A REVIEW OF MAJOR STORMS WHICH HAVE OCCURRED IN THE UPPER COLORADO RIVER WATERSHED

Prepared for

State of Colorado

By

Loren W. Crow, consulting Meteorologist

September 30, 1960

Report No. 31
CER60LWC55

A REVIEW OF MAJOR STORMS WHICH HAVE OCCURRED IN THE UPPER COLORADO RIVER WATERSHED

Prepared for

State of Colorado

By

LOREN W. CROW, Consulting Meteorologist

September 30, 1960

Report No. 31

TABLE OF CONTENTS

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

INTRODUCTION

This is a second report by the author dealing with precipitation frequencies in Western Colorado. The former report, Report No. 29, dated March 10, 1960, dealt with precipitation frequencies at individual stations and proposed methods for adjusting original precipitation records to improve their usefulness in relating rainfall to streamflow.

While reviewing the actual sequence of precipitation amounts recorded at each of 18 stations in Western Colorado during a 46-year sample, the author noted that on rather rare occasions heavy precipitation amounts occurred simultaneously at many stations. A very cursory investigation showed that the occurrence of only one such storm in any particular year tended to increase sharply the annual streamflow as measured at Lees Ferry.

The purpose of this investigation has been to carefully review the entire 46-year sample in order to find all major storms and to formulate a definition of such storms. If the frequency of such storms is less than one per year, some method needs to be devised to exclude the effect of such storms in developing a typical single year runoff pattern. It would also be interesting to know the order of magnitude of the runoff yield from these major storms.

The author is indebted to Dr. Morris E. Garnsey for his supervision and guidance in this entire research project, "Past and Probable Future Variations in Streamflow of the Colorado River." Dr. Richard A. Schleusener has assisted in reviewing portions of the material contained in this report. Mrs. Helga Slauson has worked with the author in the detailed tabulation of precipitation data and in preparation of the report.

I. TABULATION PROCEDURES

In the 46-season sample, running from 1911-12 through 1956-57, there have been several instances when individual storms lasting for two to four days have produced rather sizable amounts of precipitation throughout the 18-station network in Western Colorado. In a prior research effort the daily values were examined and all instances of .4" precipitation or more were plotted on large graphical charts. By visual reference to these charts it is possible to note the cases in which several of the various stations are experiencing .4" or more precipitation simultaneously. This affords the chance to suspect that a major storm might be occurring if the several stations are considered on a consolidated basis.

After some trial and error attempts at choosing a threshold value which would be certain to collect all major storms, the following procedure was arbitrarily developed. It was purposely decided to keep the threshold value relatively low so that all major storms could be included, and subsequently some of the less important storms might be eliminated.

It was arbitrarily decided that any single storm should produce 5% or more of the annual average precipitation at most stations. For purposes of this study of major storms the initial sifting of data was based on the collection of all cases when one-half or more of the several stations in each of the major sub-basins were equal to or above the following threshold values:

Above .7"

Silverton	Glenwood Springs	Pagosa Springs
Telluride	Durango	Meeker
Steamboat Springs	Dillon	Collbran
Crested Butte	Fraser	

Above .6"

Paonia	Cortez

Above .5"

Rifle	Gunnison

Above .4"

Grand Junction	Montrose	Delta

Using these criteria the entire 46-season sample was examined. When any one or more than one of three major sub-basins satisfied the preliminary criteria for a major storm, they were tabulated in sequential order.

After all such storms had been tabulated, the next step was to establish minimum limits for the total quantity of precipitation that would be experienced by the several stations either in the entire 18-station network or the combination of two sub-basin groups or for an individual single sub-basin.

