SUMMER HYDROLOGY OF THE HIGH SIERRA 1/

By

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Introduction

The study area of this hydrologic research project is the higher elevation portion of California's Sierra Nevada, extending from the latitudes of Sacramento to Bakersfield and ranging from approximately 5,000 to over 14,000 in elevation.

In the snow zone of the Southern Sierra, most of the annual precipitation occurs as snow during the winter, November through May, while the major portion of annual runoff occurs during the snowmelt period, April through July. However, occurrence of precipitation in summer months, often the result of thundershower activity in the higher mountains, does produce some runoff during the summer in addition to that which would have occurred from the normal snowmelt recession and base flow. Little study has been made of location, quantity and timing of this runoff produced as a result of summer precipitation or of quantity and areal distribution of this precipitation. Absence of detailed study may be partially the result of paucity of basic data, particularly precipitation, in higher, more remote areas of the Sierra.

The general objective of this research project was to study runoff produced as a result of summer precipitation in order to gain further understanding of the role of this runoff in the overall hydrologic cycle and to determine by inference some of the characteristics of the precipitation which causes this runoff.

More specifically to meet Atmospheric Water Resources Research's objectives, results were first to reveal whether summer precipitation did produce significant volumes of runoff in any specific areas of the Sierra or at any specific times. If so, then to provide information to predict from physical (and meteorological) characteristics of an area, basins and situations with highest potential for producing runoff under natural conditions. Presumably, greatest runoff producing potential for weather modification activities could be defined in this manner.

No attempt was made to evaluate any effect of summer precipitation other than runoff, even though timber and range management, recreation, fire suppression, and similar related activities also could be affected.

Approach

The project was undertaken with the knowledge that lack of adequate hydrologic data would complicate analysis. Few, if any, local precipitation records were available which could be successfully related to specific rises on any of the more isolated basins. Consequently, it was decided to approach the problem entirely from the basis of streamflow records. A substantial number of such records have been maintained according to standardized methods and published by the United States Geological Survey (1) in the Southern Sierra for many years, often in connection with power or irrigation projects. Over the years the number of stations has increased, and quality of record is exceedingly good considering the isolated locations of many gaging sites.

Initial hand analysis of hydrographs from several basins indicated that runoff attributable to summer precipitation might be as high as 2 - 3% of annual runoff in certain high-elevation watersheds. Preliminary analysis also indicated that successful separation of summer precipitation-caused runoff from base flow or late snowmelt recession could be accomplished on basins as small as 20 square miles using mean daily discharge.

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Since it was anticipated that evaluation of about 30 stations for an average of 15 years of record would be required, it was decided to run the analysis on an IBM computer available at Fresno State College.

Analysis techniques and programs were designed to develop the following information on each subject watershed:

A. Volume of Runoff: The historical volume of runoff on a unit runoff, sub-basin by sub-basin basis to be used as a measure of production and potential for individual sub-basins and areas is defined.
B. Number of Occurrences: For purposes of this report, an "occurrence" indicates a detectable increase in runoff over the established recession or base flow. The number of "occurrencees" in any given time period, although not precisely related to number of summer storms, gives an indication of the minimum number of summer storms which would have to be treated if a summer-time weather modification project were undertaken.
C. Timing: The timing of runoff occurrences is defined with respect to some hydrologically significant date such as the end of snowmelt. Analysis of volume and timing would indicate decreased effectiveness of precipitation in producing runoff as the basin dried out during the summer. However, interaction of snowmelt and early summer precipitation would tend to mask the true effect of precipitation occurring before the end of snowmelt.
D. Relationship of Summer-Runoff to Basin Characteristics: By analyzing a large number of basins with different hydrologic, topographic, geologic, ecologic and meteorologic characteristics, it was proposed to develop a relationship between runoff resulting from summer precipitation and physical characteristics of an individual watershed. Final results would be mapped to permit prediction of areas with highest potential for summer weather modification activities.

