State agencies. The first loop, connecting Sacramento and Los Angeles was installed in 1957. Additional loops serving Northern California, the desert areas, and San Diego were added over the years. A series of mountaintop repeater stations relay microwave communications and can each communicate with up to 99 remote stations by VHF radio.

Communications can move in either direction through the communication loops, providing substantial protection against system failure in the event of a repeater failure. Individual telemetry stations communicate directly with one of the mountaintop microwave repeaters by VHF radio; the data then moves via microwave to the central interrogation station in Sacramento. If a repeater fails, only the telemetry stations polled by that repeater are silenced.

A central interrogation station, operated by DWR, communicates with the remote stations via the PSMS. It has grown rapidly in capability and complexity. In 1967, 30 data stations linked by radio and 20 stations linked by telephone were interrogated manually by a dispatcher (DWR, 1967). In 1973 a Data General Nova 1220 minicomputer replaced the dispatcher, interrogating the stations automatically each hour. Over a period of years, the Nova 1220 data storage and database management capabilities were expanded as more telemetry stations were added to the system.

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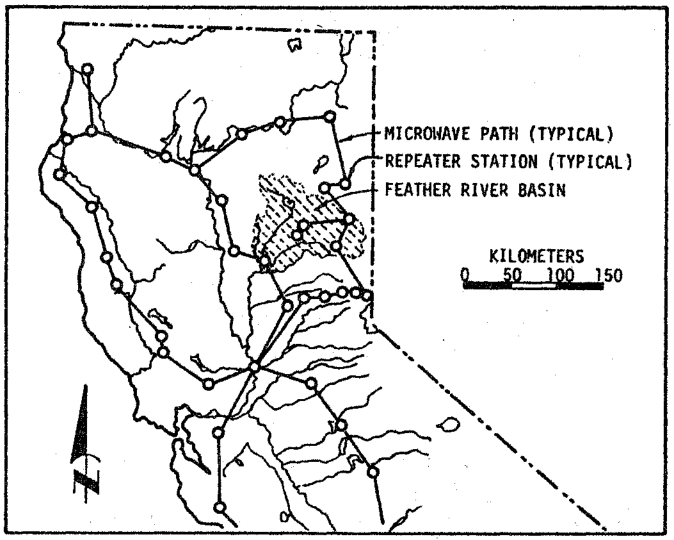

Fig. 1. California Microwave Repeater Network

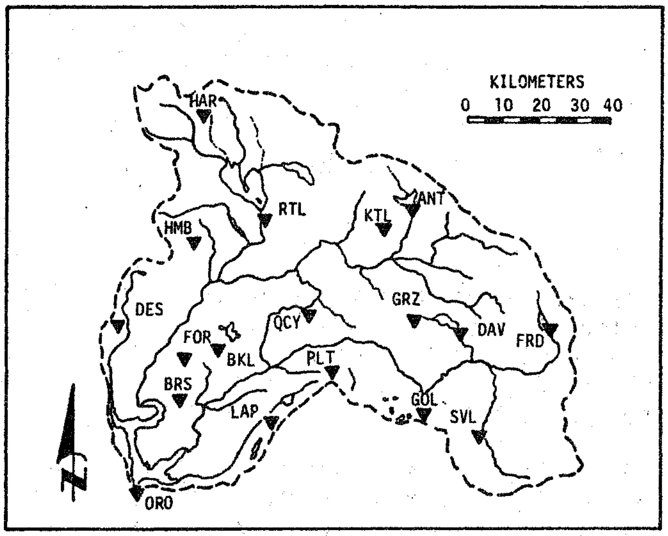

Fig. 2. Feather River Basin Telemetry Stations

In 1980, the Data General (D.G.) Nova 1220 was replaced by a more powerful D.G. Nova 4X minicomputer, and the software system was completely redesigned. The new system interrogated the remote stations, stored hourly data for several months, and simultaneously fielded calls from system users.

In 1982 a D.G. S-140 minicomputer was added to serve as a forecasting and data analysis tool. It has also taken over the task of disseminating data and forecasts to a growing number of government agencies, utilities, and other users.

Up to the present, the data telemetered to the central interrogation station has been used almost exclusively for flood monitoring and real-time flood forecasting, and no effort has been made to build consistent and complete station records for other purposes such as water supply forecasting. In fact, only for the last few years have the complete telemetry records been retained in the form of printouts. Beginning with January 1, 1983, the complete telemetry records have been saved on magnetic tape.

