PROGRESS REPORT

ON

HYDROLOGIC STUDIES OF THE UPPER COLORADO RIVER

Prepared for Presentation at

SIXTEENTH ANNUAL MEETING

COLORADO RIVER WATER FORECAST COMMITTEE

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by

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INTRODUCTION

The completion of Glen Canyon Dam will be an important milestone in the plans for control of the water of the Colorado River. Prior to the beginning of construction, it was recognized that completion of the structure would not constitute a solution for all the problems of water control; on the contrary, the problems of operation of this and other structures required an increased knowledge of many hydrologic factors for intelligent solution.

A research project to examine some of the pertinent hydrologic and economic factors associated with problems of the Upper Colorado River was conceived several years ago as a joint study among three groups at the University of Colorado and at Colorado State University. These groups included the Bureau of Economic Research and the High Altitude Observatory at Colorado University; and the Department of Civil Engineering at Colorado State University. Mr. Loren Crow has served as a Meteorological Consultant for the project.

The research project began in September 1959. It is scheduled for completion in the fall of 1961. This paper is a progress report on some of the work that has been accomplished to date. It gives a preview of some of the results that will be reported at the conclusion of the project.

OBJECTIVES

The objective of the study was to combine the efforts of the three groups in a broad-scale attack on the various phases of the problem:

1. Colorado University Department of Economics: to examine some of the economic implications of the operation of the Glen Canyon reservoir. Of particular initial concern is the filling schedule.
2. High Altitude Observatory: to examine the question of predictability of weather cycles and precipitation amounts in the Colorado River Basin, particularly in relation to high-altitude meteorological parameters and variations in solar activity.
3. Colorado State University: to obtain frequency distributions of pertinent meteorological parameters to provide basic climatological data in a more useable form than is presently available. This involves use of computer facilities, and includes the steps necessary to put back-weather records into format suitable for such computer analyses.

Since the Colorado River Water Forecast Committee is concerned primarily with physical rather than economic factors, this paper will be confined to a discussion of work done at Colorado State University and the High Altitude Observatory.

RESULTS

Dr. Paul Julian of the High Altitude Observatory of the University of Colorado has concentrated his study on two aspects:

1. To analyze past records of precipitation and streamflow in the Upper Colorado River Basin to establish the presence or absence of any predictable element in the records.
2. To analyze past records of precipitation and streamflow in the Upper Colorado River Basin to establish the presence or absence of a direct relation with solar activity that would be of value in predicting future variations in streamflow.

The results of the first study indicate that precipitation amounts by season are indistinguishable from a series of random numbers, but that streamflow amounts by water year at Lee Ferry <u>are</u> distinguishable from a series of random numbers. The runoff data at Lee Ferry exhibit a slight persistence from year to year; if a given year is low, the odds are that the next year will be low, etc.

Results from Dr. Julian's record study may be summarized by his statement that there is no evidence of a <u>direct</u> relationship between solar activity as measured by sunspot number and precipitation or streamflow.

The results of Dr. Julian have been substantiated by independent work done by Dr. V. M. Yevdjevich, who joined the Civil Engineering Staff at Colorado State University in 1960. He has examined what he calls

"Annual Effective Precipitation," defined as the net amount of streamflow appearing as runoff during a water year, excluding storage from previous water years. His results confirm those of Dr. Julian in that no significant correlation could be found from year to year in "Effective Precipitation." However, significant serial correlation was found in observed annual runoff volumes.

These results, arrived at from independent studies, lead to the conclusion that there is little probability of using "cycles" of any frequency as a prediction tool for annual precipitation amounts.

The fact that there is a significant serial correlation in observed annual runoff volumes leads one to seek the causes for the non-random component of fluctuation. Three possible reasons are suggested:

1. Carryover from year to year. This can be construed as meaning both positive carryover (excess water) and negative carryover (moisture deficit).
2. Systematic errors in collection of basic data, such as changes from staff gage readings to recorders, etc.
3. Non-homogeneity of records, such as trans-mountain diversions, increased evaporation from reservoirs, increased consumptive use, and other similar factors.

Such factors tend to increase the non-random component of fluctuations of streamflow. To these factors must be added the irregularities introduced by sampling error.