Although the original tabulation was made separating the several basins into Main Stem, Gunnison, San Juan, with three separate tabulations for Steamboat Springs, Meeker, and Telluride, it was found that further consolidation was possible by including Meeker and Steamboat Springs with the Main Stem, and including Telluride with the San Juan group. Thus in consolidating the storm data, only three sub-basins were considered separately. See Figure 1. The actual grouping of

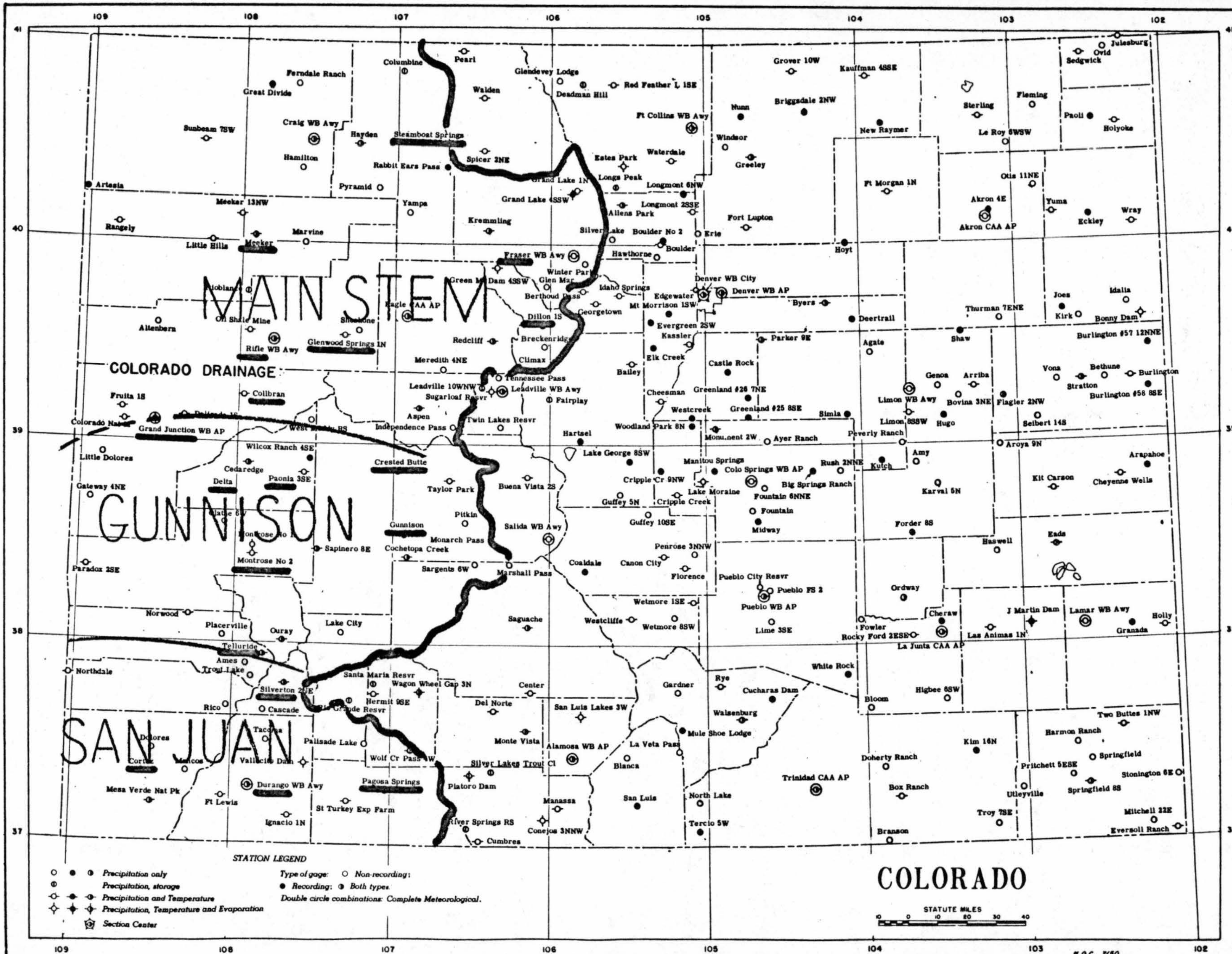

Figure 1. Location map of Colorado weather stations for which records are studied in this report. Sub-Basin grouping of stations used for major storm analysis.

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

stations is:

The Main Stem Sub-Basin includes:

Dillon	Collbran
Fraser	Grand Junction
Glenwood Springs	Steamboat Springs
Rifle	Meeker

The Gunnison Sub-Basin includes:

Crested Butte	Montrose
Gunnison	Delta
Paonia	

(with special allowance that this group could include Grand Junction if that would produce a major storm when three out of six total went above the minimum threshold values.)