In the future there will be a strong incentive to place a greater reliance on telemetry stations for hydrometeorological data as the costs of field surveys and remote site staffing continue to rise. It will therefore become increasingly important to develop good data records from the telemetered data.

This paper discusses the problems encountered in building consistent and complete station histories from the telemetered hourly data. It also discusses specific solutions and a general strategy for processing the often fragmented data base with a minimum of time and expenditure.

Most telemetered data problems are due to equipment failures or measurement problems at the remote sites. Thus an effective strategy for minimizing remote site problems is a key to developing a consistent and complete forecasting data base. Once the data has been transmitted to the central computer, the question becomes one of efficiently processing the large volumes of data to yield consistent and complete station records.

THE IMPACT OF REMOTE SITE DESIGN UPON DATA QUALITY

Remote telemetry station design for the Feather River basin was discussed in detail by Barnes (1974), but is summarized here: The heart of the remote station is a logic and control unit (LCU) with time signal generator. This unit monitors analog or digital input signals from the precipitation, snow water content, and temperature sensors at the site. It also controls a very high frequency (VHF) radio, which constantly monitors transmissions from its parent mountaintop repeater station. When the LCU hears its own address over the radio, it reads the current input values at its sensor ports, and orders the radio to transmit these current values back to the mountaintop repeater, and thence to the central interrogation station in Sacramento.

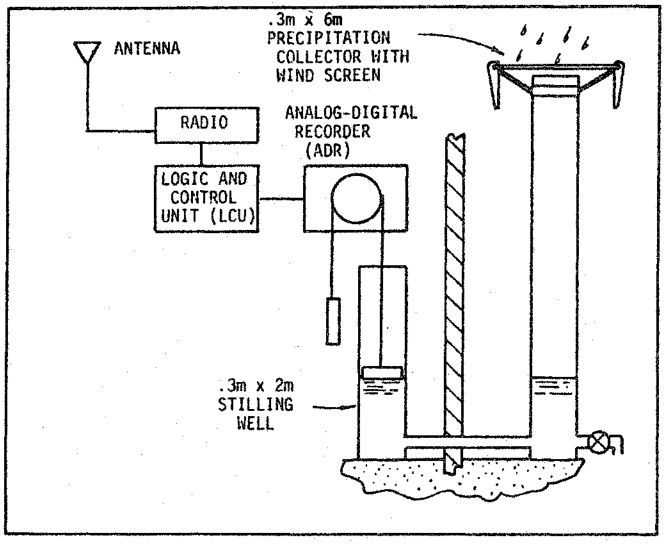

Fig. 3. Original Telemetered Precipitation Gauge

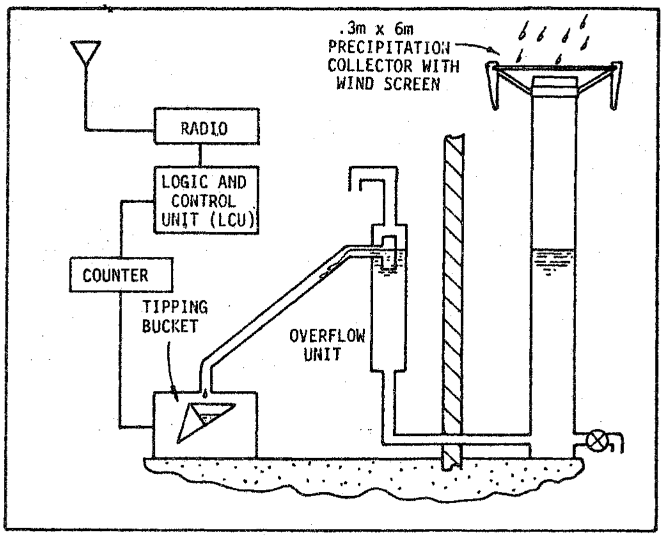

Fig. 4. Modified Telemetered Precipitation Gauge

The VHF radio also provides for voice communication between the remote site and the central interrogation facility, which helps the technician when maintaining and verifying performance of the remote site.

It has been found that the telemetry system occasionally introduces errors into the transmitted data stream. The primary reason is that the VHF radio, when transmitting, produces enough radio frequency (RF) noise to disturb analog to digital converters at the control and logic unit input ports. This problem has been solved with more recent equipment (installed in other basins) by instructing the LCU to read the input ports before beginning transmission.

