THE SURFACE INSTRUMENT NETWORK

OF THE

UPPER COLORADO RIVER PILOT PROJECT

By

L. W. Crow COM[1/], C. F. Chappell[2/], and G. W. Jones[3/]

Introduction

The surface instrument network is a part of the work associated with the Atmospheric Water Resources Program of the United States Department of Interior, Bureau of Reclamation. This project is a portion of the Upper Colorado River Pilot Project. The Pilot Project has been divided into three phases of activity: (1) surface measurements, (2) seeding operations, and (3) evaluation. The first phase of activity, providing for obtaining surface measurements of precipitation and other pertinent meteorological parameters, was initiated under contract with Western Scientific Services, Inc. in the fall of 1968. This effort will continue throughout the project period.

Field activities are centered in a 3,300 square mile area of the San Juan Mountains of southwestern Colorado (Figure 1). The area boundary generally follows the 9,000' elevation contour on the south, west, and north. The Continental Divide forms the boundary on the northeast and east. Figure 2 is a map of the Upper Colorado River Pilot Project area. The topography is described as mountainous with roughly 35% of the area 11,000' msl in elevation or higher, and many peaks exceeding 13,000' elevation. This area is a major contributor to runoff in the Upper Colorado River Basin with an average annual runoff of 14" or some 2.5 million acre feet per year.

Purpose of the Instrument Network

The primary objective of installing and operating the surface meteorology network is to collect data and prepare a comprehensive data report for subsequent use in evaluating snowfall increases and other effects due to cloud seeding. This evaluation will be based on a 24-hour randomized experimental unit.

The instrument network for observing precipitation must therefore provide an accurate description of the 24-hour precipitation distribution with elevation, and provide for estimation of the areal distribution of accumulative seasonal precipitation. Real time observations for control of operational seeding activity are not a requirement of this network.

Four wind recorders, six temperature recorders, and three ice nuclei counters and snowflake replicators have been installed to further describe the sequence and microphysical characteristics of storms in the San Juan area. Discussion presented in this paper will be limited to the design and discussion of measurements obtained thus far from the precipitation network.

The data collected will be made available for evaluation purposes and for other studies in the form of comprehensive data reports and on punched cards.

Criteria For Network Design

In order to design a network which optimizes the number of measurements obtained for the effort expended, it was necessary to perform a number of studies prior to selection of the network sites. The following design studies were performed during the 1968-69 winter season.

1/ Western Scientific Services, Inc., Fort Collins, Colorado.

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Reconnaissance Surveys. Surveys were conducted within 15 hydrologic basins during the first winter season (shown in Figure 2). Potential sites in each of these basins were examined in December, February, and May via oversnow vehicle to determine the accessibility and suitability of sites for obtaining measurements; snow conditions which would be encountered on service trips as the snowpack accumulates; the length of travel and time required to reach potential sites; and the presence of hazards, such as avalanches, to service and maintenance personnel while enroute to these remote measurement locations.

Measurements from Other Sources. A number of other types of measurements have been made within the area, some with a historical record of 20 years or more, by other agencies such as the U. S. Weather Bureau, Soil Conservation Service, and the U. S. Forest Service. Data from these sources were collected and evaluated as to their usefullness for purposes of this project. The locations of useful measurements were noted and integrated into the network of data sources to be collected.

Preliminary Measurements. Observations of precipitation distribution with elevation were obtained daily on two mountain pass profiles to study detailed profiles of snow accumulation, develop procedures for determining interstation precipitation ratios, and to examine the correlation coefficients of sites with progressive separations in both distance and elevation. The correlation and standard deviation of multiple measurements at the same site was examined. Hourly, daily, and monthly accumulative precipitation amounts and distributions were reviewed to determine gage resolution and capacity requirements.

The results of these studies were compiled and controlling factors for designing the surface network then became evident.

