PRELIMINARY REPORT

of

PRECIPITATION FREQUENCIES AND POTENTIAL YIELDS OF RUNOFF WATER AT 18 WEATHER STATIONS IN COLORADO IN THE UPPER COLORADO RIVER WATERSHED

Prepared for

State of Colorado

By

LOREN W. CROW, Consulting Meteorologist

March 10, 1960

Report No. 29

PRELIMINARY REPORT

of

PRECIPITATION FREQUENCIES AND POTENTIAL YIELDS OF RUNOFF WATER AT 18 WEATHER STATIONS IN COLORADO IN THE UPPER COLORADO RIVER WATERSHED

Prepared for

State of Colorado

By

LOREN W. CROW, Consulting Meteorologist

March 10, 1960

Report No. 29

T A B L E   O F   C O N T E N T S

Figures and Tables are placed immediately following the page on which they are first mentioned.

SUMMARY

Median precipitation and median runoff figures are consistently below the published average figures in a semi-arid climate. The difference is least for high mountain stations and highest for the low, hot portions of the watershed above Glen Canyon.

The total annual runoff from the entire watershed above Glen Canyon fluctuates between approximately 1 inch in very dry years to 3 inches in very wet years.

Most of the runoff in the Upper Colorado River Basin is produced from infrequent storms delivering between .5 and 1.5 inches per storm.

Large single storms which can add 1 inch runoff to the entire watershed above Glen Canyon do occur, and the yield from such a single storm can add 6,000,000 acre feet to that year's annual flow.

Frequency and characteristics of major storms deserve continued and detailed analysis effort.

There is a carryover effect from heavy precipitation years to subsequent drier years at high elevations. This produces frequency arrays of annual values which are abnormally concentrated near the median. These combine with the highly-skewed array patterns from low elevation sub-watersheds to give a combined frequency pattern at Glen Canyon which is nearly (but not quite) normally distributed.

By reducing actual precipitation data in amounts that approximate evaporation losses at different times of the year and at different elevations, adjusted precipitation data can be obtained. These data have a much closer relationship to subsequent runoff measurements than the original unadjusted data.

INTRODUCTION

With water as the major limiting factor on the agricultural, industrial, and economic development of the upper basin of the Colorado River it becomes imperative that continued efforts be made to understand the sources of supply of such water. The overwhelming upstream source of moisture for the State of Colorado is the atmosphere.

This is a preliminary study of some precipitation and temperature records at 18 Colorado stations located in the drainage area of the Colorado River. It is expected that the present preliminary analysis and the further, more elaborate analyses of these weather records when the data have been placed on punch cards will add an increment of knowledge to understanding the nature of precipitation frequencies and resultant runoff probabilities. Such information can eventually improve the planning decisions of all agencies concerned with water supplies and uses in the upper basin of the Colorado River.

Early last fall a review was made by Mr. Paul C. Jennings of the available literature on the climatology of the Upper Colorado River Basin. The 32 reference annotated bibliography, although not included in this preliminary report, was available to all personnel concerned with planning this current research effort. In addition to this literature review, background discussions took place either in person or by correspondence with: Colorado River Forecast Committee, U.S. Geological Survey, the Denver and Boulder City Offices of the U.S. Bureau of Reclamation, Upper Colorado River Commission, and the U.S. Weather Bureau.

The placing of all daily data prior to 1948 on punch cards is continuing at Fort Collins. This work is being performed by Colorado State University Research Foundation under the direction of Dr. A.R. Chamberlain and Dr. R. A. Schleusener. Data from 1948 onward have already been placed on punch cards by the U. S. Weather Bureau, and a duplicate set of these cards has been furnished to this project by the National Weather Records Center in Asheville, North Carolina. Correspondingly, a duplicate set of cards for the entire period prior to 1948 will be made and forwarded to the National Weather Records Center when all the punching has been completed.

Following the completion of punching of all past data, the cards will be processed and tabulated by electronic computer techniques.

The detailed weather records for each of the stations treated in this report were supplied by the United States Weather Bureau. Mr. J. W. Berry, who is in charge of the Weather Bureau's Climatological Office in Denver, has been very helpful in assembling these data.

The author is indebted to Dr. Morris E. Garnsey for his supervision and guidance in this entire research project. Dr. Richard A. Schleusener has been particularly helpful in directing the detailed hand tabulation of large masses of data. He was aided by Research Assistant George L. Smith and Students W. C. Hopper, C. D. Thomas, D. L. Kaser, and L. R. Maxey.

Assisting the author in analysis work and in preparation of this preliminary report were Mr. John Moore, Meteorologist, and Mrs. Helga Slauson, Secretary.

I. WEATHER STATIONS ANALYZED

Daily weather records of precipitation and temperatures are currently recorded by over 250 conscientious cooperative observers throughout the entire State of Colorado. A great many of these observing locations have been started within the past 30 or 40 years. However, records for several localities extend back to approximately the beginning of the current century, a few of them going back into the early 1890's.

In choosing the 18 stations which have served as background for this preliminary analysis, it was desirable to choose a group of stations which were spread throughout the upper drainage area of the Colorado River and to utilize stations having a reasonably long period of record. Figure 1 shows the location of these stations. Figure 2 shows the period of record for the 18 stations for which data have been tabulated and for which daily data are being placed on punch cards.

Some broken records are available prior to the dates indicated in this chart; however, the general series of continuous record, which is almost entirely complete, are represented in the time scale shown in Figure 2.

Stream flow records on a monthly basis beginning in 1912 were published for Lees Ferry* in USGS Water Supply Paper 1313. It was thus decided that for the preliminary hand analysis daily records from 1912 onward would be tabulated in detail for each of the several stations.

The importance of elevation is considerable, both with respect to temperature ranges and total precipitation amounts that are experienced at the

*Upstream from Lee Ferry which is the dividing point between the Upper and Lower Basins of the Colorado River. The Paria River enters the Colorado River between these two points.

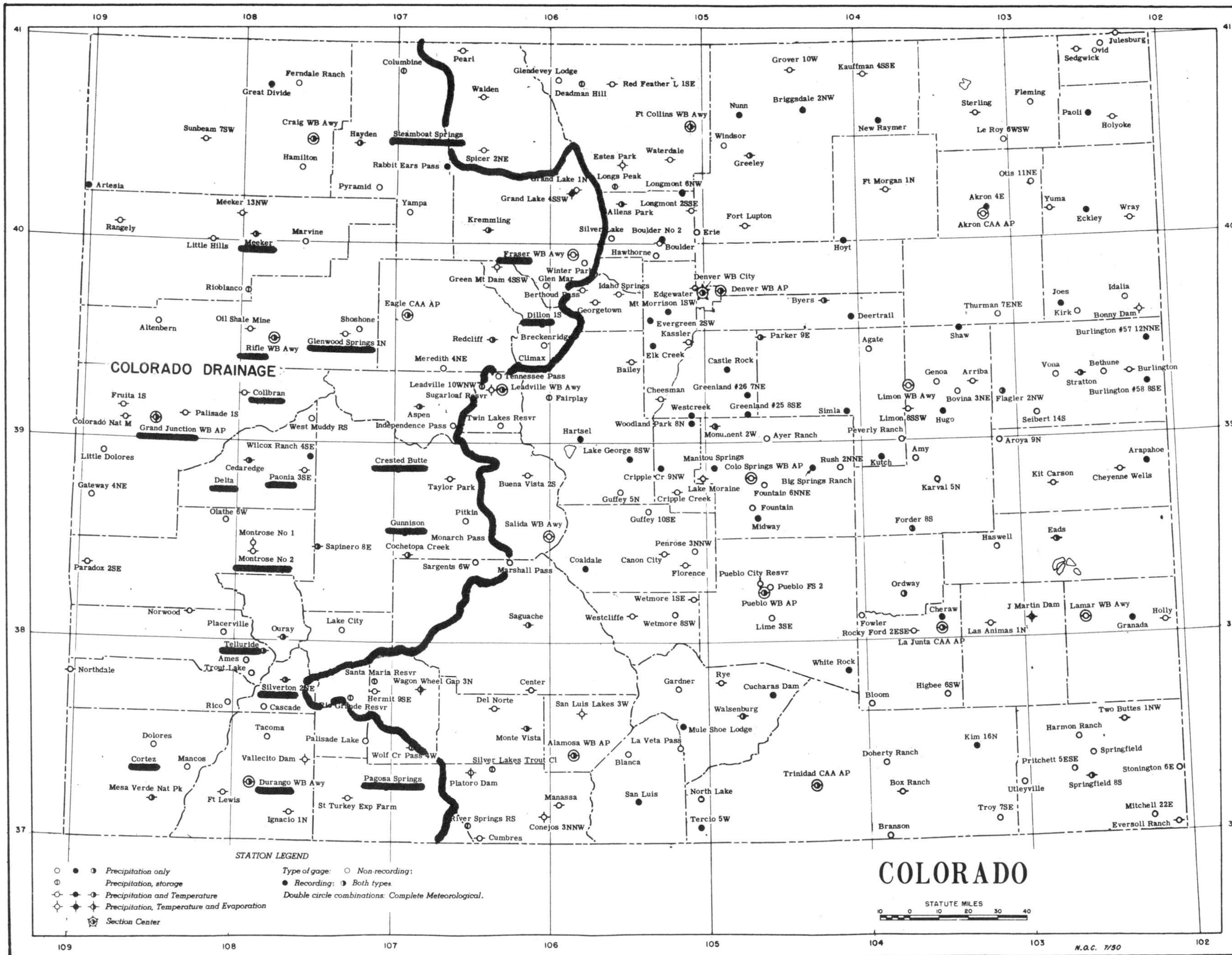


Figure 1. Location map of Colorado weather stations for which records are studied in this report.

GPO-S.F.-F.S.O.