When sampling error is added to the three factors listed above, there is little variability in runoff which remains that can be explained in terms of other possible physical factors, such as cyclic variations, solar activity, broad-scale atmospheric circulation parameters, or other similar causes.

Thus a major result of the joint study is negative; that hydrological parameters over the basin show little promise as long-range predictors (beyond one-to-two years) of future runoff.

DIRECTION OF FUTURE WORK ON THE FORECAST PROBLEM

Lacking physical parameters over the basin which can be used in making long-range forecasts of river flow, what direction should be taken in future work to improve our ability to predict the flow of the Colorado River? Four avenues are suggested:

1. To improve the physical forecasts of river flow for short periods. This will involve an extension and improvement of the forecasting techniques reported in this and prior meetings of the Colorado River Water Forecast Committee. Some of the (refined) climatological data which will be available from the work done at Colorado State University in the current project may be of assistance in work of this nature. Improvement in forecasting techniques will, no doubt, continue to be a major objective of the agencies represented at this meeting.
2. To extend forecasts of medium time range by looking <u>outside</u> the basin

for parameters which may serve to improve forecasts in this time range. Such studies might examine parameters such as ocean temperatures, air mass characteristics outside the basin, and other atmospheric circulation parameters for improvement of forecasts in this time range. Work of this nature is being planned by Drs. Riehl and Yevdjevich at Colorado State University.

3. To use pure probability methods in making forecasts. Such an approach offers promise of giving a range of values that can be expected, with the likelihood of each, but is somewhat limited in its answer to the question of what precisely can be expected next year.
4. To combine all of the first three methods. This procedure appears to offer the greatest prospects for success, by combining the most promising methods available today.

TYPES OF DATA WHICH WILL BE AVAILABLE FROM THE PRESENT STUDY AT COLORADO STATE UNIVERSITY

Work at Colorado State University has been concerned with analysis of existing climatological data, in an effort to provide a refinement of basic data useful in any of the four types of studies listed above.

Fig. 1 shows the stations from which climatological data is being analyzed. Data from these stations have been collected by unpaid cooperative observers of the U. S. Weather Bureau. Records of daily maximum and minimum temperatures, precipitation, snowfall, and other data are available for about 50-60 years prior to 1960. Since 1948 the Weather

Bureau has been placing all such data on IBM cards for machine tabulation and analysis. Prior to 1948, however, climatological data were in tabular form only, not in a format suitable for machine computation and analysis.

Placement of Back-weather Records on Punched Cards - The first phase of the work at Colorado State University was to place the climatological records for the stations shown in Fig. 1 on IBM cards for the periods of record available prior to 1948. Additional IBM cards were obtained from the Weather Bureau for the period after 1948. The total number of daily weather records that are now available in IBM card form in and near the Upper Colorado River Basin at Colorado State University is now about 608,000, as shown in Table 1.

TABLE 1

SUMMARY OF CARD PUNCHING COMPLETED

Stations In	Number Of Stations	Station-Years Punched By CSU	USWB	Total
Colorado				
Western Slope	18	839	170	1,009
Fort Collins	1	70		70
New Mexico	1	42	12	54
Utah	5	113	137	250
Wyoming	5	219	58	277
Total Station-Years		1,283	377	1,660
Total Number of Cards (Approximate)		470,000	138,000	608,000

Reduction of Daily Precipitation to Storm Totals - A first step in the analysis of these data was a reduction from daily precipitation amounts to "storm totals". (A "storm total" is defined as the total amount of precipitation received during a period of time in which precipitation greater than a trace was received on each day.) This procedure reduced the total number of cards from about 600,000 to about 60,000.

Frequency Analyses - Following this reduction to storm totals, various analyses are being performed to determine probabilities of precipitation for annual, monthly, and seasonal amounts. In addition, various analyses are being performed to determine the probability of occurrence of given amounts of precipitation, beginning at various times of the year. It is not possible to give a complete description of these analyses in this paper. The following example illustrates the type of information that is being prepared and its possible use in problems of forecasting runoff.

Illustrative Example - Data for this example are drawn from a special study by Mr. Loren W. Crow, who acted as Meteorological Consultant to the project. In this illustration, data are drawn from the stations in Colorado shown in Fig. 1.