1. Daily precipitation measurements, or sets of such measurements, are the primary observations for use in evaluating seeding effects.
2. A one-hour resolution of recording precipitation measurements is desirable for describing the sequence and movement, hourly intensity distribution, and diurnal characteristics of precipitation in the San Juan Mountains.
3. Daily observations of snowfall along mountain highways transversing the area are required and will serve as primary data to describe the distribution of precipitation accumulation with height.
4. Reasonable estimates of precipitation distribution with height (within $\pm$ 5%) can be made on profiles intermediate between mountain pass profiles by installing two weighing type precipitation gages at locations which are separated by 1,000' or more in the vertical.
5. The shape of the precipitation-elevation relationship; i.e., whether it is convex, linear, or conceve; is influenced by topographic features of the mountain massive in the vicinity of profile installations.
6. Reasonable estimates of accumulated precipitation for purposes of areal distribution can be made utilizing interstation ratio procedures for a distance of about 10 miles from a particular representative measurement site.
7. About 20 gages located in 10 hydrologic basins can be serviced and maintained on a monthly schedule by two persons and one oversnow vehicle.
8. The capacity of recording precipitation gages to be installed near 9,000' and higher than 10,000' on intermediate profiles must be approximately 12" and 20" respectively if a monthly servicing schedule is maintained.
9. Resolution of 0.01" precipitation is preferred for recording gages. Reasonable estimates of daily precipitation amounts obtained from gages having 0.10" resolution can be derived from adjacent gages having 0.01" resolution by use of interstation ratios.

Description of the Network

The set of information consisting of preliminary studies and resulting design criteria was utilized to select the measurement sites comprising the surface network for the Upper Colorado River Pilot Project. In some cases, the criteria for design were not compatible and a compromise solution was accepted. For example, a reliable hourly recording precipitation gage with measurement resolution of 0.01" and 20" capacity was not commercially available. It was necessary to sacrifice resolution in favor of capacity for installation at high elevation remote locations.

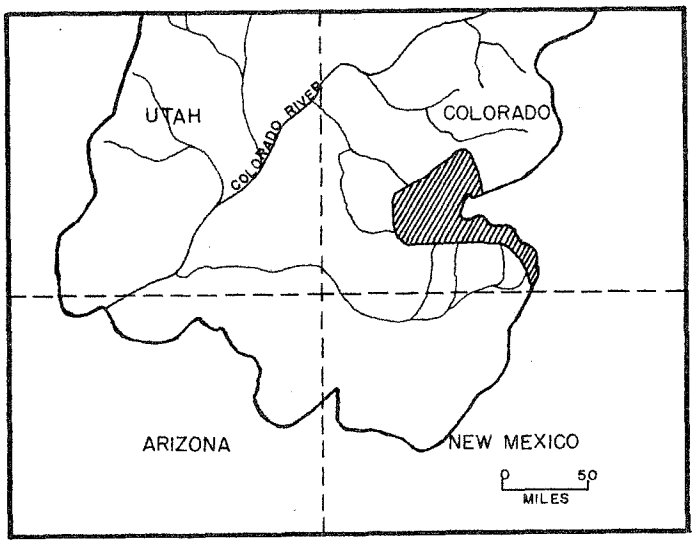

FIGURE 1: LOCATION OF THE UPPER COLORADO RIVER PILOT PROJECT AREA

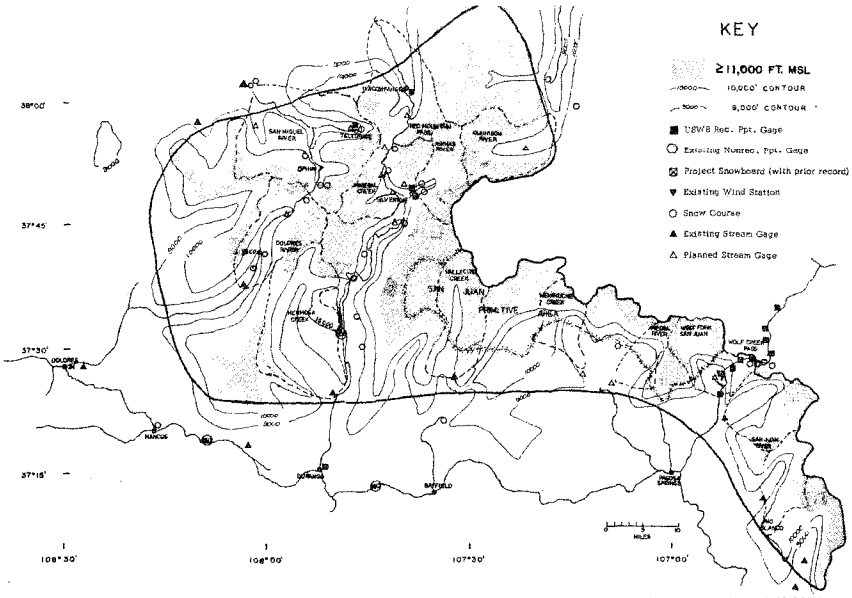

FIGURE 2: TOPOGRAPHY AND LOCATION OF HISTORICAL DATA MEASUREMENT SITES IN THE SAN JUAN MOUNTAIN AREA

The surface network for precipitation measurements utilizes the set of measurements from other sources and measurements obtained from the network operated by the Pilot Project.