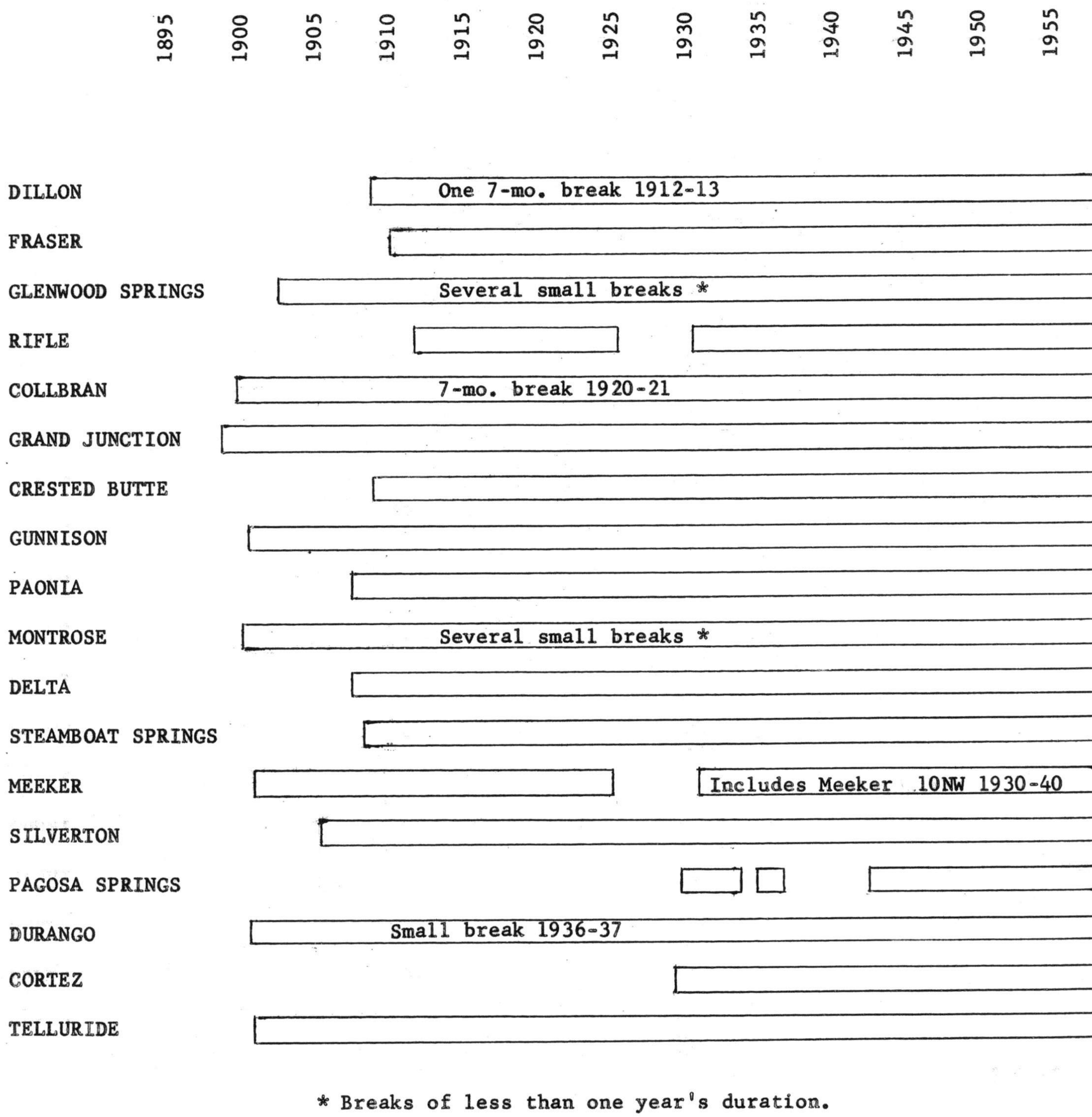


Figure 2. Bar charts showing the period of record of daily precipitation amounts and daily maximum and minimum temperatures for 18 Colorado localities examined in this report.

various stations. Spreen has shown that direction of the terrain exposure is also an important factor in determining the amount of total precipitation that may be expected at given high elevation stations in Colorado. Table I is presented to show the comparative relationship of elevation, precipitation amounts, and annual temperatures.

In order to gain a general understanding of the variations between three broad ranges of station groups, arbitrary grouping into three levels of weather stations has been made in the right-hand side of Table I. It is fully realized that each individual station has its own unique characteristics as far as weather records are concerned, but the convenience of considering the three levels will allow some generalizations that can be developed in this report.

II. WHEN PRECIPITATION OCCURS

The pattern of monthly precipitation amounts is shown in Figure 3 for the three groups of stations representing the three general altitude levels. It can very easily be noted that two months stand out as low average months. They are the months of November and June, with November being the lowest month in the entire year.

Although this chart does not illustrate the background of the type of storm that produces precipitation during the various months of the year, it can be stated that the late winter and spring period of heavier precipitation throughout the year generally occurs from broad general storms covering thousands of square miles of cross-sectional area as they move through Colorado. In contrast, the relatively high summer precipitation peaks of July, August, and September are a result of local shower activity, each storm

TABLE I

COMPARATIVE LISTING OF EIGHTEEN COLORADO WEATHER STATIONS BY ELEVATION, PRECIPITATION, AND TEMPERATURES

Above MSL (Ft.)	By Elevation	Annual Average (inches)	By Precipitation*	Annual Average (^{o}F.)	By Temperatures	Arbitrary 3-Level Grouping
9400	Silverton	24.85	Silverton	33	Fraser	**High Level Stations**
8900	Dillon	24.00	Telluride	34	Dillon	Fraser Dillon
8855	Crested Butte	23.30	Steamboat Springs	35	Silverton	Silverton Crested Butte
8756	Telluride	22.90	Crested Butte	35	Crested Butte	Telluride Steamboat Springs
8560	Fraser	19.28	Glenwood Springs	37	Gunnison	
7694	Gunnison	19.16	Durango	39	Telluride	**Middle Level Stns.**
7118	Pagosa Springs	18.80	Dillon	39	Steamboat Springs	Gunnison Pagosa Springs
6770	Steamboat Springs	18.72	Fraser	42	Pagosa Springs	Meeker Glenwood Springs
6550	Durango	17.90	Pagosa Springs	43	Meeker	Durango Collbran
6350	Collbran	16.39	Meeker	46	Durango	
6242	Meeker	15.03	Collbran	46	Collbran	**Low Level Stations**
6177	Cortez	14.80	Paonia	47	Glenwood Springs	Paonia Cortez
6125	Paonia	13.31	Cortez	48	Paonia	Rifle Montrose
5830	Montrose #2	10.52	Rifle	48	Rifle	Grand Junction Delta
5823	Glenwood Springs	10.20	Gunnison	49	Cortez	
5300	Rifle	9.08	Grand Junction	49	Montrose#2	
5115	Delta	9.07	Montrose #2	51	Delta	
4849	Grand Junction	7.99	Delta	52	Grand Junction	

*There are also once-per-month snow course data currently available for approximately 65 high altitude Colorado locations in the drainage area of the Colorado River for late winter and early spring months.

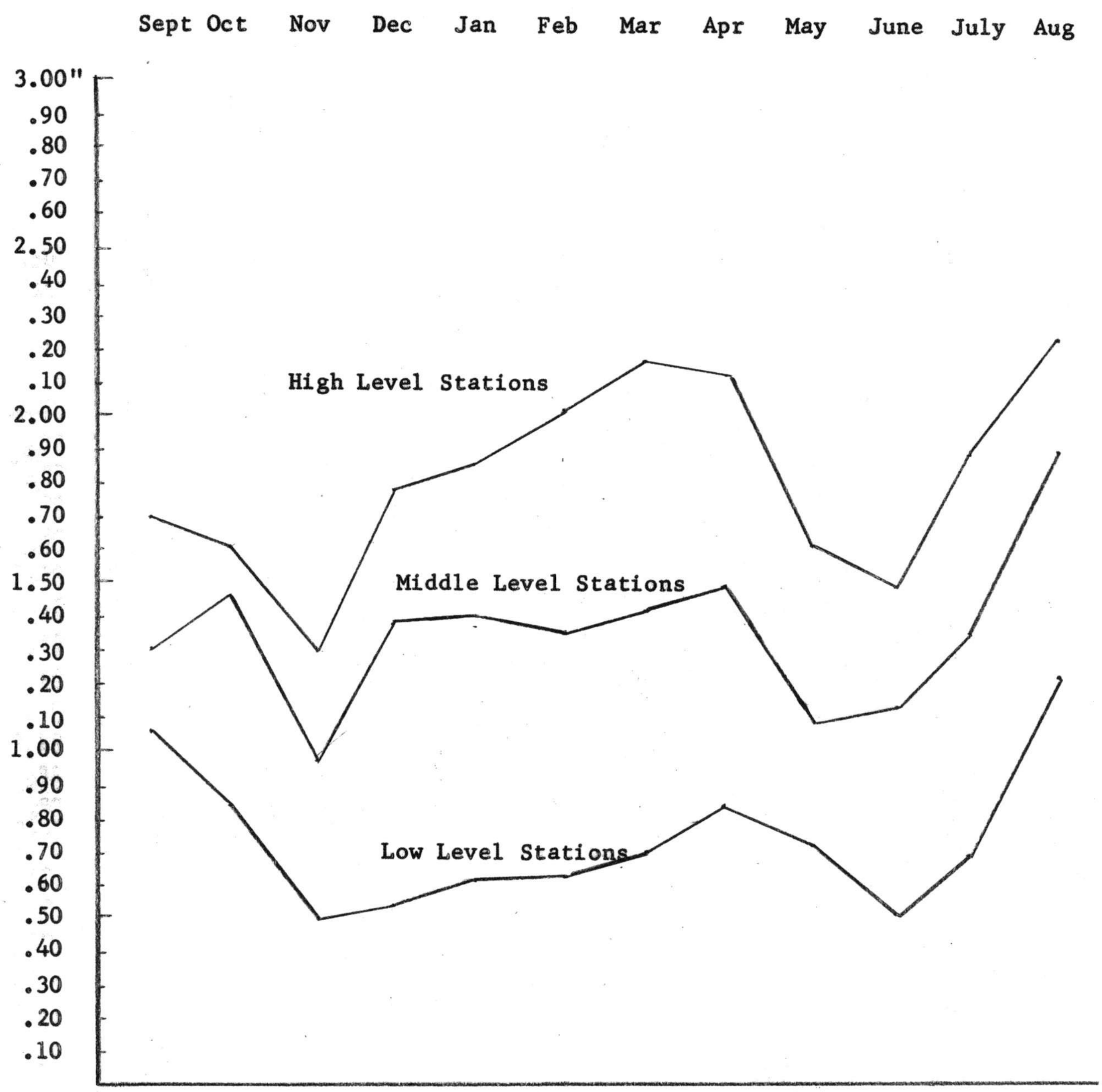


Figure 3. Average monthly precipitation amounts throughout the year from September through August at three elevation groups of Colorado weather stations.

High Level	Middle Level	Low Level
Fraser	Gunnison	Paonia
Dillon	Pagosa Springs	Cortez
Silverton	Meeker	Rifle
Crested Butte	Glenwood Springs	Montrose
Telluride	Durango	Grand Junction
Steamboat Springs	Collbran	Delta

covering only small areas. The summer storms also occur during the period when evaporation rates are very high.

Contrast in the amounts of precipitation can be noted easily in that the high level stations tend to have precipitation amounts between two and three times greater than those at low level stations.