Fig. 2 shows average monthly precipitation totals at three elevation levels and resultant runoff in inches after arbitrary reduction for evaporation at these same levels. ("High level" stations are those higher than about 8000 ft msl; "medium level" between about 8000 and 6200 ft msl; and "low level" stations are below 6200 ft msl.)

Fig. 2 illustrates a well-known fact--that after consideration of evaporation losses, the contribution to runoff from precipitation from low-level stations is very small in relation to that from high-level stations.

Determination of such "Net Runoff" amounts and resultant frequency analysis is tedious and time consuming with manual methods, but easy to obtain with machine analysis techniques. Such determinations are being made as part of the work being done at Colorado State University.

Application to 1960-61 - Application of such data can be illustrated with reference to the water year 1960-61. The accumulated amounts of average precipitation and "Net amount contributing to runoff" during the water year are shown in Fig. 3. Observed values of the same parameters for 1960-61 through February are also shown in the same figure.

At any particular date, the forecast problem is essentially this: Knowing the total accumulated precipitation to date and the state of the basin, to forecast the total runoff "Z". With these factors known, an estimate must be made of the probability of receiving "X" inches of precipitation to yield "Y" inches of runoff during the remainder of the water year to yield the average annual runoff "Z'".

Data from the present study at Colorado State University will provide information which can be used in determining the probabilities of receiving "X" inches of precipitation, which in turn should be of value in estimating the likelihood of receiving "Y" inches of "precipitation contributing to runoff" to yield a "normal" runoff "Z'" instead of a lower amount "Z".

Significance - At the present time the analyses have not been completed which would permit estimating these probabilities for the current water year. Several points are worthy of note, however:

1. Application of a procedure as described above would permit forecasts of increasing accuracy as the water year progresses. This raises the question of whether the operational needs of the various interested groups could be satisfied with a number of forecasts prepared at successively later dates during the water year, each of which could be expected to be of increased accuracy as the water year progresses.
2. The data which will be available in the frequency analysis of "Net" precipitation will be limited, and no claim is made for the accuracy of the estimates of evaporation losses used in their determination. However, the basic data are available from which refinements could be made to obtain improved estimates of obtaining values for "Y" (runoff deficit). Further study of this procedure is recommended.
3. Basic data for further studies of this type are available in the IBM cards of daily and storm precipitation which are on file at Colorado State University. Further studies for specific problems could utilize these data in analyses by machine methods.

SUMMARY

The indications from the joint study may be summarized as follows:

1. No significant serial correlation was found between annual precipitation amounts.

2. Significant serial correlation in annual runoff volumes can be explained largely in terms of hydrologic factors within the basin.
3. Probabilistic methods are considered most promising for predictions of runoff volumes for time periods in excess of 1 to 2 years.
4. Improvement of forecasts of river flow should result from further study of short-range (approximately 6 months) and medium-range (6 months to 1 to 2 years) forecasting techniques. For such studies, use of the refined climatological data and precipitation probabilities is recommended, such as those prepared by Colorado State University.
5. A combination of improved physical methods and probabilistic techniques appears to offer greatest promise for solution of future forecast problems.

The results of the joint study which has been presented here do not constitute a panacea for forecast problems on the Colorado River. However, it is hoped that the results will constitute a step in the direction of progress on the problems of forecasting river flow on the Colorado River--a problem of marked difficulty which is of economic importance to all of western United States.

KENDALL
BEDFORD
BORDER
WYOMING
EVANSTON
DIXON
JULESBURG
FT. COLLINS
STEAMBOAT SPGS.
ELKHORN
ASHLEY
WRAY
AKRON
MEEKER
FRASER
THEODORE
(DUCHESNE)
BURLINGTON
RIFLE
GLENWOOD SPGS.
DILLON
ARRIBA
HIAWATHA
LIMON
COLLBRAN
EADS
GRAND JUNCTION
CRESTED BUTTE
CHEYENNE
WELLS
RUSH
PAONIA
UTAH
DELTA
GUNNISON
HASWELL
MONTROSE
LAMAR
HOLLY
ROCKY FORD
TELLURIDE
COLORADO
TWO BUTTES
ESCALANTE
SILVERTON
GRAYSON
(BLANDING)
CORTEZ
PAGOSA SPGS.
SPRINGFIELD
DURANGO
DULCE
NEW MEXICO

Fig 1. Stations for meteorological data used in this study.