The location of measurement sites which yield data from other sources are shown in Figure 2. Six recording hourly precipitation gages and seven daily gages are maintained by the U. S. Weather Bureau. Measurements from 26 additional Weather Bureau sites (not shown) adjacent to the Pilot Project area are also being collected. The Soil Conservation Service has established a number of snow survey courses in the San Juan area and collected snowpack accumulation data on a monthly basis for use in forecasting runoff available to water users as the snowpack accumulates. Currently 19 such sites are observed within the Pilot Project boundaries with eight high elevation sites having a record of 24 years or more. The U. S. Forest Service maintains three daily precipitation gages and has installed six seasonal cumulative type precipitation gages. Measurements from these sources serve as a part of the complete data set which describes precipitation in the San Juan area. The cooperation shown by these agencies has contributed significantly to the successful initiation of the surface measurement effort.

The Upper Colorado River Pilot Project surface measurement network is shown in Figure 3. Profile measurements for description of daily precipitation amounts are in operation on three mountain pass highways crossing the eastern, middle, and western sections of the project area at Wolf Creek, Red Mountain, and Lizard Head passes respectively. A total of 42 daily precipitation stations and nine recording weighing-type gages are located on these profiles. The remainder of stations shown as squares in Figure 3, not located on mountain pass highways, comprises the portion of the network which describes precipitation in the more remote areas of the project. Sixteen instruments in eleven hydrologic basins are currently in operation with an additional eight gages in four basins scheduled for installation and operation during the coming winter season 1970-71. These installations, generally two in number per basin, provide data for estimating the precipitation distribution with height at points between the primary mountain pass profile installations, and therefore provide for distribution of accumulative precipitation amounts over the project area. Daily precipitation amounts recorded will serve as primary data for analysis of seeding effects. Gages with 12" capacity were installed at elevations near 9,000' and 20" capacity at higher elevations.

The map in Figure 4 shows the combined network of some 116 data points which comprise the surface network for observing precipitation in the Upper Colorado River Pilot Project area.

Characteristics of Precipitation in the San Juan Mountain Area

Preliminary analyses of Pilot Project data have dealt with investigations which indicate the confidence with which these data may be used, development of procedures for describing the precipitation-elevation relationships, and the development of techniques for distribution of precipitation over the area.

Accuracy of the Observations. Three sets of data were examined to gain indications of the accuracy and representativeness of the measurements. For purposes of horizontal spacing of network stations, it was necessary to determine how stations with both horizontal and vertical separation are correlated. Correlation coefficients were computed for the set of daily precipitation data observed on mountain pass profiles in the 1968-69 winter season. The coefficients derived ranged from .97 to .99 for locations approximately two miles apart to .94 to .96 for locations of 10-to-12 miles separation. Precipitation can therefore be estimated with a high degree of confidence from representative stations for a distance of 10 miles.

The problem to be then satisfied is to determine if data, intended for areal distribution purposes, are representative of the precipitation which accumulates in its immediate area. Two approaches to the solution of this problem were investigated. First, the accumulative precipitation amounts in gages on mountain pass profiles were compared to amounts observed by the Soil Conservation Services at snow courses located at or near the gages. These data are shown in the table.