III. DIFFERENCE BETWEEN AVERAGE AND MEDIAN PRECIPITATION TOTALS IN SEMI-ARID CLIMATES

In using past records of precipitation to obtain general information of what may be expected in the future, it has been the policy of most climatological reporters to present precipitation quantities as monthly accumulations, and these are assembled in average precipitation by monthly totals for any particular location. This average is obtained by the simple mechanics of adding together all of the monthly totals for the series of record available and dividing that total number by the quantity of months used in the sample. This is a very easy solution to obtaining a general indication of the precipitation that may be expected in a given area, but can be definitely misleading if the array of precipitation quantities throughout the record is made up of a few very high monthly totals and the majority of the monthly totals ranging around a much smaller value.

The semi-arid region from which the Colorado River obtains its runoff needs further clarification of the precipitation frequency patterns which prevail in that area. Although it will be argued later that cumulative totals of storms capable of producing runoff are probably a better indicator of runoff yield potential than monthly total precipitation quantities, for convenience here, an illustration will be developed to show the difference between the average monthly precipitation and median monthly precipitation.

The median is defined as the point in a total sample which has half the number of individual values above it and half below it. Table II shows the array of historical monthly precipitation values at Grand Junction, Colorado, for January and July. From the Table it can easily be seen that the average value is somewhat above the median in both these months. The figures shown opposite the average show the number of individual cases that are equal to, above, or below that particular average. The median values are the middle values having 28 values above and 28 values below in the 57-month samples.

The graphic illustration of this type of frequency pattern is illustrated in Part A of Figure 4. This shows the distortion of a frequency pattern which results when the total sample is made up of a few high values and many smaller values.

It should be noted that the difference between either the average or the median and the highest monthly precipitation total is considerably greater than the difference between that average or median and the lowest quantity observed.

In order to examine this matter for several stations throughout the Upper Colorado River watershed, a frequency analysis was completed on the monthly precipitation totals at seven different locations. These were Fraser, Crested Butte, Steamboat Springs, Durango, Collbran, Paonia, and Delta. The following differences by individual months show the seven-station average value in precipitation quantities (in inches) between the monthly average precipitation and the median value for these months. The average is consistently above the median.

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
7-Station Average	.16	.21	.07	.09	.15	.19	.16	.19	.16	.30	0	.28

TABLE II
ARRAY OF HISTORICAL MONTHLY PRECIPITATION VALUES
AT GRAND JUNCTION, COLORADO

January 57 Years		July 57 Years	
1.73 in.		2.72 in.	
1.43		1.85	
1.40		1.60	
1.33		1.50	
1.18		1.38	
1.18		1.15	
1.13		1.00	
1.07		.99	
1.01		.99	
.95		.97	
.95		.96	
.84		.94	
.78		.91	
.78		.87	
.77		.86	
.77		.86	
.77		.84	
.73		.81	
.70		.78	
.66		.78	
.66		.76	
.62	Av.	.75	
.61	.60 23	.74	
.58	34	.67	Av. 24
.58	57	.64	.64 1
.54		.62	32
.53		.62	57
.50		.58	
.48	median	.57	median
.48		.54	
.48		.53	
.45		.50	
.44		.48	
.44		.46	
.43		.41	
.41		.40	
.41		.40	
.40		.40	
.40		.35	
.38		.35	
.37		.34	
.35		.34	
.35		.31	
.33		.30	
.31		.28	
.27		.26	
.27		.19	
.26		.19	
.23		.17	
.22		.16	
.21		.16	
.19		.14	
.15		.13	
.15		.10	
.14		.09	
.10		.09	
.05		.09	

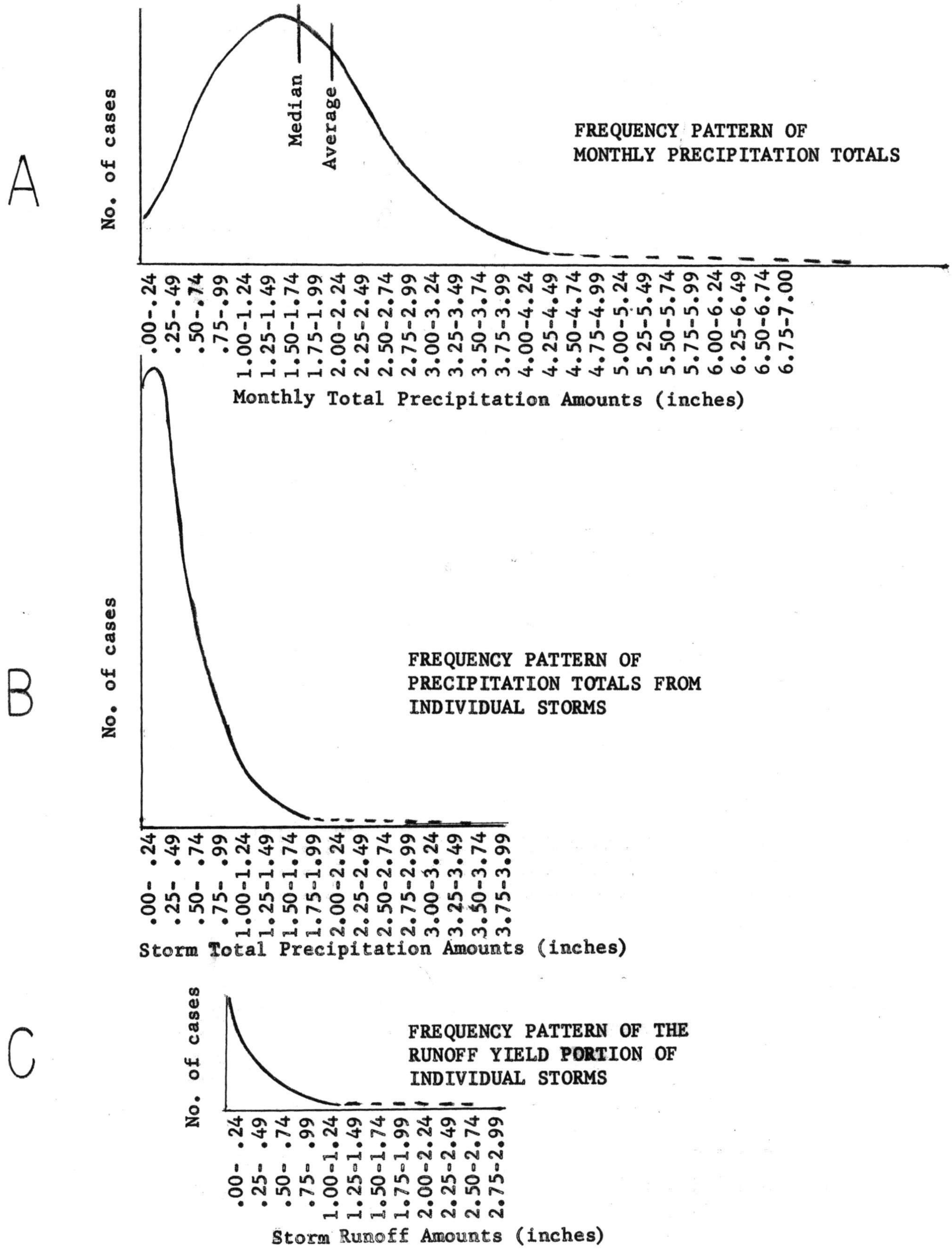


Figure 4. Comparative frequency diagrams of: A, monthly precipitation; B, individual storm precipitation; C, runoff yield from individual storms in the semi-arid climatic zone of Colorado.

The frequency array of monthly precipitation totals for semi-arid climates does not fit the ideal "normal" distribution curve in which the average (mean), the median, and the mode are all at the same point. We must understand the true distribution frequencies of precipitation occurrences and realize the magnitude of distortion brought about by using averages. A strong plea is made here for the publication of median values as well as the average values.

A further plea is made for publication of median values of streamflow. The more arid the individual watershed the greater will be the difference between median and average values.

IV. STORM TOTAL PRECIPITATION vs. MONTHLY TOTALS

All storms that produce any precipitation contribute to the monthly totals for the month in which they occur. Months which contain several large storms will naturally have large monthly totals. However, when considering precipitation related to expected runoff the monthly totals may or may not give good indications of runoff potential. This is particularly true in the semi-arid region which feeds the Colorado River. From three October storms ten days apart, each producing .33 inch of precipitation at any station below 8,000 feet in western Colorado, the expected runoff reaching the Colorado River would be zero. On the other hand, one single storm of .99 might be expected to produce some runoff. The monthly total in both cases would be the same.

In this preliminary study individual daily precipitation totals have been treated in considerable detail. This has only been done for sake of convenience during the hand analysis portion of this continuing study. The author strongly recommends the analysis of all precipitation data in terms of storm totals. With the availability of electronic computer analysis this will become an easy undertaking.

In Parts A and B of Figure 4 it can be seen that there is a marked difference between the frequency arrays of all individual storms and monthly precipitation totals. In the case of individual storms there is a very large number which produce very small amounts of precipitation. Still there are a few extreme individual storms which may be large enough to exceed the median or average for total monthly data.

Part C of Figure 4 is really the matter of greatest concern when considering precipitation and runoff relationships. Detailed information on the runoff yield potential from one or several storms is well hidden inside monthly precipitation totals.

V. RUNOFF REQUIRED TO PRODUCE THE MEASURED FLOW IN THE COLORADO RIVER

The measurement of runoff in acre feet allows a quick computation of the total quantity of runoff in inches that takes place over a year's time to produce the total annual runoff at any given point where measurements are made along a river basin. If 12 inches of water over one acre equals one acre foot, then one inch of runoff over 12 acres would also equal an acre foot of water. With 640 acres per square mile, one inch of runoff would produce 53.33 acre feet of water. (640 divided by 12 = 53.33.)

Table III is presented to illustrate the very wide range in inches of runoff at many fractional portions of the watershed of the Colorado River above Lee Ferry. The first two columns of data in Table III have been copied from the report published November 29, 1948 by the Engineering Advisory Committee of the Upper Colorado River Basin. They show average historic flows in thousands of acre feet at several points along the Colorado River and the square miles of watershed above each point. The right-hand column of this Table has been added to show the inches of runoff required to produce the average streamflow measured at each point.