The San Juan Sub-Basin includes:

Silverton	Cortez
Pagosa Springs	Telluride
Durango	

In order to check the general response in streamflow that might be produced by major storms, the reference material used was the "Present Modified Monthly Streamflow at the Colorado River at the Glen Canyon Damsite." These data are derived from flows originally measured at Lees Ferry. This material so far is unpublished but has been carefully prepared by the Salt Lake office of the Bureau of Reclamation.

II. THE ANNUAL SNOWPACK "STORM"

With the cold temperature ranges which prevail for several months throughout the year at elevations above 6,000 feet in Western Colorado, much of the snow which occurs during the winter months tends to accumulate and develop the SNOWPACK which produces the major portion of runoff collected in the Colorado River. At 6,000 feet only the months of

December and January are generally cold enough to allow continuous accumulation. At 8,000 feet this is increased to four months. At 12,000 feet the accumulation begins in October and continues through April. At the extreme mountain peaks, nine months of the entire year have temperatures which can allow snow to continue to accumulate.

It is not the purpose of this particular report to review in detail the variations in quantity of snowpack which occur in Western Colorado. It is necessary to point out that this can be, in many respects, treated as one large single "major storm" in its ability to produce runoff in the Colorado River. The melting process at the end of the season is relatively slow and therefore does not have the characteristic of typically large rainstorms which can produce local flooding and over a large watershed cause devastating floods along the main stem of major rivers which drain areas at lower elevations with warmer temperatures prevailing.

III. HISTORICAL MAJOR STORMS DURING 46 SEASONS, 1911-12 THROUGH 1956-57

After tabulation of all the storms which could be classed as possible major storms, the second step was to find the storms which were really the larger storms during the 46-season sample. The first attempt at this was to include all storms in which half or more of the stations in each of the three separate basins had simultaneous precipitation amounts above the preliminary threshold values. By relating several of the larger storms and corresponding responses in stream runoff, it was possible to make a rough approximation as to the size of a storm capable of having a marked influence on the annual runoff measured at Glen Canyon. It was determined that any storm which affected the three basins but had less than 15 inches total from the 18 stations tended to have little immediate effect on subsequent streamflow measured at Glen Canyon. Although it is highly desirable that some adjustment be made for the time of year when the storm occurs when deciding on its relative importance to streamflow, for purposes of this particular analysis a fixed value was used for the entire year.

In Figure 2 we find the 15 storms which have occurred in the 46-year period having total precipitation amounts above 15 inches as measured at the 18 stations in Western Colorado

It was somewhat surprising to find that in four of the seasons more than one such storm occurred. Referring to Figure 1 we note that in the water year of 1913-14 there were three storms separated by two months or more which produced 15 inches in two or three days respectively. While it is true that the storm of September 22-23, 1913, actually produced precipitation prior to October 1, the streamflow response measured at Glen Canyon would have been in the 1914 water year.

A similar situation occurred in late September of 1915 when the storm occurring between the 24th and 26th could not have produced any large increase in runoff measured at Glen Canyon until after October 1. The situation in 1929 was somewhat different in that the storm occurred the early part of September and a goodly portion of the increase in runoff was measured in that same month at Glen Canyon. This was, however, a case in which some of the precipitation in