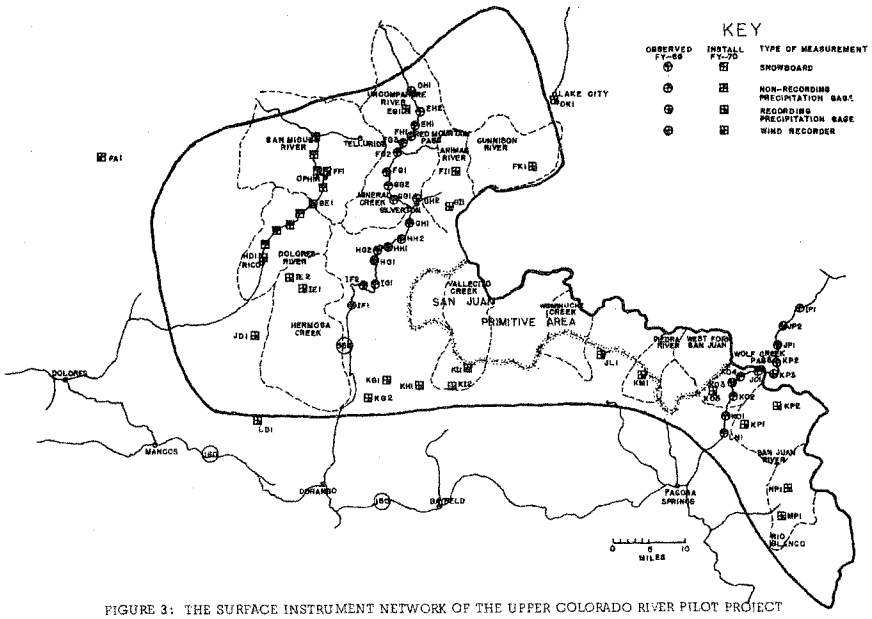

FIGURE 3: THE SURFACE INSTRUMENT NETWORK OF THE UPPER COLORADO RIVER PILOT PROJECT

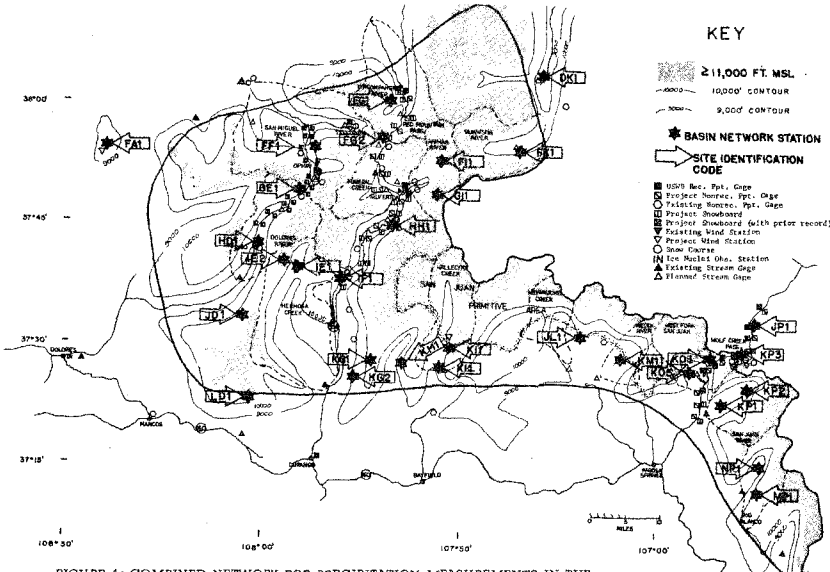

FIGURE 4: COMBINED NETWORK FOR PRECIPITATION MEASUREMENTS IN THE SAN JUAN MOUNTAIN AREA.

Comparison of SCS Snow Survey and Pilot Project
Accumulative Precipitation Amounts--January 1 - April 1, 1969

SCS Snow Course	Amount	Project Site	Amount	Difference
Wolf Creek Summit	22.9	J01	26.15	+3.35
Upper San Juan	24.4	K04	27.12	+2.72
Spud Mountain	23.0	HH1	23.50	+0.50
Red Mountain	24.0	FG2	24.11	+0.11
Berthoud Pass	9.2	K7B	7.85	-1.35
Mineral Creek	7.0	GG2	7.64	+0.64
Ironton Park	5.5	EH1	6.43	+0.93

These measurements are felt to be in good agreement. The tendency is noted for precipitation amounts from Pilot Project sites to be on the order of 10% greater than snow course amounts and is under further investigation. It is felt the deviation may be due to evaporations of snowpack from snow courses, slightly different characteristics of the observation sites, or due to differences in observation method.

The second approach was to compare two measurements at the same observation sites by computation of the standard deviation of a set of daily measurements. Observations were obtained each day of precipitation occurrence in a shielded 8" precipitation gage and on a nearby snowboard placed on the snow surface. The set of data used for this computation included estimates derived from interstation ratios on days when observers noted snowboard amounts did not represent surrounding snowfall due to wind swept or drifted conditions. The standard deviations computed were:

Site #	No. of Observations	Range of Observations (inches ppt.)	Standard Deviation (Corrected Data) (inches ppt.)
K7B	37	0.00 - 0.46	0.03
K7A	37	0.00 - 0.45	0.02
J7C	37	0.00 - 0.51	0.03
LN1	16	0.00 - 0.34	0.01
K01	16	0.00 - 0.35	0.01
K02	16	0.00 - 0.35	0.01
K04	16	0.00 - 0.32	0.03
J01	16	0.00 - 0.47	0.03

This analysis again indicates one can be reasonably confident when utilizing carefully chosen point measurements for areal distribution of precipitation amounts.