Twenty-nine Sierra west slope watersheds from the Mokelumne River on the north to the Kern River on the south were used in the study. Records from all watersheds used were unimpaired (or used in this analysis only for periods for which they were unimpaired) in order to avoid superimposing any artificial effects upon the analysis. In a few cases records could be satisfactorily corrected to unimpaired flows on a daily basis. Basins used to date in this study are delineated on Figure I.

Characteristics of watersheds analyzed were as follows:

A. Areas ranged from approximately 15 to 1,000 square miles.
B. Basin mean elevations ranged from 3,400 feet to over 10,000 feet.
C. Basin characteristics varied from steep, rocky watersheds above timber line to much flatter timber-covered or meadow basins at the lower elevations.
D. Distances from the centroid of the basin to the main Sierra crest (or other sizeable meteorologic barrier) varied from approximately 2 to 20 miles.
E. Record length used in analysis varied from about 7 to 25 years. Bear Creek was analyzed from 1922 through 1964 or 43 years. Short record stations were used as required to get better coverage of the other basin variables. Characteristics of basins used in analysis are detailed in Table I.

Analysis Techniques

The primary analysis requirement was separation of the systematic base and/or summer recession runoff from the total hydrograph. The overall period used for separation was May 1 through October 31, in order to have adequate record before end of snowmelt for all basins analyzed. The computer program developed made this separation day by day, anticipating the shape of systematic runoff by searching record up to 30 days in advance of date of computation. It should be noted that this systematic runoff was not always decreasing during the summer. It was found that the systematic flow tended to increase in the fall (September-October) even without significant precipitation, probably as a result of decreased transpiration requirements at this time of year (2).

A second program was developed to separate runoff into specific occurrences and to assign a volume and date to each occurrence. Separation of occurrences was based upon reversal of slope of the hydrograph. Since a hydrograph may rise for several days, especially on larger basins, separation took place only after the hydrograph reached a peak and started to recede. Successive days with ever increasing amounts of runoff were considered as a single occurrence, even though such runoff could possibly result from separate showers occurring on successive days. Volume for each separated hydrograph was computed using a recession curve, and the date assigned to the volume was the day of highest mean daily discharge for that particular occurrence. Resulting volumes were reduced to acre-feet per square mile to allow comparison between basins.

In order to permit spot checking of results, a program was prepared to plot total runoff as separated in the first program so that the shape of separated hydrographs could be observed visually. With the large number of station years of record used it was not feasible to check all stations used in the project by this method.

Two programs were prepared to analyze separated volumes and dates. The first analyzed on an annual basis the total volume of runoff occurring within certain specified time intervals, and determined number of occurrences falling within certain size intervals to give some idea of size distribution of occurrences.

Time Intervals

1. End of Snowmelt through September 30
2. July 15 through October 31
3. July 15 through September 30
4. July 1 through September 30
5. June 15 through September 30
6. June 1 through September 30

Size Intervals - Number greater than

1. 0.01 acre-feet per square mile
2. 0.2 acre-feet per square mile
3. 1.0 acre-feet per square mile
4. 10.0 acre-feet per square mile

End of snowmelt was taken as the date upon which the total runoff during the snowmelt recession of Bear Creek near Lake Thomas A. Edison dropped below 2 cubic feet per second per square mile. On lower watersheds, the date was still tied to Bear Creek but taken as a given number of days before the Bear Creek date based upon inspection of data.

Annual volumes for two representative watersheds for end of snowmelt through September 30 are delineated in Figures 2 and 3.

The second analysis program summarized runoff attributable to summer precipitation by ten-day periods in order to give an indication of the distribution of volumes and number of occurrences during the season. Average values for the entire period of record were used in order to obtain a smoothed distribution curve throughout the season. One set of curves was developed by calendar date (10-day periods before or after June 1), and another set developed by the end of snowmelt date. Figure 4 shows time distribution of runoff and average number of occurrences per year exceeding 0.2 acre-feet per square mile based on end of snowmelt time for Bear Creek, a typical high production watershed.

Runoff Before End of Snowmelt

In the higher elevations of the Sierra, snow may remain throughout the year, particularly in heavier snowfall years. Consequently, it is rather difficult to set any given date as "end of snowmelt" for a given basin or area. As pointed out earlier, Bear Creek was used as a key to the date of "end of snowmelt", or rather, the date on which direct influence of snowpack upon runoff becomes insignificant for our purposes.