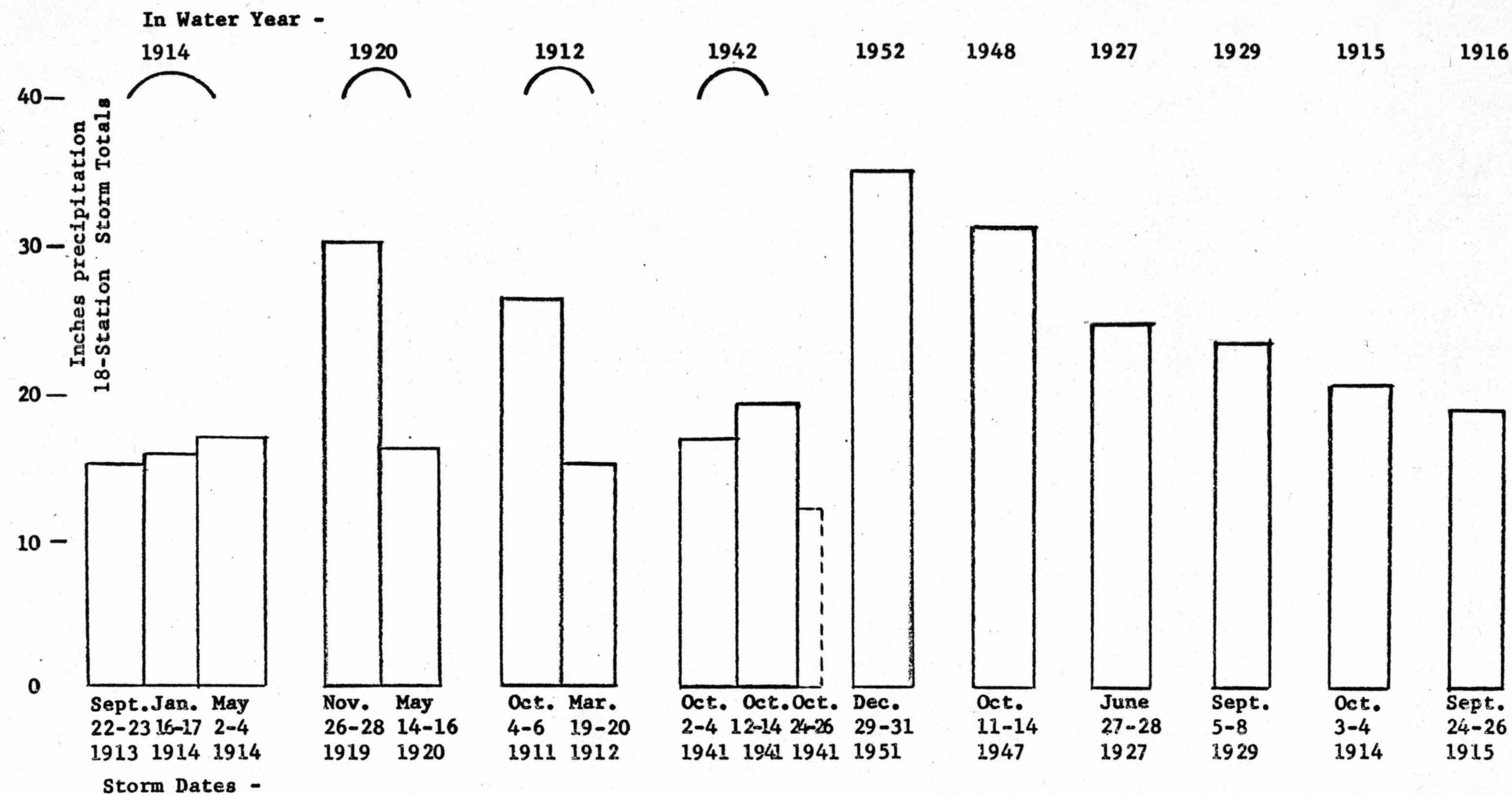

Figure 2. Listing of the 15 largest major storms occurring in Western Colorado during the 46-year period, 1911-12 - 1956-57. Note that these occurred during only 10 of the 46 water years.

September did influence the following water year and produced abnormally high amounts of runoff for the respective quantity of precipitation measured in the 1929-30 water year.

The following table furnishes a very rough approximation of the resulting change in annual streamflow measured at Glen Canyon during seasons when the major storms occurred as listed in Figure 2. The simple method of analysis was to determine the percentage relationship of precipitation totals--including the major storms--in each of the various seasons as compared with the long-period annual normals for the same set of stations. When this same percentage is applied to the 46-season (1912-1957) average annual streamflow of 12,640,000 acre-feet at Glen Canyon, we can relate this to the actual flow which was measured in that water year to get a rough approximation of the influence of these particular major storms--or multiple major storms.