Precipitation Gauges

Most of the telemetered precipitation gauges installed by DWR in the Feather River basin (Fig. 3) originally consisted of a 0.3 m diameter aluminum tube, 3.77 m to 6 m tall, equipped with a wind shield and charged with an antifreeze solution to prevent ice formation (Barnes, 1974). Each precipitation gauge was connected to a 0.3 m diameter by 2 m tall aluminum standpipe in an instrument shelter, in which the liquid level was measured with a float actuated analog to digital recorder (ADR). Each gauge was charged with approximately 190 liters of 45% methanol, 55% ethylene glycol, with a specific gravity of 0.97 at 20 degrees centigrade. Approximately one liter of oil was added to suppress evaporation. Precipitation falling into the gauge, having a slightly higher specific gravity, sank through the solution, mixing with it and preventing ice formation (Mayo, 1972).

As pointed out by Mayo (1972), when the depth of liquid in a storage cylinder is used to measure precipitation, temperature induced changes in liquid depth can induce significant measurement errors which increase as precipitation accumulates during the season. The Feather River basin gauges exhibited temperature induced errors of up to 2.2 cm in response to spring diurnal temperature fluctuations of 25°C.

In 1983 the gauges were modified to reduce these temperature induced errors. In the modified system (Fig. 4) an overflow pipe draining to a tipping bucket has replaced the stilling well with stage recorder. This limits the fluid depth to that of the original antifreeze depth, thereby limiting the magnitude of temperature induced depth fluctuations.

While thermal effects have not been entirely eliminated, they have been significantly reduced. A slight amount of false precipitation registers as the fluid column expands if temperatures rise after a storm. But each increment of thermally induced overflow leaves more room for subsequent expansion-contraction cycles, so the effect is self limiting, with a cumulative effect of less than 0.2 cm. At the beginning of the next storm the thermal overflow volume must be replaced before the tipping bucket registers precipitation.

There have been some problems with the currently used tipping buckets, however. In one manufacturer's design, the funnel guiding water into the bucket allowed part of the fluid to flow radially outward from the orifice to bypass the tipping bucket. Once identified, the problem was corrected by sharpening and extending the funnel orifice. A second problem has been occasional leakage between the compartments of the tipping bucket, with resultant undermeasurement. The tipping buckets are also vulnerable to freezing: Splash or condensation freezing the bucket bearings has occasionally locked a bucket in place.

At lower altitudes the tipping bucket mechanisms have occasionally been fouled by insects and spiders. Spider webs can become extensive enough to lock the buckets in place. Careful attention to screening at all access points to the mechanism solves this problem.

The tipping bucket counters currently used do not have any memory protection features, with the result that any power interruption resets the cumulative count to zero. Precipitation occurring while a station is down is not measured, resulting in gaps that can only be filled by estimates from other stations.

Several conclusions may be drawn from our experience with precipitation gauges in the Feather River basin:

1. The effects of temperature fluctuations on measurement accuracy must be carefully considered in the system design.

2. If tipping bucket mechanisms are used they should be of the highest quality and carefully designed for resistance to freezing, leakage, mechanical failure, and insect and spider access.

3. Careful attention should be given to data protection in the event of power or telemetry system failure. With storage-type precipitation gauges, the stored fluid serves as a memory of cumulative precipitation. But, if tipping bucket mechanisms are used, some form of nonvolatile memory is crucial to the integrity of the long-term station record. This can take the form of an electronic counter with its own power supply, a mechanical counter on the tipping bucket, a tank for retaining the tipping bucket discharge, or a second, independent tipping bucket unit in series with the telemetered unit, with its own recording mechanism.

Snow Sensors

Beginning in 1969 DWR began installing snow sensors in the Feather River basin. The original configuration consisted of a 3.66 m diameter butyl pillow, with a weight driven Stevens A-35 recorder sensing the fluid level in a stilling well connected to the pillow. The butyl pillows occasionally leaked: rodents chewed holes in them, bears tore at them, and grazing animals stepped on them. However, the recorders worked very well, providing good, complete records when the pillows were not leaking. One such installation, at Harkness Flat, is still performing well after 15 years of service.

In the ensuing years, DWR performed extensive tests of a variety of snow sensors to arrive at the current configuration (Fig. 5) (DWR, 1976). It consists of four 1.22 m by 1.52 m stainless steel tanks, bedded in sand and covered with native soil, interconnected with 9.5 mm copper tubing, and filled with roughly 210 liters of ethylene glycol-methanol mix (specific gravity 1.0).