Before end of snowmelt in a given basin, precipitation can fall in two forms, snow or rain, or a combination, perhaps differing with elevation. Precipitation can fall on either snowpack or the exposed basin, or any combination, differing with elevation and basin condition. Thus, the effect upon the hydrograph can vary from immediate runoff to complete retention of precipitation by snowpack resulting in an eventual increase of snowmelt runoff. Snowmelt during precipitation also enters the picture.

Since there are currently no precipitation records available from the high elevation watersheds, it was impossible to correlate a rise in runoff directly with precipitation

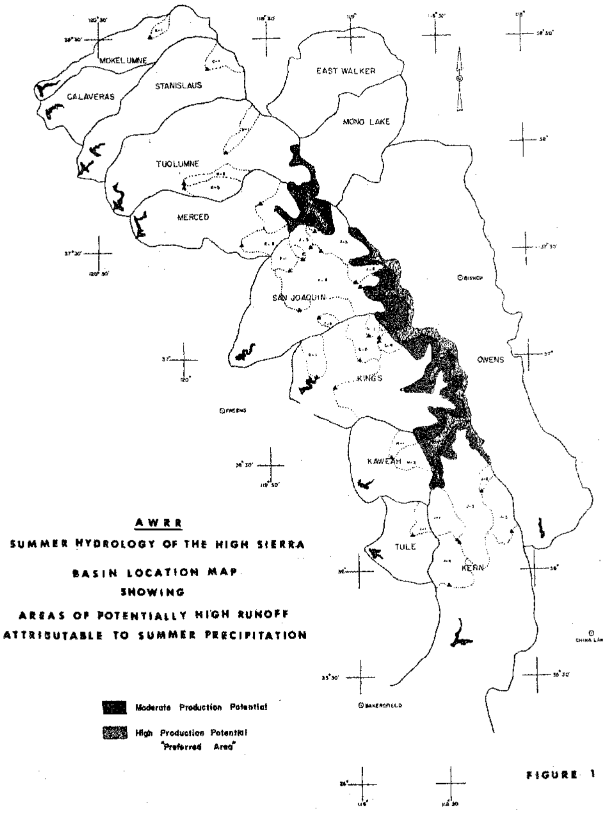

FIGURE 1

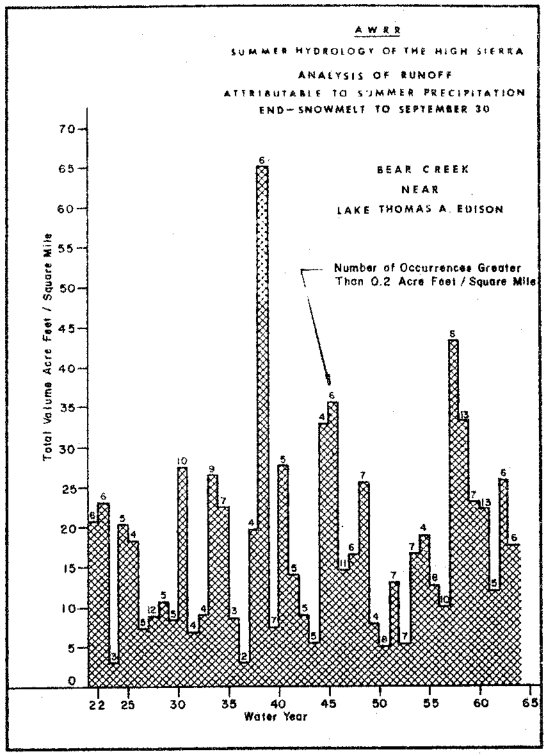

FIGURE 2

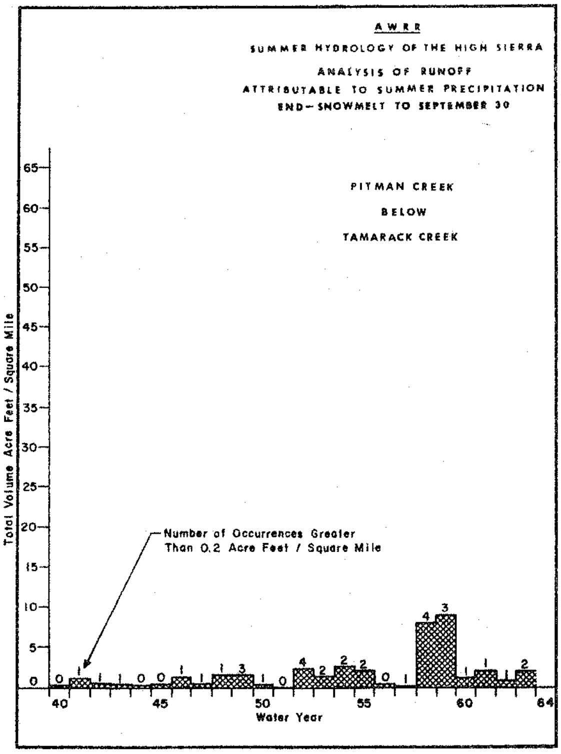

FIGURE 3

summer storms in the Sierra. The smaller, high, rocky basins without much timber cover probably show more runoff occurrences for any or all of the following reasons:

   a. There are undoubtedly more precipitation occurrences. Experience in the Sierra would certainly point to this as a factor.
   b. Losses in the higher, rocky basins are lower so that even small precipitation amounts may produce detectable runoff.
   c. Small basins should show occurrences, in terms of acre-feet per square mile, more easily than larger basins for geographically localized precipitation events.

3. The physical characteristics of a watershed which seem to be associated with high runoff production from summer precipitation are discussed below.
   a. Hydrologic: Steep, rocky, high elevation basins, major portions of which are above timber line, seem to be greatest producers. Losses are much lower in these basins than in more heavily forested basins found at lower elevations. Basins with substantial area of meadow also seem to be poor producers, perhaps as a result of both transpiration losses and stream gradient which would tend to mask hydrograph shapes.
   b. Meteorologic: The closer a basin is located to the main Sierra crest or other major barrier, the higher the production, indicating that the intensity of storms and perhaps the number of storms may be greater than in the lower basins located further from the crest.