TABLE I

Rough approximation of response in increased annual streamflow at Glen Canyon related to major storms occurring in Western Colorado. (Streamflow Unit - 1000 acre-feet)

Water Year Containing 1 or more Major Storms (See Fig.1)	Percentage of Annual Average Precipitation Recorded Oct.-Sept.	Resulting Runoff when same Percentage is Applied to 46-Season Average Runoff of 12,640	Actual Water Year Runoff Recorded	EXTRA Runoff which may be due to Major Storms
1914	112	14,157	18,007	+ 3,850
1920	111	14,030	18,818	+ 4,788
1912	114	14,410	17,421	+ 3,011
1942	101	12,766	16,394	+ 3,628
1952	122	15,421	17,613	+ 2,192
1948	104	13,146	13,224	+ 78
1927	139	17,570	15,570	- 1,780*
1929	133	16,811	18,387	+ 1,576
1915	93	11,755	11,605	- 150
1916	115	14,536	16,307	+ 1,771

*Three-basin major storm in June and special 14-day rainy period in September resulted in +3,104 excess streamflow following year when annual precipitation was 90%. The combined 2-season net excess is +1,324.

The above table shows the results without considering any influence from other tributaries above Glen Canyon and can, at best, only be considered as a general guide. Several criticisms can be made of this simple technique in determining major storm influence, but it cannot be denied that these major storms do exert a strong plus factor to increasing streamflow.

The total extra runoff for the 15 storms during the ten seasons when they occurred amounted to 22,068,000 acre-feet. This would be an average per major storm of 1,400,000 acre-feet. Please bear in mind that this is in addition to the direct fractional portion of the total annual runoff attributable to the fractional portion of the annual precipitation produced by each single storm. For instance, the single major storm which occurred on December 29-31, 1951, produced approximately 12% of the annual average total precipitation at the 18 stations. This 12% is a part of the 122% of annual precipitation which occurred in water year 1952 and would be expected to yield a corresponding 1,517,000 acre-feet (12% of 12,640,000) within the 15,421,000 acre-foot total at Glen Canyon. When this 1,517,000 is added to the probable excess of 2,192,000, the total attributable to this one storm is 3,709,000 acre-feet.

This current analysis is being made prior to the development of the concept of adjusting actual precipitation data to "precipitation contributing to runoff." When such work has been completed and these major storms are treated as fractional portions of the much lower annual values of "precipitation contributing to runoff" it will even accentuate their importance. Thus, it is the author's opinion that with continuing improvement in analysis effort it can be shown that the single three-day storm of December 29-31, 1951, probably contributed over 4,500,000 acre-feet to the 17,613,000 acre-feet recorded in water year 1952.

Further conjecture would indicate a potential importance of the rare major storms as being worth the following approximate value in total yield of runoff, if they occur during winter months.

36-inch storms at 18 stations within 4 days		4,500,000 acre-feet
30 " " " " "	" " "	3,500,000 " "
24 " " " " "	" " "	2,500,000 " "
18 " " " " "	" " "	2,000,000 " "

Lower yields would apply to the same sized storms if they occur during the warm summer months. The fall season of the year is highly favored as the most likely time occurrence for major storms. If we consider only the nine major storms which have produced 18 inches or more of precipitation, we find that six of these occurred in the two months of September and October. There was one such storm in November, one in December, and one in June.

IV. DETERMINING CAUSES FOR MARKED INCREASES FOR FLOW AT GLEN CANYON

After having checked for all the major storms having 15 inches or more at 18 stations in Western Colorado, it was noted that while these storms did show a general reflection in increased flow for annual runoff, there were instances of sharp increases in the monthly streamflow measurements which were not included in the group of major storms shown in Figure 1. The months when such sharp increases can be detected are rather limited in the flow data at Glen Canyon. They primarily include the months from July through October, since all of the other months are influenced at higher elevations by accumulating snowpack and/or snow melt.

Figure 3 is presented to show the type of storm which was capable of producing a sharp increase in streamflow at Glen Canyon.

In case A the streamflow at Glen Canyon for August, 1927, was 887,000 acre-feet, but in September it jumped to 2,013,000. This compares with a typical long-period monthly flow for these two months of approximately 750,000 for August and 550,000 for September. Instead of a 200,000 drop, there was 1,126,000 increase, or a net increase of 1,316,000.