In order to verify performance of the snow sensor installations, DWR makes manual snow water equivalent measurements adjacent to the sensors (Peterson and Brown, 1975) at the time of regularly scheduled snow course measurements.

It has been shown that a properly calibrated and maintained snow pillow should yield more precise readings of snow water equivalent than snow tube samples (DWR, 1976). However, Cox, et al. (1978) pointed out that many snow sensor problems can interfere with data accuracy. These problems include leaks, large and small, effects of tree canopies on nearby structures, meltwater drainage anomalies, snow creep, temperature effects on sensor fluid and equipment, improper bedding of sensors, and sensor deformation. Cox,

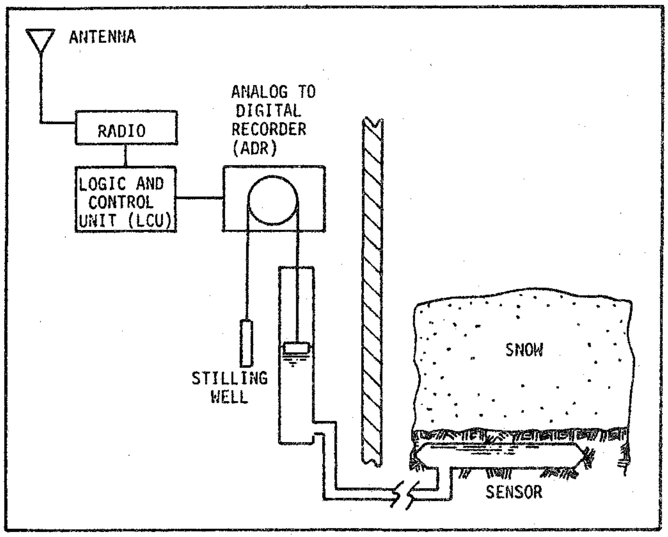

Fig. 5. Telemetered Snow Sensor

SENSOR	MNEMONIC	SINCE	NUMBER OF DATA SAMPLES 1/	CORRELATION COEFFICIENT, R 1/	% OF TIME WORKING 2/
KETTLE ROCK	KTL	9/78	12	.978	96%
GRIZZLY RIDGE	GRZ	10/69	29	.995	47%
PILOT PEAK 3/	---	9/78	0	---	1%
GOLD LAKE	GOL	10/69	27	.993	60%
HARKNESS FLAT 4/	---	10/69	30	.980	---
HUMBUG	HMB	9/80	0	---	---
BUCKS LAKE	BKL	10/69	15	.977	41%
FOUR TREES	FOR	11/78	3	---	63%
RATTLESNAKE HILL	RTL	8/80	0	---	---

NOTES:

1/ INCLUDES UNTELEMETERED AND TELEMETERED DATA, CONTROL SAMPLES CORRECTED ACCORDING TO SNOW DENSITY VS. SENSOR OUTPUT
2/ TELEMETERED RECORD ONLY. QUESTIONABLE DATA IS INCLUDED.
3/ OPERATED BY OROVILLE WYANDOTTE IRRIGATION DISTRICT
4/ NOT TELEMETERED. OPERATED BY PACIFIC GAS AND ELECTRIC COMPANY

Table 1. Data Summary for Telemetered Snow Sensors

et al. concluded that good data quality requires careful attention to installation, maintenance, calibration, and documentation.

While these criteria are well documented in the literature, compromise must often be made in field installations. It is often difficult, for example, to locate the sensor tanks in spots with just the right slope and drainage characteristics.

There are additional impediments to reliable data. First, the datum for manual samples is established with every core because each sample includes soil, verifying ground surface contact. On the other hand, a datum is established for snow sensors only at the beginning and end of the season, with no possibility of direct verification during the season unless the snow melts off completely.

Second, when a sensor replaces manual snow course measurements, only one point is sampled rather than ten. With the large spatial variations in depth, density, and drainage patterns, typical in many locations, a certain measure of reliability is lost when measurements are confined to one point. Also, if the snow above the sensor tanks is disturbed, the remainder of the season's data can be compromised.

Third, a telemetered sensor currently provides no information about the snowpack density, wetness, and structure, all important in evaluating the condition of the snowpack.

Thus in exchange for real-time data availability and potentially high precision, losses in measurement reliability and representativeness can be expected. Experience with snow sensors in the Feather River basin substantiates this conclusion.