TABLE III

UPPER COLORADO RIVER BASIN KEY GAGING STATIONS

Ref. p.5, Engineering
Advisory Committee Report.
Nov. 29, 1948

	Streamflow Station	Drainage Areas Square Miles	Mean Historic Flow Water Years 1914-45 1000 Acre-Feet	Inches of Runoff Required from Above that Point to Produce the Streamflow as Measured
1.	Green River at Green River, Wyoming	7670	1260.5	3.6
2.	Blacks Fork near Millburne, Wyoming	156	113.2	13.6
3.	East Fork of Smith Fork near Robertson, Wyo.	53	32.5	11.6
4.	West Fork of Smith Fork near Robertson, Wyo.	37	16.3	8.1
5.	Green River near Linwood, Utah	14300	1501.6	1.8
6.	Burnt Fork near Burnt Fork, Wyoming	53	25.1	9.0
7.	Henrys Fork near Lonetree, Wyoming	55	32.4	11.2
8.	Henrys Fork at Linwood, Utah	530	66.8	2.4
9.	Little Snake River near Dixon, Wyoming	1028	423.5	7.7
10.	Little Snake River near Lily, Colorado	3680	472.4	2.4
11.	Yampa River at Steamboat Springs, Colorado	604	345.1	10.1
12.	Yampa River near Maybell, Colorado	3410	1189.5	6.6
13.	Brush Creek near Jensen, Utah#	255	36.0	2.7
14.	Ashley Creek near Vernal, Utah	101	78.0	14.5
15.	Whiterocks River near Whiterocks, Utah	115	94.1	15.4
16.	Duchesne River at Myton, Utah	2705	439.5	3.0
17.	Duchesne River near Randlett, Utah	3820	653.3	3.2
18.	White River near Meeker, Colorado	762	461.7	11.2
19.	White River near Watson, Utah	4020	582.0	2.7
20.	Price River near Heiner, Utah	430	92.6	4.0
21.	Green River at Green River, Utah	40920	4658.4	2.1
22.	Colorado River at Hot Sulphur Springs, Colo.	782	476.7	11.3
23.	Colorado River at Glenwood Springs, Colorado	4560	2080.4	8.4
24.	Roaring Fork at Glenwood Springs, Colorado	1460	1028.0	13.1
25.	Colorado River near Cameo, Colorado	8055	3505.0	8.1
26.	Plateau Creek near Cameo, Colorado	604	186.3	5.8
27.	Gunnison River near Grand Junction, Colorado	8020	2054.9	4.8
28.	Dolores River at Gateway, Colorado	4350	788.1	3.4
29.	Colorado River near Cisco, Utah	24100	6186.0	4.8
30.	Sum of San Juan, Rio Blanco and Rito Blanco Rivers at Pagosa Springs, Colorado	379	399.5	19.9
31.	Navajo River at Edith, Colorado	165	131.8	14.6
32.	Piedra River at Arboles, Colorado	650	380.6	10.8
33.	San Juan River at Rosa, New Mexico	1990	956.6	9.0
34.	Pine River at Ignacio, Colorado	448	256.4	10.7
35.	San Juan River near Blanco, New Mexico	3558	1260.2	6.6
36.	Animas River at Durango, Colorado	692	654.7	17.7
37.	Animas River near Cedar Hill, New Mexico	1092	806.7	13.9
38.	Animas River at Farmington, New Mexico	1360	753.8	10.4
39.	San Juan River at Farmington, New Mexico	7245	2111.4	5.4
40.	La Plata River at Colorado-New Mexico State Line	331	30.9	1.7
41.	San Juan River at Shiprock, New Mexico	12876	*	
42.	Mancos River near Towaoc, Colorado	550	52.0	1.8
43.	McElmo Creek near Cortez, Colorado	233	41.0	3.4
44.	San Juan River near Bluff, Utah	23010	2275.6	1.8
45.	Paria River at Lees Ferry, Arizona	1550	25.3	0.3
46.	Colorado River at Lees Ferry, Arizona	108335	13763.3	2.3
47.	Colorado River at Lee Ferry, Arizona	109889	13788.6	2.3

*Mean for Water Years 1914-1945 not computed.

#Represents flow at head of irrigation.

Near the bottom of the Table is shown the flow of the Colorado River at Lee Ferry, Arizona (the terminal point of the Upper Basin) -- ONLY 2.3 inches per year. The general range of runoff from low years to high years would be approximately between one inch and three inches. This runoff comes from an area which receives precipitation quantities ranging from only a few inches up to an excess of 30 inches.

It is easy to see from this analysis that any one single storm covering this broad area which is capable of producing one inch of runoff over the whole watershed above Lee Ferry, would in fact, change the flow by approximately 6 million acre feet. Thus it is important to carefully analyze the precipitation records of the past to determine when and how runoff yields are produced from the precipitation patterns that move through this area.

VI. GENERAL EVAPORATION AND RUNOFF RELATIONSHIPS

The capacity of air to contain moisture is directly related to temperature. The absolute quantity of moisture which can be contained in saturated air at 32^{o} is less than one-fifth the amount that can be contained in saturated air at 80^{o}F. Furthermore, the changes in absolute moisture between 50% saturation and 100% saturation in the lower range of temperatures is considerably less than it is in the higher ranges of temperature.

The altitude range between the lowest elevation in the watershed above Glen Canyon and the mountain peaks at the rim of the Continental Divide is such that there is an extremely wide range in evaporation loss at different points in the water shed and at different times of the year. Figure 5 presents the average monthly temperature at 2,000-foot intervals within the air mass covering the upper water shed of the Colorado River throughout the year.

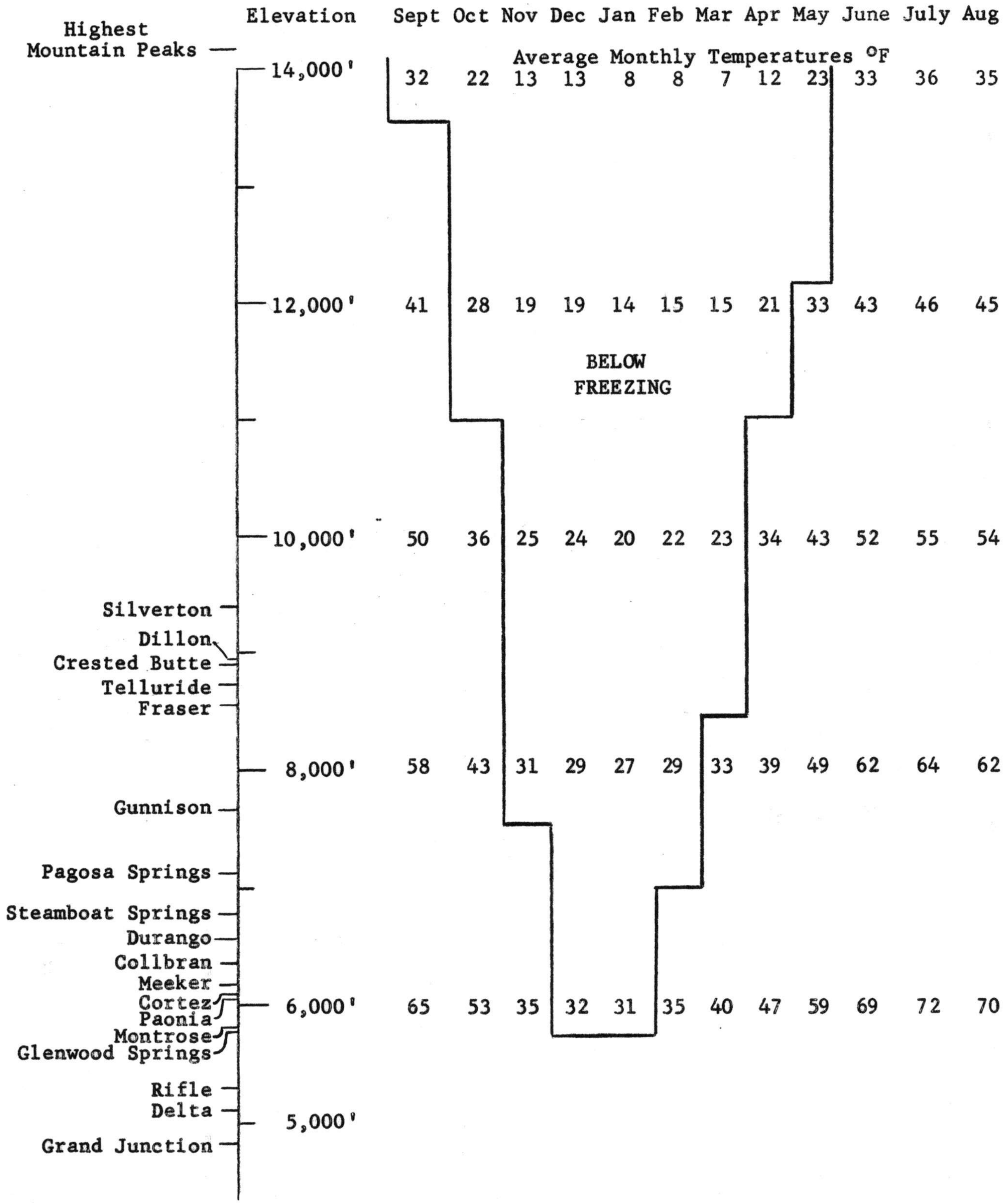


Figure 5. Average monthly temperatures at 2,000-foot intervals within the air mass which moves against or envelopes the Colorado portion of the collection basin of the Colorado River throughout the year - based on a three-year sample of data obtained by radiosondes released from Grand Junction, Colorado.

Looking first at the 14,000-foot elevation, which is approximately the same as the highest peaks, we note that average monthly temperatures remain below freezing for nine months out of the year, and the other three months have temperatures only slightly above freezing. The capacity of this air to carry water away from these highest elevations is extremely limited and can be considered as negligible throughout the entire year.

By contrast, at the 6,000-foot level all months have temperatures above freezing, with the exception of December and January, and these two months are approximately at the freezing level. The warmer months at the lower elevations have temperatures and dry air capable of accepting tremendous quantities of moisture either through direct evaporation or transpiration from plant life.

The lower elevations of the watershed above Glen Canyon Reservoir are also characterised by being made up of generally flat sandy soil with tremendous capacity for absorbing large quantities of rainfall and preventing any direct runoff. The many dry washes are perennial evidence to this fundamental fact. Only in the instances of extremely heavy local thunderstorms do these dry washes carry any water, and many times this water disappears long before it reaches the main stem of the Colorado River. Almost all of the water which does enter the soil returns in delayed evaporation into the atmosphere before ever reaching the Colorado River.