In checking back through the historical record of precipitation amounts we find that a lengthy period of precipitation was recorded with a particularly outstanding quantity falling in a 14-day period at Crested Butte. The following table gives the 14-day sequence and 14-day total accumulation for the 18 stations. Since the storm covered a fairly long period, the accumulation was well in excess of the 15 inches required for a 4-day storm to produce what could be defined as a major storm for the entire Western Colorado area.

TABLE II

Daily Sequence of Precipitation in Western Colorado, September 1-14, 1927

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	14-day Total
Dillon	.01						.19	.02		.02		.17			.40
Fraser				.19	.03		.01		.03				.35	.02	.64
Glen.Springs					.18				.34			.16	.15	.41	1.24
Rifle						No	Record								
Collbran						.30		.25				.36	.52	.32	1.75
Gr.Junction				.04		.13	.06	.01	.34	.11		.81	.33	.03	1.86
Stmbt.Springs			.01	.07	.07	.05		.07	.06	.06	.01	.26	.24		.90
Meeker						No	Record								
Cr.Butte	1.05	1.20	.98	.59	.62	.60	.77	1.10	1.23	1.25	1.13	1.01	1.00		12.53
Gunnison					.03	.10	.01	.16	.18	.17	.01	.26		.10	1.02
Paonia					.11				.40	.20	.60	.50	.09		1.90
Montrose						.01	.02		.22	.02	.14	.32	.01		.74
Delta							.39	.06	.41	.29	.04	.32	.06	.07	1.64
Silverton				.06		.58	.77	.98	1.47	.83		1.62	.22	.25	6.78
Pagosa Springs						No	Record								
Durango					.04	.14	.68	1.02	.90	1.00	.22	1.12	.12		5.24
Cortez						No	Record								
Telluride			.07	.10	.05	.75	.21	.41	.75	.67		1.04	.24		4.29
14-station total (4 had no record)															40.93