The telemetered snow sensor data for the Feather River basin was analyzed to identify sensor and telemetry problems and to evaluate data quality. The daily snow sensor readings were digitized, machine plotted, and compared to the control samples. Station history notes were copied directly onto the data plots to help clarify data problems.

The results of the analysis (Table 1) show that when it's available, the data is reasonably good. The coefficient of correlation between the control samples and snow sensor readings for the same day range from .978 to .995. Double mass plots of the available control sample data versus the sensor data (one point per year) do not indicate substantial slope changes, despite the many changes in sensor and instrumentation configurations over the period of record (Fig. 6 and 7).

The primary data problems are data interruptions, erratic reports, sudden shifts, and systematic over or undermeasurement. After analyzing 1,135 station years of record, Cox, et al. (1978) concluded that most operational problems can be identified and corrected for by examining the sensor data. Although reasonable corrections can be made

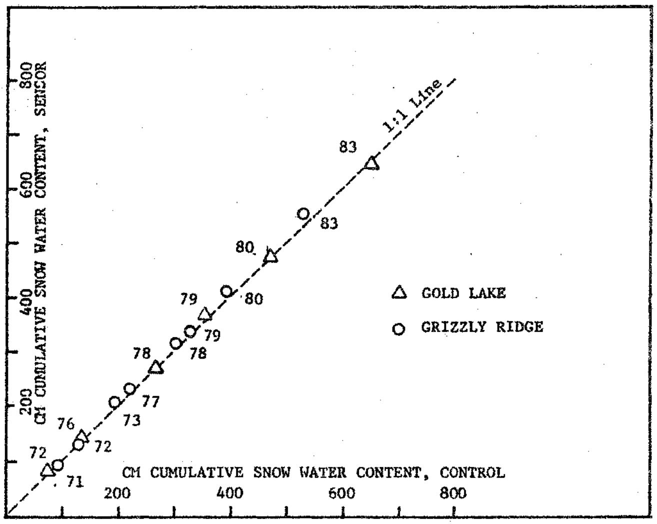

Fig. 6. Manual Control Samples, Corrected for Sampling Error, Versus Sensor Readings

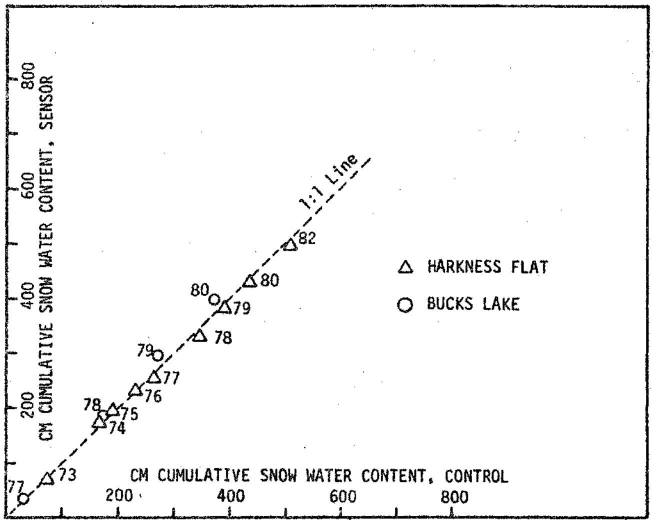

Fig. 7. Manual Control Samples, Corrected for Sampling Error, Versus Sensor Readings

if good data is available from other sensors and from manual samples, in the current study a number of gaps and erronious data segments remain unexplained. In fact, 36 percent of the data interruptions could not be explained based on the available data. The remainder could be attributed to one of the following equipment problems:

1. Radio problems: Radio failures resulted in the loss of 3.5 station years of record, representing about 37 percent of all outages over the period analyzed.

2. Sensor system problems accounted for 21 percent of the outages. Sensor leakage was a serious problem with the original butyl pillows and with some of the earlier versions of the stainless steel tanks. These problems have been eliminated with the introduction of the California standard tanks. In most cases leaks were large enough to rapidly drain the pillows, thus terminating the data stream. However, one stainless steel pillow at the Grizzly sensor site developed a small seam leak, which went undetected until near the end of the season. The seasonal record appeared normal in its response to snow deposition and melt, but registered less than expected relative to the control samples and other sensors. The leaking fluid melted a 1 m diameter cavity in the overlying snow, causing the observed undermeasurement.