It may be helpful to review the way in which moisture from a particular storm is distributed between evaporation and runoff. Figure 6 illustrates in a schematic way the distribution of a storm which might produce one inch within a ten-hour period. The quantity of the storm which goes to runoff can only be delivered after both immediate and delayed evaporation have been

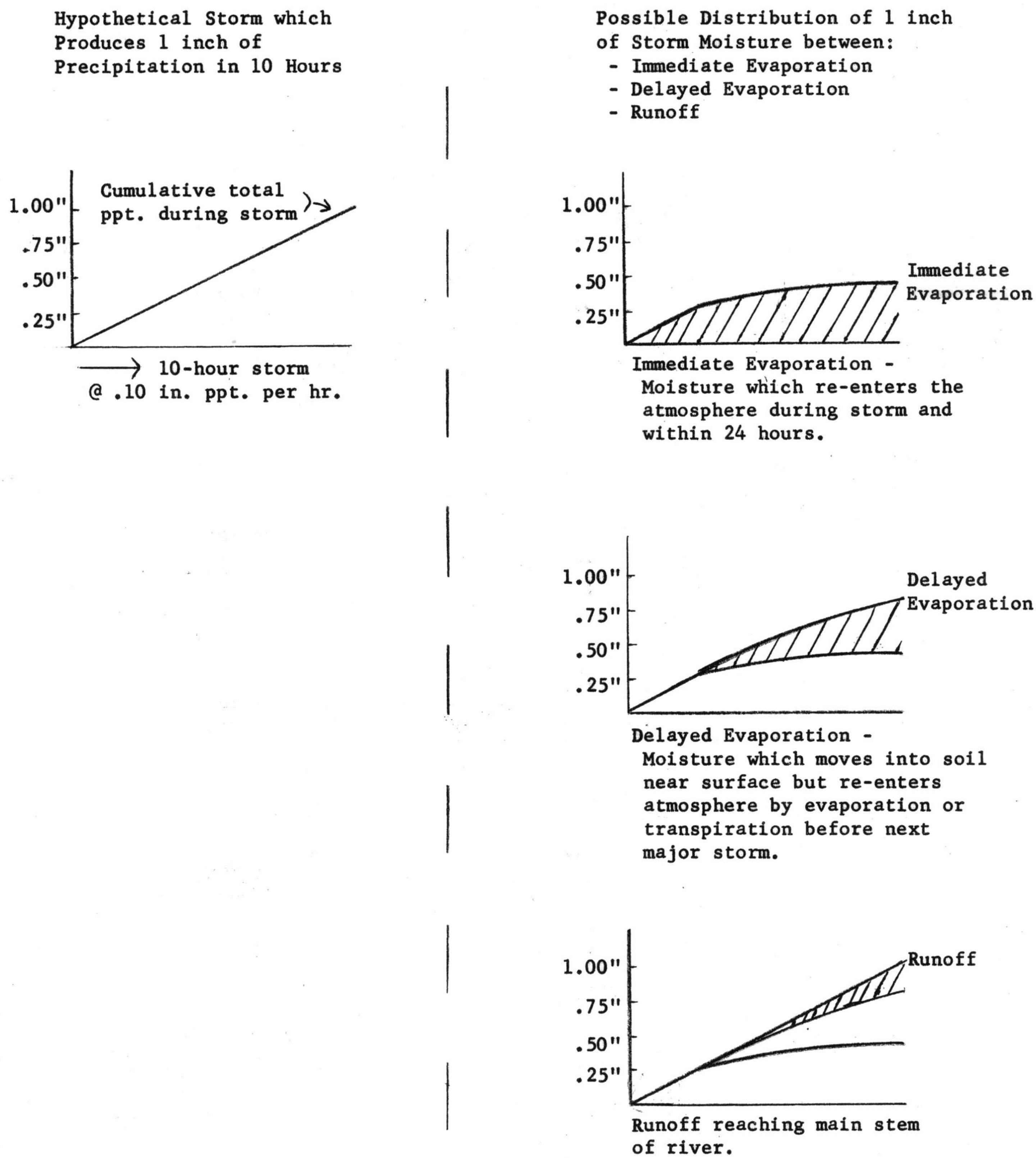


Figure 6. Schematic diagram illustrating possible distribution of a hypothetical storm which produces 1 inch of precipitation in a given 10-hour period.

satisfied. It is easy to see from this illustration that the small storms are not producers of runoff.

With reference to individual storms producing runoff in western Colorado, consideration must be given both to elevation and to the time of year. Figure 7 illustrates the contrast in both summer vs. winter, and between low elevations and high elevations.

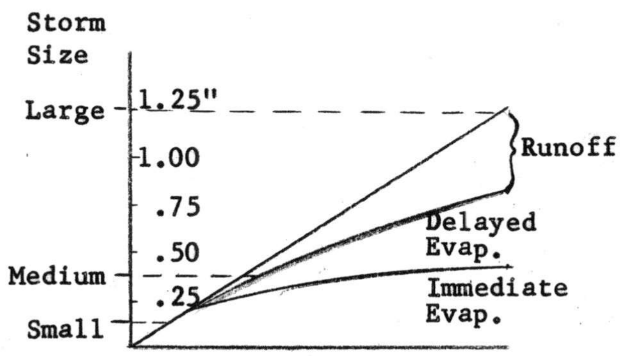
In the top part of Figure 7 a contrast can be noted in the difference in the amount of moisture which goes to either immediate or delayed evaporation at low elevations compared with high elevations. Also there is a tendency for the storms at high elevations to be only slightly higher than those for low elevations in the summertime. All such storms are generally of shower-type and very local in nature. Therefore, they do not tend to cause major increases in broad areas of the watershed runoff.

During the winter there is a much greater contrast between low elevations and high elevations. This is first due to the marked contrast in the size of precipitation amounts, the higher elevations getting nearly three times as much per storm as the low elevation stations. Immediate evaporation at high elevations is negligible, and the delayed evaporation tends to be consolidated in the amount of moisture entering the soil either at the beginning or end of the snowpack season.

At the elevations above 10,000 feet, all the storms which occur from approximately early November through mid-April tend to accumulate as if they were one large storm and the runoff from this accumulation also can be treated as if it were one large storm.

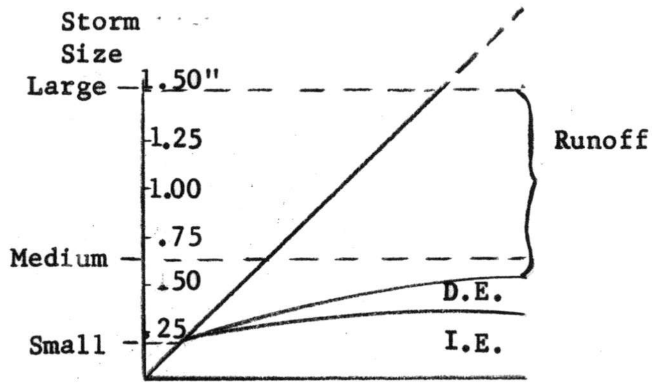
SUMMER SITUATION
in Colorado Storms

LOW ELEVATION STATION



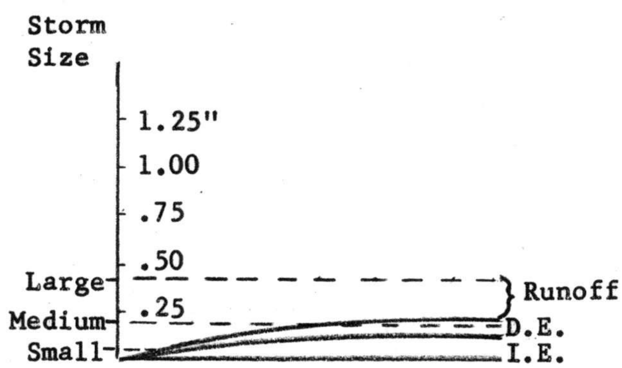
(Some runoff, but from very local-type storm)

HIGH ELEVATION STATION

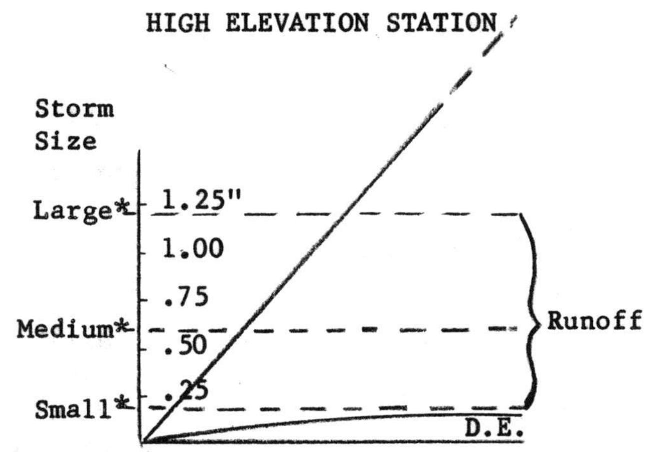


WINTER SITUATION
in Colorado Storms

LOW ELEVATION STATION



HIGH ELEVATION STATION



(No immediate evaporation)

*At the higher elevation stations where snow is not melted between winter storms several separate storms combine as if to produce only one single extremely large storm and very high ratios of runoff to precipitation.

Figure 7. Schematic diagram showing comparative ratios of storm portions going to evaporation and runoff:
Summers vs. winters
Low elevations vs. high elevations

VII. THE IMPORTANCE OF MAJOR STORMS

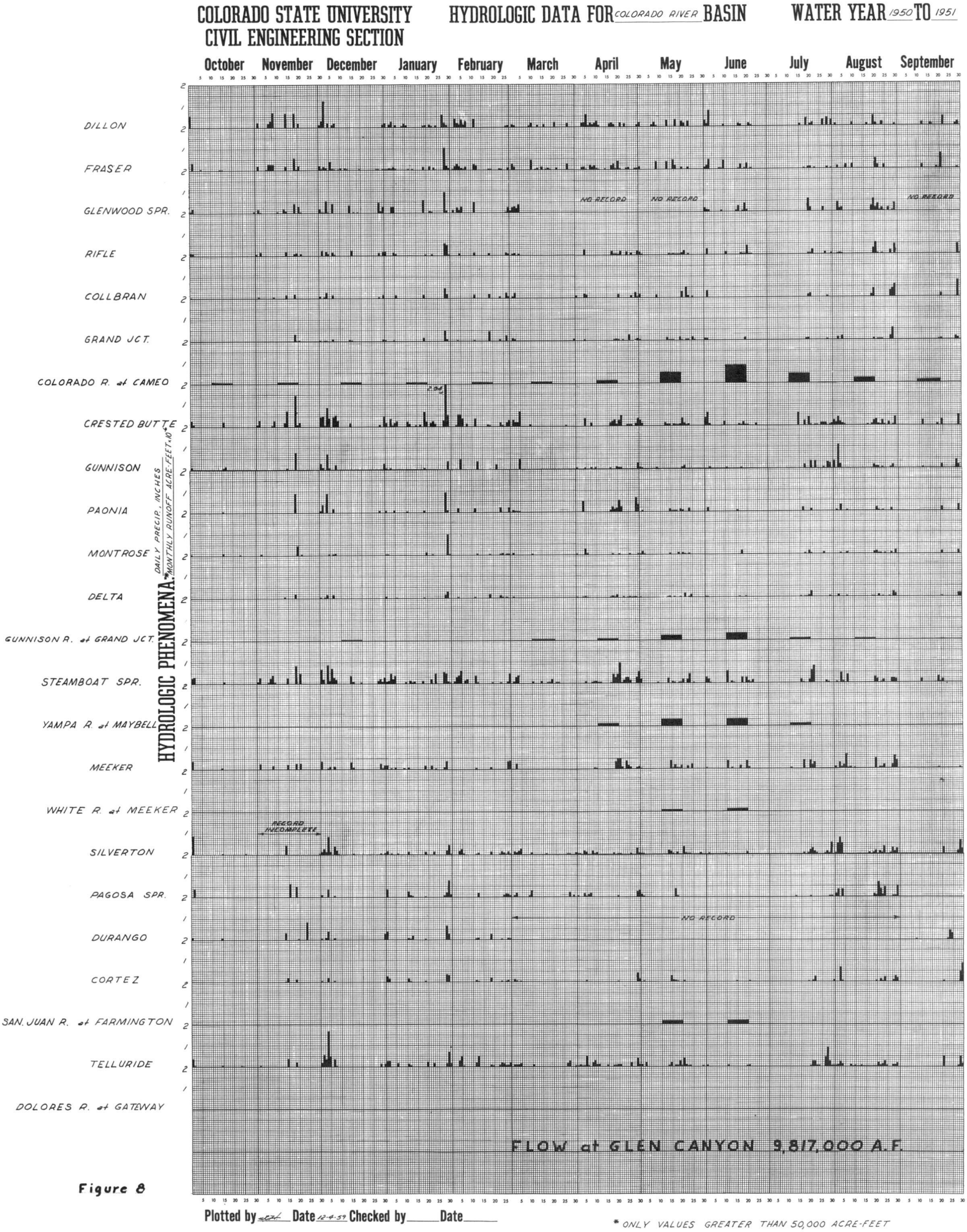
Although the ultimate analysis work to be carried out for adjusting actual precipitation records to values which more closely relate to runoff will deal with storm totals, the easiest data to work with for hand analysis were daily precipitation amounts. Initially these data were copied from the original published records for each of the 18 locations for each day from 1912 through 1958. These are the same daily data that are being placed on punch cards for machine analysis later.