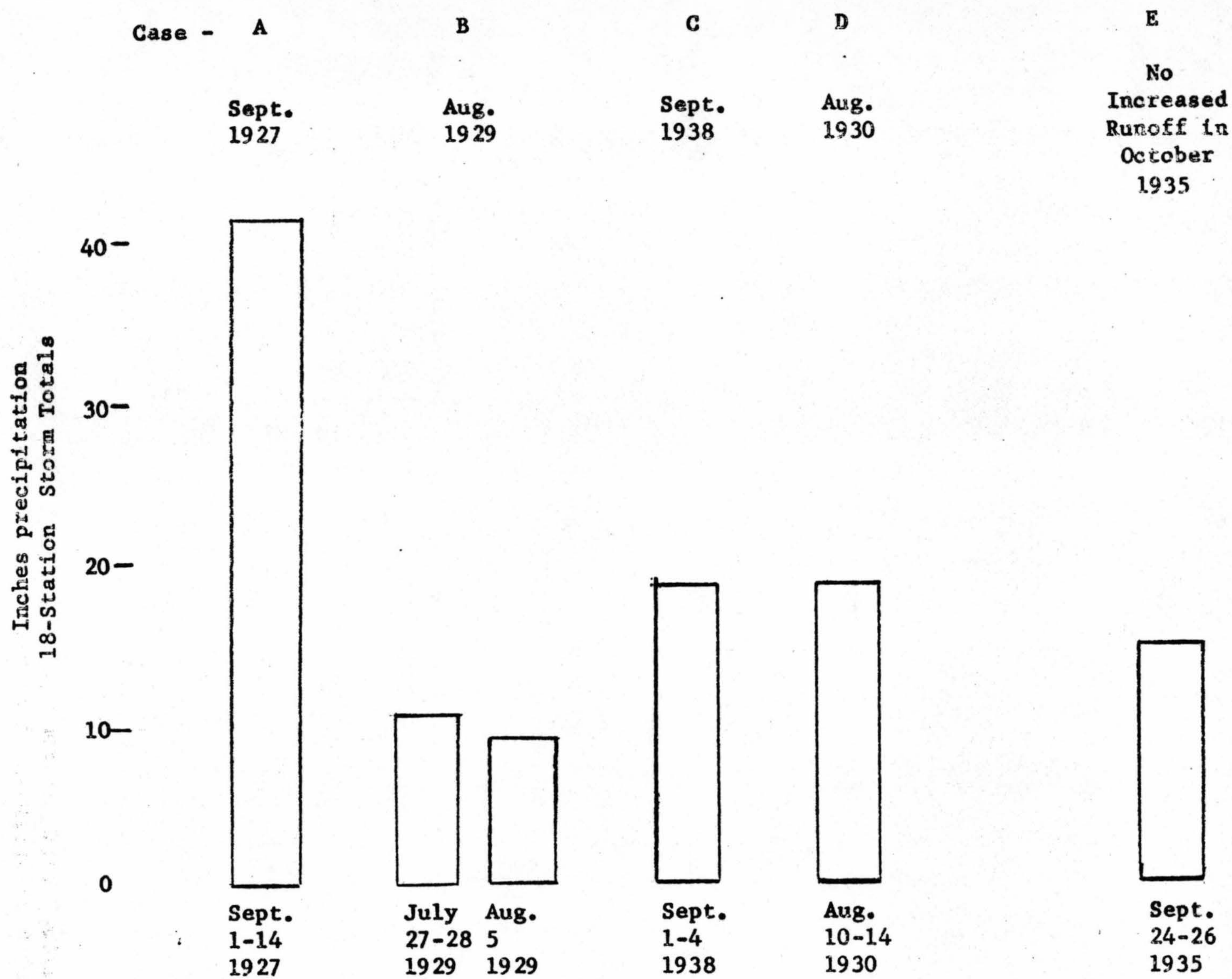

Figure 3. Anticedent precipitation for four cases (A - D) when sharp increases in streamflow were noted at Glen Canyon. Also shown is one case, E, when a storm of 15 inches over an 18-station area did not produce a marked increase in streamflow.

Having examined this particular table it is easy to see why the footnote listed in Table I shows that the water year 1927-28 had so much carryover influence.

A second case that appeared interesting was in August, 1929. In this case the streamflow for August was 1,850,000 acre-feet, which was only 33,000 less than the July runoff measured at Glen Canyon. This compares with the typical drop of approximately 800,000 acre-feet between July and August. In checking back through the precipitation record, it was determined that the month of July contained a single storm which produced between ten and eleven inches in a two-day period, July 27-28. This was followed by another storm producing approximately nine inches on August 5. Although neither one of these storms passed the criteria for a single major storm (15 inches), when combined they produce a total well above the 15-inch limitation. It appears that the two storms are responsible for an extra quantity of runoff approaching 800,000 acre-feet at Glen Canyon.

This was followed by a major storm on the 5th to 8th of September, 1929, which has already been included in the listing of major storms in Figure 2. Since all three of these storms came fairly late in the water year, this is another instance in which there was a strong carryover of runoff moving into the following year.

The third case, C, finds an increase of runoff noted for September, 1938. In that year the four-day period of September 1 to 4 had a storm which could be classed as a two sub-basin storm. It produced heavy rainfall in the Main Stem and the Gunnison watersheds, while the San

Juan area received only a limited amount of precipitation. However, the 18-station total for this four-day storm was approximately 18 inches. The streamflow at Glen Canyon between August and September moved up 414,000 acre-feet instead of down by 200,000 acre-feet, thus making a net increase of approximately 600,000 acre-feet.

The fourth case shows a jump in streamflow between July and August, 1930. The streamflow in July at Glen Canyon had been 962,000 feet; whereas in August it jumped to 1,427,000. This is in contrast to a typical drop of approximately 800,000. Thus the net increase was approximately 1,265,000 acre-feet. In checking back through the precipitation record it was noted that a particular storm measured only for the three-day period of the 11th, 12th, and 13th of August, 1930, gave a total production at the 18 stations of approximately 12 inches. If, however, two more days, the 10th and the 14th, are added to the storm period, precipitation totals approaching 18 inches for a five-day period are obtained. This 18 inches would be a total storm producing an average of one inch per station for the 18 stations.