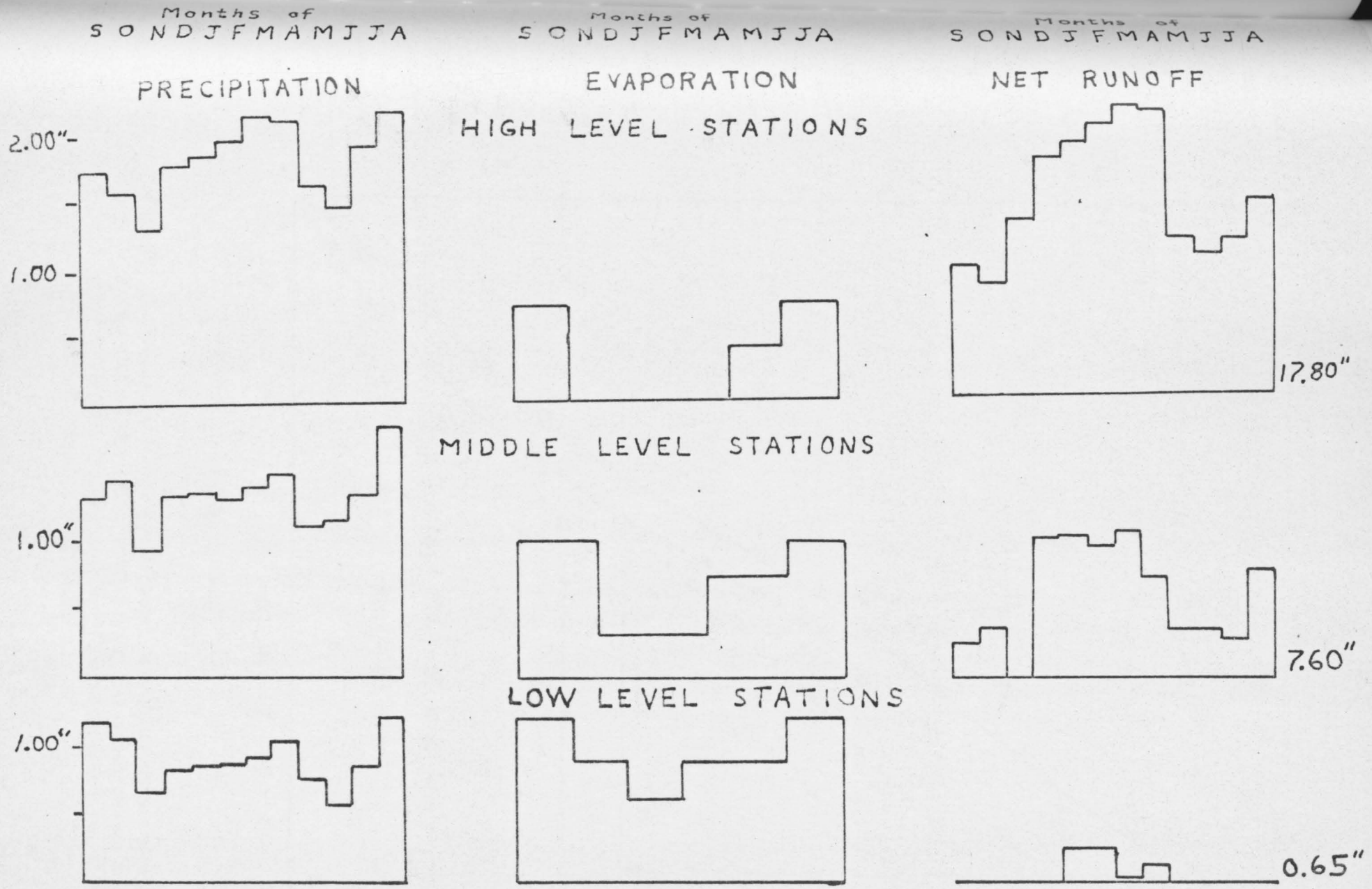

Fig. 2. Average monthly precipitation totals at three elevation levels and resultant runoff in inches after arbitrary reductions for evaporation at these same elevations. Values shown are for stations in Western Colorado shown in Fig. 1.