In Figure 8 we see a plot of the actual daily values at all 18 stations for the entire year, October through September, 1950-51. The scale permits the plotting of two inches of precipitation per day for each station. For instances when the daily precipitation is above two inches, the actual number is written on the chart. This chart has been reduced by photographic method to approximately 1/4 the original worksheet size.

Also in Figure 8 are shown the runoff totals recorded by months at five different gaging stations. The precipitation stations have been arranged in an order to fit the watersheds above these various gaging stations on the upper area of the Colorado River.

It is easy to see that most of the days with any precipitation throughout the year are days when storms produced less than .5 inch. If one considers Delta for the moment, there are no days throughout the entire year which had over .3 inch. At Montrose only one storm went above .5 inch. At Paonia there were six storms which reached .5 inch or more.

One of the shortcomings of using daily data is immediately discernable when looking at these charts. The precipitation which occurs on several consecutive days should really be considered as being produced from a single storm.



COLORADO STATE UNIVERSITY
CIVIL ENGINEERING SECTION
HYDROLOGIC DATA FOR COLORADO RIVER BASIN
WATER YEAR 1950 TO 1951
October November December January February March April May June July August September
HYDROLOGIC PHENOMENA: DAILY PRECIP. INCHES
*MONTHLY RUNOFF ACRE-FEET×10⁶
DILLON
FRASER
GLENWOOD SPR.
NO RECORD
RIFLE
COLLBRAN
GRAND JCT.
COLORADO R. at CAMEO
2.94
CRESTED BUTTE
GUNNISON
PAONIA
MONTROSE
DELTA
GUNNISON R. at GRAND JCT.
STEAMBOAT SPR.
YAMPA R. at MAYBELL
MEEKER
WHITE R. at MEEKER
RECORD INCOMPLETE
SILVERTON
PAGOSA SPR.
DURANGO
CORTEZ
SAN JUAN R. at FARMINGTON
TELLURIDE
DOLORES R. at GATEWAY
FLOW at GLEN CANYON 9,817,000 A.F.
Plotted by Date 12-4-59 Checked by Date
* ONLY VALUES GREATER THAN 50,000 ACRE-FEET

Figure 8

The flow of the Colorado River at Glen Canyon for the water year ending September 30, 1951, was 9,817,000 acre feet. This would be equivalent to approximately 1.5 inches of runoff from the entire watershed above Glen Canyon. It is easy to see that this would be a very small faction of the total precipitation throughout the entire year. It can also be seen that the one single storm which occurred about January 27 was capable of producing between .5 inch and 1.0 inch of precipitation at most stations. This single storm coming in the wintertime when evaporation rates are very low could have been worth a very major portion of the total annual runoff for the season involved.

Because of the very negligible contribution of small storms, particularly at the lower elevations, it was decided that for the long series of years, 1912 through 1957, data would only be plotted on the charts for those days when individual daily precipitation totals would be .4 of an inch or more. Figures 9 and 10 were prepared in this manner. The scale is exactly the same as in Figure 8, but only the days have been plotted when precipitation was .4 of an inch or more.

Referring to Figure 9, note the major storm which occurred the last three days of December. This storm produced over .4 inch at 15 of the 18 stations being studied. Amounts greater than 2 inches occurred on two consecutive days at Crested Butte. The amounts were 3.2 and 3.6 inches, producing a two-day total of 6.8 inches.

Again referring to Figure 9, it will be noted that the period of February, March, and April were quite dry throughout western Colorado. May and June were only approximately normal or slightly below in their precipitation amounts at these stations.