   In two of the Feather River basin sensor installations, pressure transducers served in place of stilling wells and river stage recorders. A pressure transducer was used at the Grizzly site from water year 1975 to 1977 inclusive, and at Pilot Peak since its installation in October 1978. The pressure transducer for the Grizzly site consisted of a pressure activated strain gauge, generating an output voltage proportional to pressure. A temperature compensated servo mechanism rotated a shaft in proportion to the strain gauge output voltage. The shaft position was sensed and digitized by an ADR which punched paper tape and passed the digitized signal to the LCU.

   In practice the system performed erratically. The servo mechanism generated large voltage swings while hunting for the balance voltage, so that when a reading was telemetered, it could be several centimeters off the correct value. The system appeared to be temperature sensitive, although this could not be verified from the available record.

   The Pilot Peak installation employs a solid state analog to digital converter that senses the pressure transducer output and provides a digital signal to the LCU. This system has also performed poorly, yielding little useful data, due to transducer problems, plumbing leaks, and radio problems.

3. Logic and control unit problems accounted for 5 percent of the outages. The LCU controls both the radio and the ADR. The recorder punches paper tape only when it

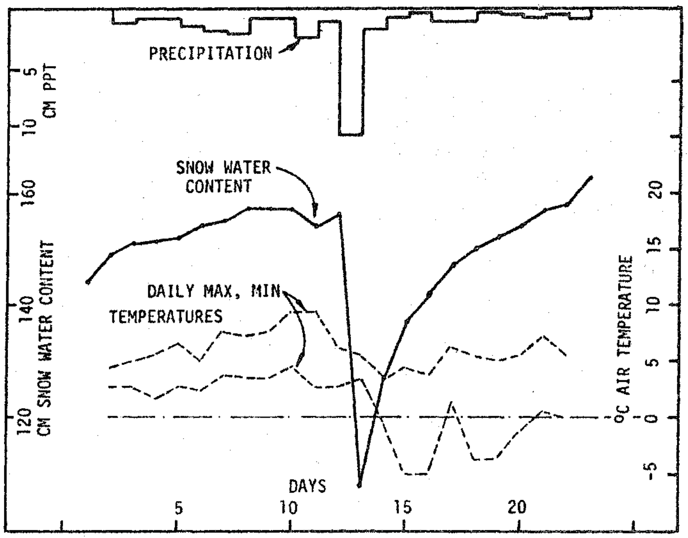

Fig. 8. Rain on Snow Event, March 1983, Gold Lake Sensor

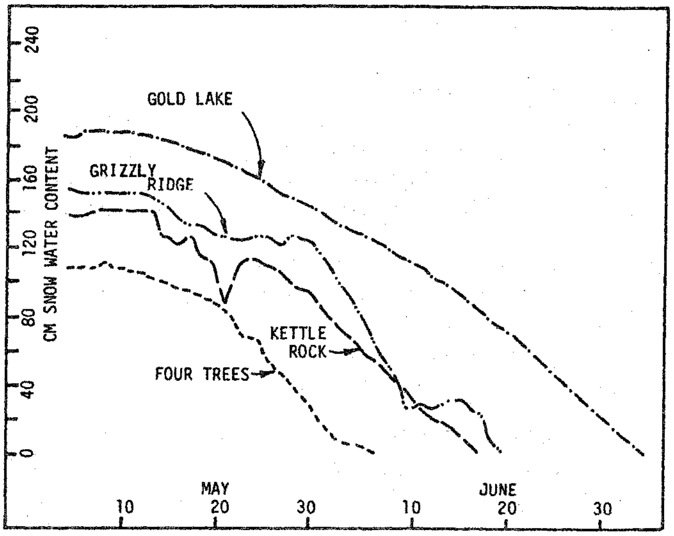

Fig. 9. Spring Melt Pattern, May-June 1983, Grizzly Ridge Sensor

receives a signal from the LCU, so if the LCU fails, the punched tape record is also interrupted. Since the failure of the LCU or power supply has been a major cause of telemetered data interruption, the paper tape record has yielded little additional useful information over that provided by the telemetered data.

Also, the paper tape record does not include the time of each reading; this must be inferred from the starting time and the recording interval. It is a simple matter to forget to mark the paper tape when restarting a system which has failed; the repair work is often done under difficult field conditions and severe time constraints. The tape marking has often been forgotten, with the result that the time of recorded measurements cannot be determined.