The last case, E, in Figure 3 is included here to illustrate the basis for using approximately 15 inches as the short term storm total which divides major storms from those that are considerably less important. In this instance, there was some measure of precipitation quantities at all stations during the three-day period, September 24 to 26, 1935. The 18-station total was 14.93 inches, which is approximately .83" average for each of the 18 stations. In this case the measured monthly streamflow at Glen Canyon for August, September, and October were respectively as follows: 492,000 acre-feet, 410,000 acre-feet, and 351,000 acre-feet. Any sharp increase in runoff which should have arrived at Glen Canyon in October fails to be noted.

V. DEFINITIONS OF MAJOR STORMS

Having treated this broad general analysis of the historical occurrences of major storms during the 46-season sample, it is the author's opinion that the following definitions will furnish the criteria for recognizing important major storms when they occur. Only the three-basin storms and the very largest of the two-basin storms will markedly affect the streamflow at Glen Canyon. The single-basin storms tabulated in this analysis may be useful for subsequent studies related to sub-basin planning problems.

A. A three-basin major storm

A three basin major storm is defined as one which produces precipitation above 5% of annual precipitation at one-half or more of the stations in each of the three sub-basins and produces an 18-station total precipitation greater than 15 inches. This is to be collected in a period not to exceed four days.

B. Two-basin major storms

There are two combinations of sub-basins which can be treated as producing two-basin major storms. The first can be the Gunnison plus the Main Stem. This includes 13 of the 18 stations studied in Western Colorado. The definition for such a major storm would be as follows:

"This is a storm which produces above 5% of annual precipitation at one-half or more of the stations in both basins and a 13-station total is 7.80" or more (13 x .60)."

The second two-basin area is the Gunnison plus the San Juan. This is a storm for which the definition would be:

"A storm which produces above 5% of annual precipitation at one-half or more of the stations in both basins and a 10-station total of 7.00" or more (10 x .70)."

C. Single Basin major storms

1. Main Stem. Amounts are above 5% of the annual at one-half or more of the stations and the 8-station total is 4.80" or more.

2. Gunnison. Amounts are above 5% of the annual at one-half or more of the stations and the 5-station total is 3.00" or more.

3. San Juan. Amounts are above 5% of the annual at one-half or more of the stations and the 5-station total is 3.50" or more.

VI. FUTURE REFINEMENTS IN MEASUREMENTS OF MAJOR STORMS

With the development of a better understanding of the relationship of precipitation to runoff which is anticipated in subsequent studies correlating runoff to net precipitation amounts after dropping out all minor non-contributing storms, it should be possible to make gradations of the critical threshold limits which apply to major storms at different times of the year. It is quite evident that the high incidence of September and October storms which are included in the major storm listing will be greatly affected when reliable dropout quantities are determined.

An expanded network of precipitation measuring locations should also improve the understanding of the influence of major storms.

VII. CONCLUSIONS

Having reviewed the historical record of major storms and, in a very general way, the respective influence these storms have had on runoff, the following conclusions have been reached:

1. Snowpack totals can be used as a general substitute for an annual "major storm." The cumulative total of this "major storm" will differ markedly from year to year, but will have a high correlation with the total annual runoff figures at Glen Canyon.
2. Major storms capable of producing within four days an extra yield of 1,500,000 acre-feet or more of runoff are not a part of the annual recurring weather phenomena. Therefore, long-term planning for the most probable one-year runoff values should permit exclusion of the extra runoff yields obtained from such major storms. A projected five-year sample could logically contain one such storm.
3. Major storms can be identified from the current network of precipitation stations in Western Colorado the day following their occurrence.

4. The occurrence of even one major storm adds a plus factor to the impending annual runoff total. However, the one storm, in itself, does not indicate an above normal water runoff year. This will also depend on the precipitation occurring during the other 361 days.

5. Since most major storms occur in the four-month period, September through December, a favorable lead time is gained to allow an upward adjustment of the late winter and early spring runoff estimates for the balance of the current water year, after a major storm is known to have occurred.

6. The fractional portion of additional runoff produced by any September major storm which is to be properly measured at Glen Canyon and included in the current water year will be highly dependent on the date when the storm occurred. Late September storms in the State of Colorado can yield only extra runoff that will be measured in the subsequent month--and subsequent water year--at Glen Canyon.