COLORADO STATE UNIVERSITY
CIVIL ENGINEERING SECTION

HYDROLOGIC DATA FOR COLORADO RIVER BASIN

WATER YEAR 1951 TO 1952

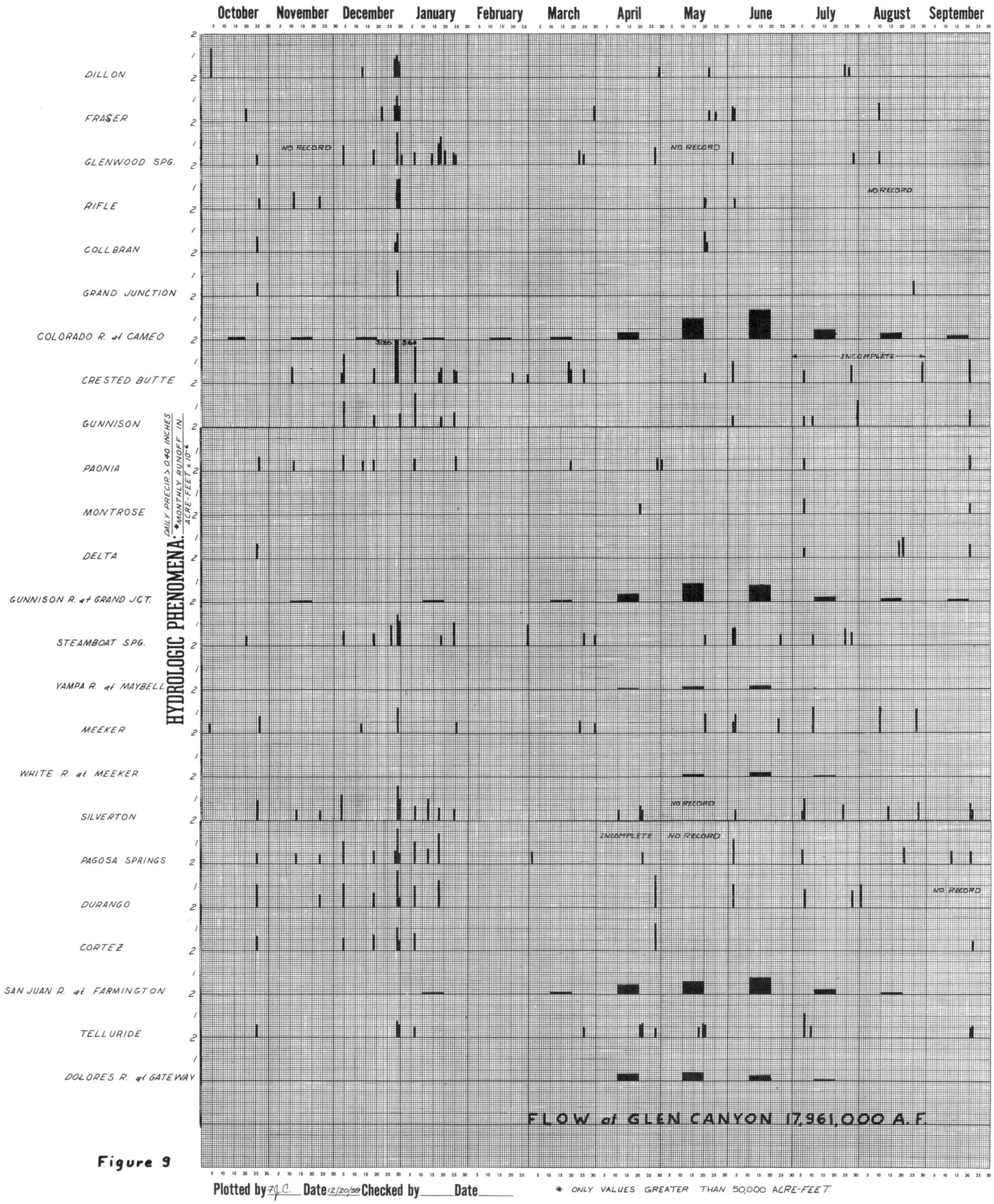


Figure 9

Plotted by 7J.C. Date 12/20/59 Checked by ____ Date ____

* ONLY VALUES GREATER THAN 50,000 ACRE-FEET

COLORADO STATE UNIVERSITY HYDROLOGIC DATA FOR COLORADO RIVER BASIN WATER YEAR 1953 TO 1954

CIVIL ENGINEERING SECTION

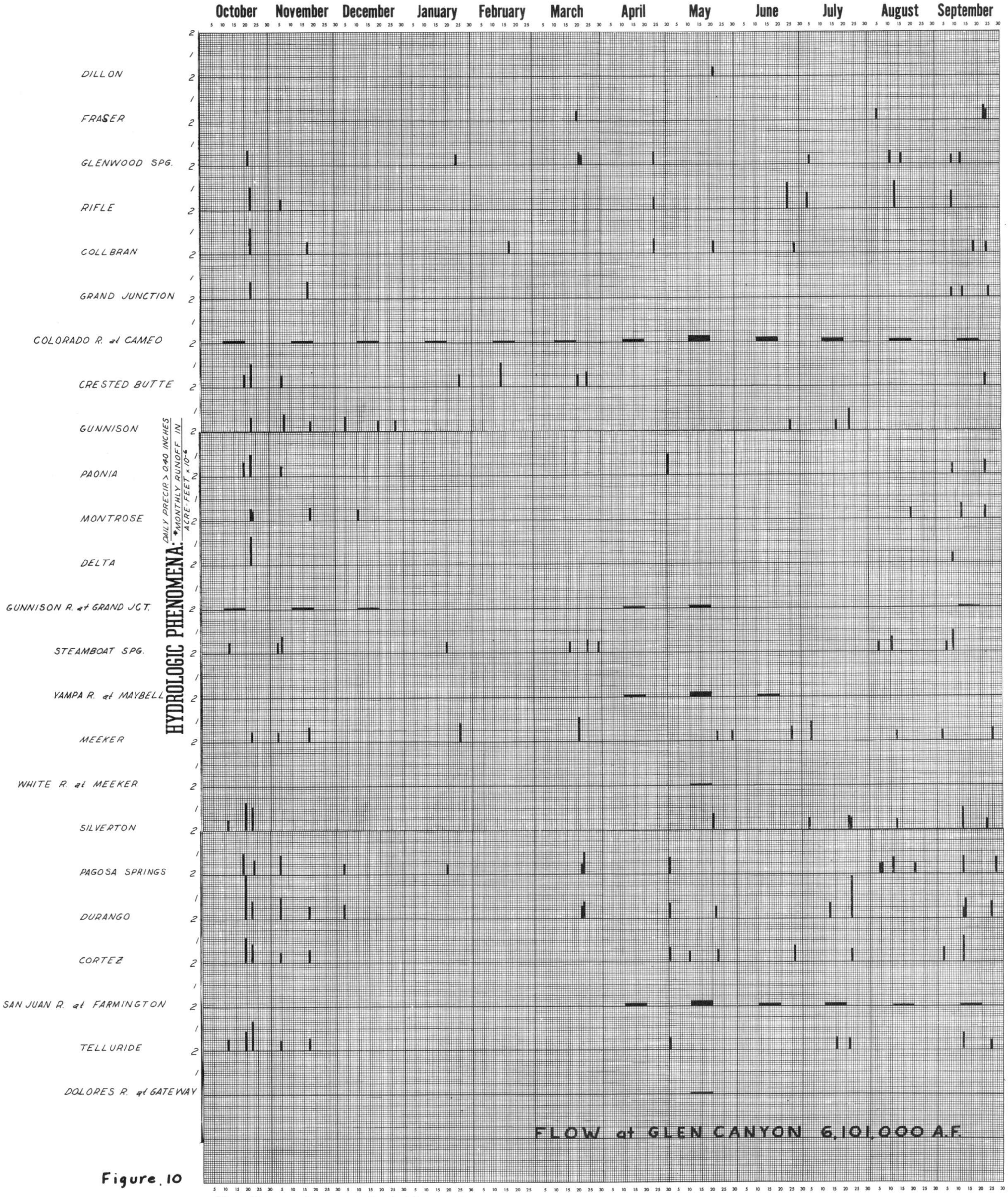


Figure. 10

Plotted by F.A.C. Date 12/22/59 Checked by ______ Date ______

* ONLY VALUES GREATER THAN 50,000 ACRE-FEET

This water year produced 17,961,000 acre feet of flow at the Glen Canyon Dam site. This is some 8 million above the flow the previous year. The total runoff above Glen Canyon amounts to approximately three inches for the entire watershed above that point, and it is the author's opinion that this one single storm in late December is worth at least one inch of those three inches of total runoff throughout the year.

Looking now to Figure 10, we have the precipitation pattern which prevailed during a dry year. The total runoff for the water year ending in September, 1954, at Glen Canyon was only 6,101,000 acre feet. This is approximately one inch of runoff over the watershed above that point. It is easy to see that the period from December through July was quite dry, and very few storms exceeded .4 inch at any point.

This year also includes a good illustration of how little can be contributed in runoff from fairly sizable October storms. The storm period which occurred about the 23rd of October produced an average precipitation of approximately 1.3 inches over the 18 stations for a three-day period. However, the response in runoff at Glen Canyon can be somewhat illustrated by the monthly streamflow measurements of September, October, and November. They were respectively 258,000, 369,000, and 386,000 acre feet at the Glen Canyon site. Runoff attributed directly to this storm was probably below 200,000 acre feet. This adds good confirmation to the idea that fairly large amounts of precipitation can be dropped out as contributing nothing to runoff during the late summer and fall months.

VIII. FREQUENCY OF DAILY PRECIPITATION ABOVE .4 INCH

In order to summarize the findings of this analysis of extreme precipitation storms, a tabulation was made of all of the days at nine of the 18 stations at which precipitation was recorded of .4 inch or more. Table IV shows results of this tabulation in class intervals of .1 inch, from .4 through 1.0 inch, and for .5 inch intervals from there upward. It can be noted that very few individual days experienced precipitation of over 1.5 inches. The period covered was 46 years. However, a few months found data not published at most stations, and for Cortez and Pagosa Springs the period of record was 27 and 28 years respectively out of the 46. Eventually similar information can be tabulated by storms rather than limiting it to daily values.

Having determined that the typical single day precipitation value of major storms was somewhere between .4 and 1.5 inches, it was thought desirable to find out how often these storms of this size occurred on consecutive days, and also the number of months which went by <u>without</u> any single storm of that quantity occurring at each of the various stations.

The top 3/4 of Table V presents information showing the frequency of months containing 1, 2, and 3-or-more days with daily precipitation of .4 inch or more. Looking initially at Fraser in the top of the Table for the months containing 3-or-more days, we note that there has only been one September in 46 years which had three days with .4 inch or more. There have been four Octobers with a total of three or more such days in the entire month.

The second part of the Table shows the number of instances when months contained two such days. Again these numbers are relatively small out of a 46-year sample (27 and 28 years at Cortez and Pagosa Springs).

TABLE IV

NUMBER OF DAYS HAVING STORMS PRODUCING .40 INCH
OR MORE OF PRECIPITATION IN 46-YEAR PERIOD* - 1912-1957

											Degree of Infrequency	
	.40-.49"	.50-.59"	.60-.69"	.70-.79"	.80-.89"	.90-.99"	1.00-1.49"	1.50-1.99"	2.00-2.49"	≥ 2.50"	Total Days ≥.40"	During Total Days of Record
Fraser	185	97	58	32	16	9	23	6	2	3	431	16,560
Dillon	157	107	65	40	27	13	22	12	2		445	16,650
Silverton	192	122	71	68	29	27	51	11	4	1	576	15,880
Pagosa Springs	103	97	60	43	23	21	35	12	5	3	402	9,950
Glenwood Springs	152	105	86	39	24	12	20	2	2		442	15,780
Durango	171	130	88	69	46	32	65	13	6	2	622	16,560
Cortez	84	54	35	25	12	3	22	3	1		239	9,800
Rifle	101	44	30	32	12	13	14		1		247	15,330
Delta	69	46	18	15	13	5	14	1			181	16,770

*46 years contain 552 total months or 16,800 days. Actual number of days in months of published daily record available is shown for each station (only about 27 "net" years at Cortez and Pagosa Springs within this period).

TABLE V

FREQUENCY OF STORM DAYS WHICH PRODUCED .40 INCH PRECIPITATION OR MORE WITHIN INDIVIDUAL MONTHS DURING 46-YEAR PERIOD, 1912-1957

No. of cases in which the month contained THREE OR MORE days with ppt. ≥ .40 inch

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total Such Cases			
Fraser	1	4	1	1	2	2	2	5	4	2	9	3	36	During	544	Months
Dillon	5	4	1	3	1	2	5	5	6	0	2	5	39	"	547	"
Silverton	12	7	1	5	6	2	9	6	1	7	4	10	70	"	488	"
Pagosa Springs	2	3	6	2	9	3	5	3	1	2	6	8	50	"	326	"
Glenwood Springs	4	3	1	2	4	2	2	4	3	2	2	3	32	"	518	"
Durango	10	10	4	5	4	5	9	7	2	2	8	10	76	"	544	"
Cortez	3	3	0	1	1	0	1	4	2	0	2	2	19	"	322	"
Rifle	1	3	0	1	1	0	0	1	1	0	3	2	13	"	503	"
Delta	1	1	0	0	0	0	0	2	1	0	0	3	8	"	551	"

No. of cases in which the month contained TWO DAYS with ppt. ≥ .40 inch

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total Such Cases			
Fraser	5	1	2	1	4	6	5	9	10	9	3	7	62	During	544	Months
Dillon	2	6	10	2	3	2	5	10	9	5	15	3	72	"	547	"
Silverton	10	11	6	4	3	6	1	5	6	4	13	8	77	"	488	"
Pagosa Springs	6	7	5	6	2	4	6	6	2	3	4	5	56	"	326	"
Glenwood Springs	8	6	11	3	8	7	10	10	10	4	9	9	95	"	518	"
Durango	7	7	4	8	10	6	6	6	8	4	10	12	88	"	544	"
Cortez	8	5	3	2	2	2	3	1	3	2	2	4	37	"	322	"
Rifle	0	4	5	1	2	0	2	4	5	3	2	6	34	"	503	"
Delta	3	6	2	0	1	1	1	0	1	1	1	3	20	"	551	"

No. of cases in which the month contained ONLY ONE DAY with ppt. ≥ .40 inch

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total Such Cases			
Fraser	18	16	13	7	15	15	15	16	19	9	16	22	181	During	544	Months
Dillon	13	17	7	14	14	14	10	14	18	13	8	16	158	"	547	"
Silverton	11	15	12	16	14	13	18	11	12	15	14	12	163	"	488	"
Pagosa Springs	10	7	6	8	6	8	5	6	6	8	6	11	87	"	326	"
Glenwood Springs	10	17	5	13	6	11	11	14	12	18	17	14	148	"	518	"
Durango	14	15	15	16	11	15	8	14	14	13	17	10	162	"	544	"
Cortez	8	8	4	11	11	10	5	5	3	5	11	15	96	"	322	"
Rifle	19	12	10	9	8	5	14	10	10	12	21	7	137	"	503	"
Dillon	16	16	5	5	5	3	6	6	16	9	12	16	115	"	551	"

No. of cases in which the month contained NO days with ppt. ≥ .40 inch

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total Such Cases			
Fraser	22	25	30	35	24	22	23	15	12	25	18	14	265	During	544	Months
Dillon	26	19	27	25	27	27	26	17	13	28	21	22	278	"	547	"
Silverton	8	8	23	13	18	20	13	20	22	15	9	9	178	"	488	"
Pagosa Springs	10	8	10	12	11	13	12	12	18	13	11	3	133	"	326	"
Glenwood Springs	23	20	27	26	24	22	19	14	16	20	15	17	243	"	518	"
Durango	14	14	23	16	20	19	23	19	21	27	9	13	218	"	544	"
Cortez	8	10	20	13	13	15	18	16	19	20	12	6	170	"	322	"
Rifle	23	22	27	31	30	37	26	28	25	27	17	26	319	"	503	"
Delta	26	23	39	40	40	42	39	38	28	36	33	24	408	"	551	"

At the bottom of Table V are shown the total number of months during the 46-season sample which had NO SINGLE STORM which produced .4 inch or more on any particular day. Generally speaking, these months can be written off as having received no precipitation contributory to runoff, with the possible exception of high elevation stations in which the small quantities of snow would have added to the total snow pack.