Procedures for Describing Precipitation-Height Relationship. Description of the profile of snowfall accumulation with elevation is keyed to the detail provided by closely spaced sites on the mountain pass profiles. These primary profiles supply the basic shape of the precipitation-elevation curve for portions of the project which are similar in topography and exposure. Three examples of precipitation-elevation curves are shown in Figure 5. The shaded areas which overlay the profile curves define a region for which measurements coincide with $\pm$0.5" of a mean precipitation-elevation profile. Greater skill and accuracy in constructing these relationships will develop as the Pilot Project progresses.

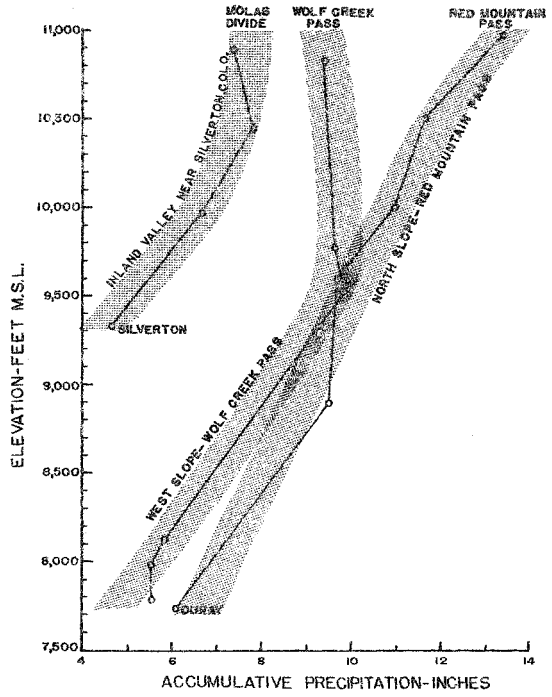

FIGURE 5: OBSERVED PRECIPITATION ON MOUNTAIN PASS PROFILES FOR THE PERIOD OCTOBER 15, 1969 - MARCH 1, 1970

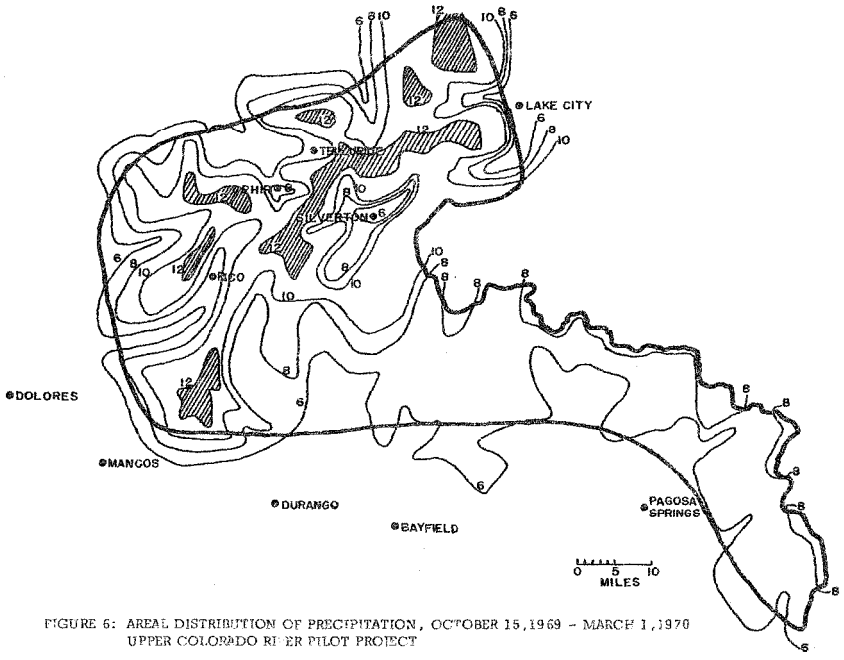

FIGURE 6: AREAL DISTRIBUTION OF PRECIPITATION, OCTOBER 15,1969 - MARCH 1,1970 UPPER COLORADO RIVER PILOT PROJECT

Curves for precipitation profiles in basins between mountain pass profiles are derived by placing properly shaped profiles on points which represent observed precipitation at known elevations.

Example of Areal Distribution of Precipitation. A reasonably representative map of accumulated precipitation for the Pilot Project area may now be drawn by utilizing the precipitation-elevation curves and a topographic map of the area. Figure 6 shows the areal distribution of precipitation for the period October 15, 1969 to March 1, 1970 for the Upper Colorado River Pilot Project area. The isohyets are inches water equivalent.

Analysis programs are being developed for computer computation and drawing of areal precipitation distribution maps.