Some data problems may be attributable to the interaction between the snowpack and the underlying sensor. A striking example occurred at the Gold Lake sensor, March 11-30, 1983 (Fig. 8).

Approximately 11 cm of rain fell in a 24-hour period on a 156 cm snowpack of approximately 40 percent density. The apparent snow water content plummeted to 107 cm, then gradually recovered over a period of 10 days. Clearly the weight of the snowpack was not being transmitted to the sensors in the aftermath of the heavy rainfall, but the reason is not known. Possible explanations might include snow creep or uneven erosion of the base of the snowpack. Gradual deformation of the snowpack after the rainfall probably resulted in a restoration of the true snow load.

Two other sensors in the basin, Grizzly Ridge and Kettle Rock, received heavy rainfall at the same time as Gold Lake, but showed a slight temporary increase in sensor load rather than a sudden drop, indicating that the erronious Gold Lake sensor data was due to site-specific causes.

The spring melt pattern for 1983 at Grizzly Ridge provides another example of data distortion probably due to an interaction between the snowpack and the sensor (Fig. 9). The apparent snow water content does not decline smoothly with a reasonable slope; rather it remains constant for a period, falls rapidly again, then repeats the pattern. The pattern remains unexplained.

Both of these examples suggest that under certain conditions the currently used sensor tanks do not provide enough surface area to properly register average snow water content.

Unlike manual snow measurements, which involve simple, independent field excursions, telemetered snow measurements require daily attention, careful maintenance, and complete, detailed record keeping. In short, they require intensive management.

In addition, snow sensors present a substantial management challenge because their components fall into several jurisdictions within State Government: The Communications Division is responsible for the radio and antenna and microwave network, the Division of Operations and Maintenance, DWR, is responsible for the data station, and the Snow Surveys Section, DWR, is responsible for the sensor, plumbing, and transducers.

Sometimes it is difficult to determine who is responsible for a particular problem. It is also difficult to keep complete equipment and maintenance records when several divisions are involved in servicing the sensor reporting network. The Snow Surveys Section has maintained station histories, but these are often incomplete, making it impossible to interpret the historical data.

The evidence suggests that substantial improvements in the management and design of the remote snow sensors is required in order to obtain complete and reliable snow water content records.

First, the sensor plumbing systems need to be more resistant to leakage. Every tube, valve and connector should be strong enough to endure mechanical stresses, corrosive soils, and thermal cycling typically encountered in snow sensor applications.

Second, as with the precipitation gauges, it is vital to provide a higher level of data protection at the remote site. This should include both a more reliable sensor system as well as equipment to log and retain the data in the event of telemetry failure. A more reliable sensor system can be obtained with existing components by introducing some redundancy into the system. For example, where stilling wells with water level recorders provide the primary snow water equivalent sensors, a pressure transducer could be connected to the base of the stilling well to report on a separate data channel. The cost of additional equipment to log and retain the data must be weighed against the level of data protection provided. For example, an electronic memory can provide data protection in the event of radio failure, whereas an independent recorder is needed to protect the data in the event of LCU failure.

Third, manual control samples are essential to the development of reliable sensor histories and should be continued. So many things can and do go wrong with snow sensor systems that manual samples provide the only reliable means of verifying sensor record accuracy.

Fourth, the daily snow sensor data must be checked to assure that sensor is responding properly to precipitation and temperature fluctuations. One must compare daily responses from a group of sensors in a basin to determine if one or more sensors is in error or is responding to site-specific anomalies.

Fifth, it may be necessary to increase the areal coverage of the sensor tanks to provide accurate readings under all snowpack conditions. This is particularly important for the spring melt period, when the snowpack may be unevenly eroded at ground level, and firm enough to bridge over the sensor tanks.

And finally, it is imperative that responsibility for each snow sensor site be clearly established. For each sensor one person should be in charge of monitoring the daily data, keeping a complete and accurate maintenance log, and assembling the station data records for use by others.

BUILDING STATION HISTORIES FROM TELEMETERED DATA

The telemetered precipitation and snow water content data now provides vital information for both flood and water supply forecasting. The precipitation data is used for real-time flood forecasting. The snow sensor data is used to estimate snow water content between monthly manual snow course measurements.

The data can also provide a basis for developing new water supply forecasting procedures. But such procedures require long, consistent records in order to establish a statistically reliable relationship between runoff volumes and hydrometeorological measurements.