IX. TEMPERATURES AND SPRING SNOW MELT

Daily temperatures were examined for the spring melt period for approximately ten years in the upper San Juan River Basin, particularly the Animas River. From this investigation the following conclusions were reached:

(1) Snow melt starts when the maximum temperatures go above 50° for a two-day period or more. The melting under these conditions is only during a part of the day.

(2) The daily range of temperature is about 30° when the maximum first reaches 50. This allows nighttime minimums of about 20°F.

(3) Snow melt increases rapidly when minimum temperatures reach 28 to 32°.

(4) During the melt period there is a long, continuous time when daily minimum temperatures stay very near, or slightly below 32°. At the same time maximum temperatures are continuing to increase since they are affected by the air mass moving across the region. The daily range increases to approximately 40° instead of the 30° which exists at the beginning of the snow melt period.

(5) When most of the snow cover is melted the minimum temperatures move on above 32° and the daily range decreases to again be in the vicinity of 30°.

(6) Temperatures are cold enough at high elevations by late August and early September that some of the water content is again locked in the form of frozen soil or ice to move into the following year as potential runoff -- this happens only during wet seasons.

(7) For elevations below 10,000 feet it is believed that the snow melt and the drainage for each season is nearly complete, with the possible exception of the few mountain meadows that act as semi-lakes with the slope and drainage toward the lower end of the meadow. Above 10,000 feet this carryover impact of the stored moisture either going into storage in a wet season or draining out of this storage during a dry season, is a very useful phenonema in balancing the continuing runoff from season to season.

X. ADJUSTING ACTUAL PRECIPITATION DATA TO "PRECIPITATION CONTRIBUTING TO RUNOFF" DATA

From the detailed examination of past records and a general relationship of precipitation to measured streamflow, it is believed possible to prepare some adjusted precipitation data and rules for future effort in this field which will furnish hydrologists with precipitation records on a current basis that are much more directly related to runoff.

On an annual basis precipitation-year totals corresponding to the water-year runoff totals at Glen Canyon Reservoir should ordinarily include data from September through August. Only very heavy storms in early September contribute to the current September runoff measured at Glen Canyon. (See September, 1927).

The quantities which can be deducted from individual storm totals to account for evaporation losses should vary for different times of the year and also for different elevations. The following are recommended as being approximately of the right order of magnitude and could be used for the initial tabulation effort by electronic computer when the data have been placed on punch cards.

TABLE VI

AMOUNTS TO BE DEDUCTED (INCHES) FROM INDIVIDUAL STORMS TO ADJUST ACTUAL PRECIPITATION TO "PRECIPITATION CONTRIBUTING TO RUNOFF"

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
High Level Stations	-.5	-.5	no deduction						-.3	-.3	-.5	-.5
			cumulative →									
Middle Level Stations	-.7	-.7	-.7	-.2	-.2	-.2	-.2	-.5	-.5	-.5	-.7	-.7
				cumulative →								
Low Level Stations	-.8	-.8	-.6	-.6	-.4	-.4	-.6	-.6	-.6	-.6	-.8	-.8

Although individual storm total data for all stations will not be available until machine tabulation is accomplished, the author has tested the adjustment technique on some samples of data covering rather small watersheds which have little or no diversion above gaging stations and found quite good results.

For instance, the actual September-August precipitation at Fraser for water year 1957 was 28.08 inches. When these data are adjusted, the net result is 23.37 inches. The runoff for a small 32.8 square mile watershed measured on St. Louis Creek near Fraser was equal to 21.58 inches. This was a wet year, and it is believed that some of the moisture was carried over into 1958.

From September to August, 1958, the actual precipitation total was 17.23 inches. The adjusted total was only 12.16, and the runoff was 15.00".

This indicates a benefit in runoff from 1957 precipitation. The two years combined show actual precipitation of 45.31", adjusted precipitation, 35.53", and runoff, 36.58".

Similar relationship problems for small watersheds near Dillon and near Silverton also gave good results for typical near average conditions and for wet and dry year extremes. Watersheds at low elevations studied included the Paria River and Chevelon Creek on the Little Colorado River in Arizona. At these two locations the median annual runoff is less than one-half inch, and practically all the annual precipitation must be deducted in the adjustment.

To illustrate the general result of adjusting the actual precipitation record a sample of average monthly data were treated with arbitrary deductions that change for different months and for three different elevation groups. Figure 11 shows the result of this adjustment in terms of annual runoff potential from the three groups of stations.

Proof that these are approximately of the right order of magnitude can be noted by referring back to Table III. Runoff yields from high catchment are in the high teens. Runoff from catchments that include large fractions of the middle level zone range between 5 and 10 inches. The Paria River, with a catchment area mostly below 7,000 feet, has only .3 inch of runoff.

Referring again to the adjusted result at the right-hand side of Figure 11, we can note the strong dependence for runoff on winter and early spring precipitation. Although the precipitation occurrence is spread over the several winter months, the cold tempertures which prevail at middle and high elevations prevent immediate melt and runoff. The accumulation of the adjusted values during the winter months for the middle and high level stations fit very closely with nearby snow course readings in the early spring months.

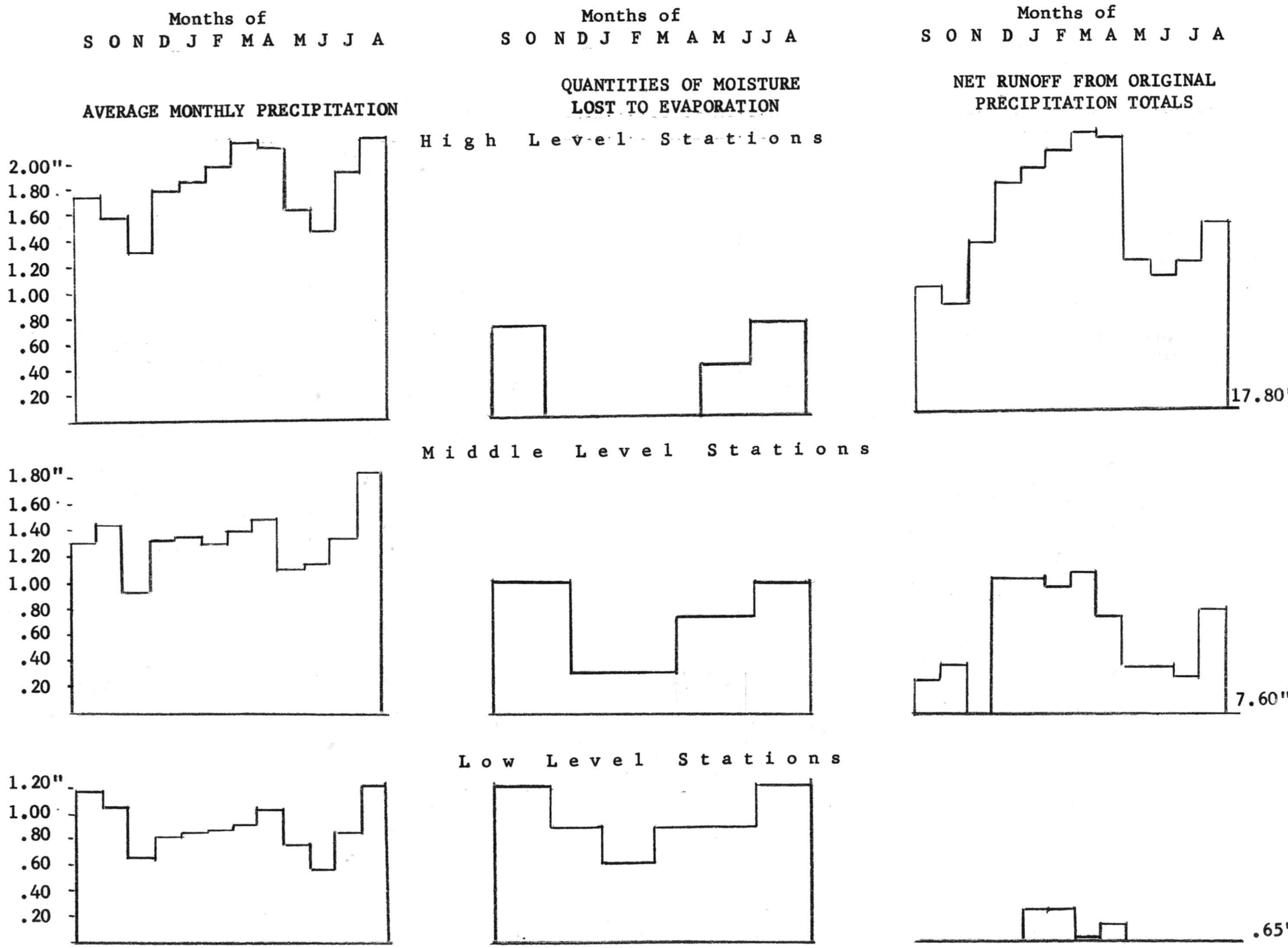


Figure 11. Relationship of Average Monthly precipitation totals at three elevation levels and resultant runoff in inches after arbitrary reductions for evaporation at these same levels.

A very rough approximation of adjustment for evaporation can be applied to annual precipitation totals in western Colorado. When the following percentage reductions are applied, the results give approximately the correct net annual runoff values which are measured.

Annual Actual Precipitation	Percentage Lost to Evaporation	Balance Contributing to Runoff
6" or less	100	0"
8	90	.8
10	85	1.5
12	80	2.4
14	70	4.2
16	60	6.4
18	50	9.0
20	40	12.0
22	30	15.4
24	20	19.2
26	10	23.4
$\geqslant$ 30	5	$\geqslant$ 28.5

This rough approximation does show some interesting general relationships. A station recording 24 inches of annual precipitation receives only <u>3 times</u> as much precipitation as a station recording 8 inches. But the runoff from the area surrounding the 24-inch location is <u>24 times</u> greater (.8" x 24 = 19.2") than the area around the 8-inch precipitation location. The increased runoff value for an "extra" 2 or 4 inches of "wet year" precipitation in the broad areas of the Colorado River watershed that ordinarily receive 8 to 14 inches, is measured by tremendous percentage differences. For instance, the runoff from 14 inches (4.2") is 280% of what it is from 10 inches (1.5").