Preliminary analysis of results has been completed involving the more obvious factors relating to physical basin characteristics to summer runoff production. Two factors which seem to correlate quite well with summer runoff production are percentage of the basin without vegetative cover and distance from the main Sierra crest or other major barriers. The percentage of the basin without vegatative cover may be significant both hydrologically and meteorologically as it integretes basin losses, elevations (above or below timber line), steepness, and perhaps other physical characteristics.

Estimated areas of highest potential are delineated on Figure 1. Detailed analysis of results will be made to develop more satisfactory means of digitizing physical characteristics for further analysis of production potential.

C. Timing

1. Early season runoff attributable to summer precipitation appears to be much greater than late season (taken by ten-day periods). This might be expected as a result of smaller losses when the basin is wet earlier in the season (Figure 4).
2. During early season, especially in the higher basins where snowmelt is an important factor, the separated runoff before the end of snowmelt shows a large increase in the average ten-day volume (Figure 4). A portion of this is variation in flow resulting from snowmelt. However, visual inspection of plotted hydrograph shapes reveals that a substantial portion of this flow is the result of precipitation on a basin which no longer has enough snow to completely mask out early summer storm effects.

It is interesting to note that the number of occurrences before the end of snowmelt does not increase as rapidly as the volume, suggesting that much increased efficiency of runoff in early season is primarily responsible for the increase in runoff, assuming that quantities of precipitation per occurrence are comparable.

D. Storm Characteristics

Although we have no precipitation data from most basins which were studied in this project, some inferences can be drawn concerning characteristics of summer storms which produced appreciable runoff.

during the snowmelt period. Initial inspection indicated snowmelt rises correlate with temperatures at Huntington Lake. However, runoff occurring much before the "end of snowmelt" was extremely difficult to separate into snowmelt runoff and runoff attributable to summer precipitation. Some success was achieved late in the snowmelt season through visual observation of the hydrograph shape, including diurnal variation. It is believed that successful separation can be achieved up to two weeks before end of snowmelt. The effects of precipitation occurring before this time are almost completely obscured by interaction of precipitation, snowpack and snowmelt.