Water supply forecasting procedures normally use snow and precipitation data as hydrologic indices rather than as absolute measurements of watershed parameters (Colson, 1970). The assumption is that there is a consistent relationship from year to year between the measured data and total watershed precipitation and snow water content. This assumption remains valid only as long as the catch characteristics of the instrumentation are unchanged.

But when the data is obtained through a telemetered hydrometeorological data network, several factors impair the development of such consistent records. The remote site equipment problems, discussed earlier, are a major obstacle. Solving these problems often means digging up and moving a snow sensor, changing a precipitation gauge, or changing the measurement instrumentation with resultant change in catch or accumulation characteristics.

The central computer occasionally goes down too, logging no data until it is repaired. Occasionally it will alter the data archived in its data files for no apparent reason.

A further obstacle to the development of good data records is the sheer volume of the incoming data: With hourly readings streaming in, there is simply not enough time to manually check and correct all the data from the telemetered stations.

It is also inconvenient to work with voluminous hourly data when the desired forecasting scheme operates on a time increment of days, weeks or months. What is the best choice of time increment for station data archives? The choice represents a compromise between volume and resolution. Daily data is typically used in deterministic models, whereas monthly data is usually used for regression models. A daily data increment was selected because this leaves the door open for the future development of either model type, yet does not result in excessively large data archives.

Ideally, the hourly data files should be analyzed by an experienced hydrologist to determine daily values, but this is a very expensive process. A practical strategy must rely heavily upon computer processing. One strategy, developed in the course of this study, relies on three programs to extract, plot, and complete the daily data files:

Program DISTIL, controlled by a master index file, can extract the daily data from the hourly data archives and assemble it in ASCII character files, for as many telemetered stations as desired. If successive data values differ by more than acceptable increments the program lists the daily data as missing. This preliminary filtering removes only the most blatant data errors, such as negative precipitation increments.

A second program, PLOT, interactively generates plots of the daily data for groups of up to five stations at a time. Such data plots provide a very efficient means for reviewing and correcting large volumes of data. Station maintenance notes can be copied directly onto the plots so that data anomalies can be visually correlated with equipment problems, if any.

Based on these plots the hydrologist can flag or correct data problems, and if supplementary data is available from untelemetered, on-site data accumulators, that data can be introduced to make further corrections or to fill data gaps.

Where telemetered data gaps exist, but there are no backup data accumulators at the remote site, the gaps can be filled by correlations between individual station records. A computer program, PEST, developed by the California Nevada River Forecast Center, computes the simple correlation coefficient between individual stations in a selected group, then fills gaps by estimates based on a simple linear regression procedure.

The complete station records should be readily transferable between computers so that they will be available to all interested users. To meet this goal the data will be stored on magnetic tape, in record-oriented character files, in a standard tape format.

The data files are organized according to formats customarily employed for each specific data type, so that existing data processing programs and simulation models can read them without modification. For example, daily precipitation data is stored in compressed daily format, in which only nonzero precipitation events are listed, along with the julian days of their occurrence.

On the other hand, snow sensor readings which will be typically greater than zero for half the year or more, are most efficiently stored in standard flow data format, which provides a specific location in the file for each day of the year.

As error free, consistent station histories in readily transferable format are developed, the full potential of the telemetered data network can be achieved: Real time data can then be used directly in developing improved water supply and flood forecasting procedures.

CONCLUSIONS

Telemetry of hydrometeorological data makes feasible real time flood and water supply forecasts. However, the telemetry process often imposes restrictions upon the field sensor design and introduces data gaps and errors. As a result, remote site data records may be incomplete and of poor quality, making it difficult to build complete, consistent station histories for developing new forecasting procedures.

Based upon an analysis of telemetered precipitation and snow sensor data, equipment, and maintenance records for the Feather River basin, California, a number of recommendations for improving data quality are suggested. They include:

1. The remote stations should be designed to log and save data in the event of power failure, telemetry system failure, or central interrogation station failure.

2. The primary sensors should be highly reliable, and critical components should be duplicated to provide adequate redundancy.

3. Responsibility for remote site data and equipment should be clearly established in order to achieve long-term data integrity. Complete records of equipment failures, maintenance trips and calibrations should be maintained.

4. A procedure for developing daily data files from the data base is recommended. The procedure relies on computer programs to extract the daily data from the compressed data files, plot the daily data for groups of stations, fill in gaps based upon nearby station data if on-site records are not available, and generate card image data files on magnetic tape for convenient access by all interested users.

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