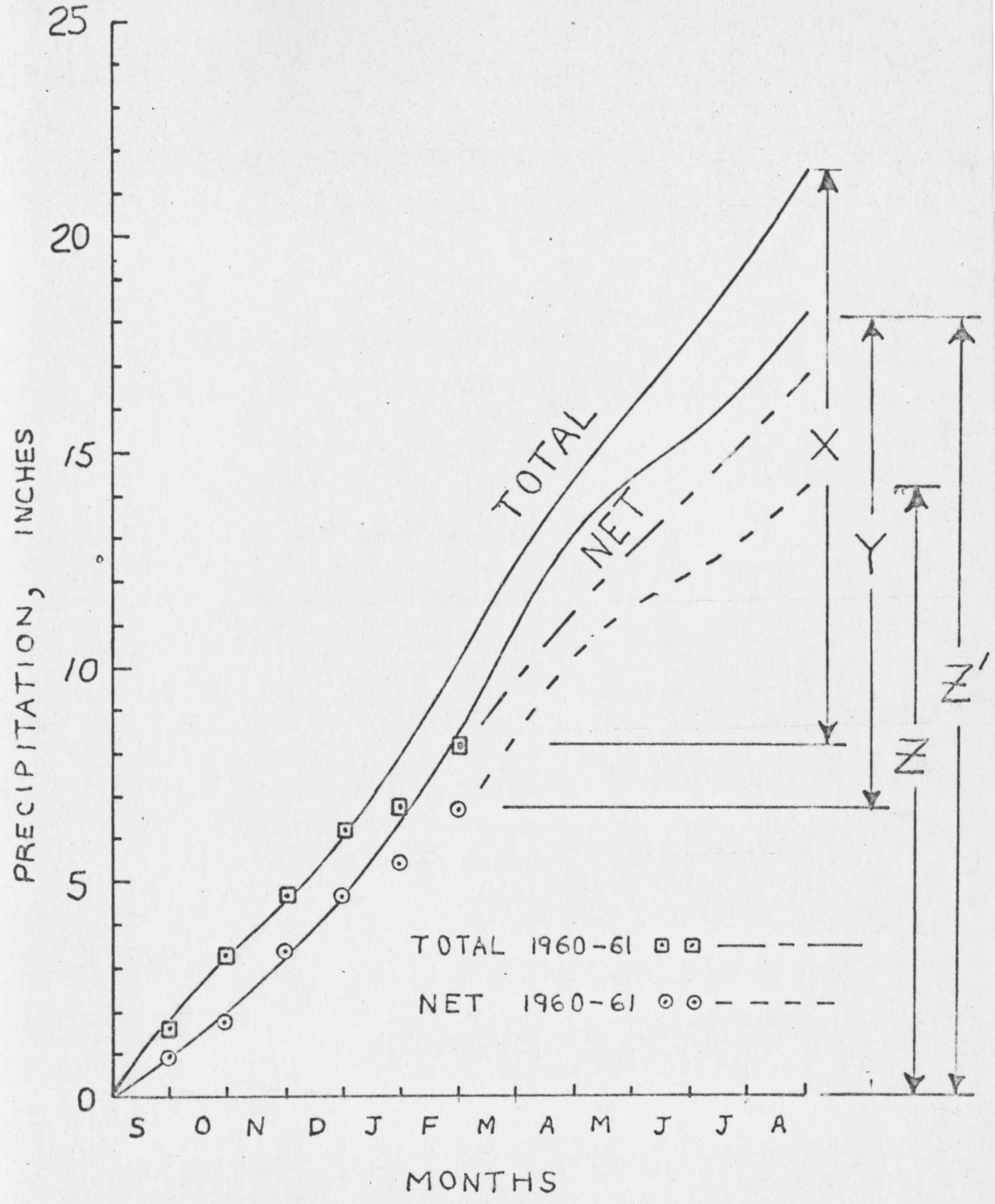

Fig. 3. Accumulated averages of total precipitation and net precipitation contributing to runoff during the water year, and amounts for 1960-61. Values are for selected stations in Colorado at elevations above 8000 ft msl.