Results

The following are the results of this study:

A. Hydrograph Characteristics
  1. Some very high elevation basins may tend to slightly overstate total volumes attributable to summer precipitation as a result of snow which remains at higher elevations throughout the summer. Rather flat, late-summer hydrographs which correlate well with temperatures occur in these basins. However, quantities are normally small compared to volumes from shower activity.
  2. The shape of hydrographs caused by summer precipitation is usually rather distinctive, with a sharp rise and fall as determined from mean daily runoff data. Rises caused by snowmelt are generally much flatter on both rising and falling limbs.
  3. Most Sierra basins studied, throughout all elevation ranges tended to show a slight rise in the base flow in late season, even in the absence of late season storms. This verifies results of others (2) indicating decreases in transpiration in the late season.

B. Volume of Runoff
  1. Volume of runoff attributable to summer precipitation between end of snowmelt and September 30 (using the 13-year 1952 - 1964 average *) varies from less than 2 acre-feet per square mile to over 40 acre-feet per square mile, (Table I) or a difference in production of over 30 to 1. Note that the period of production considered in this study (end of snowmelt to September 30) is shorter in the higher-elevation, high production basins than in the lower-elevation, low producers, further increasing the difference in potential production. If a longer period of record is used or analysis is based upon median annual volume, volumes are somewhat decreased but the ratio between the high and low contribution basins is increased. This points out that the runoff from the higher-contributing basins is not only greater, but far more dependable, than that from the lower producers.
  2. The number of occurrences producing detectable runoff does not vary as much from basin to basin as does the runoff. The ratio between occurrences in high producers and low producers is only on the order of 2 to 1 (for all occurrences, regardless of magnitude of occurrence). Note again that the study period beginning with end of snowmelt undoubtedly decreases the probable ratio between number of occurrences in high- versus low-production basins since the analysis period is shorter at higher elevations. As magnitude of runoff occurrences considered increases, this ratio increases rapidly (Figure 5) especially for the average and minimum cases, indicating that high production of runoff from summer precipitation is the result of a relatively small number of occurrences in geographically definable areas of the Sierra.

     Definition of these areas and the storm characteristics which produce high runoff will be of value to A.W.R.R. in designing future summer programs.

     Both runoff volume and number of occurrences suggest favored locations for

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* This period of record was used for averages as many of the stations used in analysis were initiated about 1952. However, a number of stations were analyzed from 1940 - 1964.

1. For purposes of this report there are three broad categories of storms which produced appreciable runoff. These storm types are not distinguished here by their meteorologic characteristics, but by runoff characteristics and geographical distribution of runoff which they produce.
    a. Isolated thundershower activity: Thundershower activity isolated either geographically (covering only a few square miles) or in time (lasting only a single day). These storms have not been consistent producers of runoff. Only on a few occasions have isolated showers produced major amounts of runoff and this runoff has been restricted to rocky, high elevation watersheds.
    b. Generalized thundershower activity: By far the greatest consistent runoff producers are thundershower type storms covering large areas and lasting for a number of days. An example of a storm of this type occurred during August 1961 (Figure 6). This storm (or series of storms) was extreme in volume of runoff it produced, but its features indicate a type of storm which may be expected to contribute significant amounts of runoff. The 1961 storm extended from the Kern River to the Mokelumne River. (It is interesting to note that shower activity extended throughout all of southern California). From available observations, each morning thunderstorms would begin to build, precipitation would be produced in afternoon and evening and clouds would dissipate overnight. The cycle would repeat the following day.

       Through comparison of runoff records on different streams, it is apparent that although precipitation did occur throughout the entire Southern Sierra, amounts of precipitation and timing must have varied tremendously from area to area (Figure 6).
    c. General storm: These storms must be very much the same as winter storms, sweeping large areas, sometimes with heavy precipitation. Hydrographs show similarity in timing from basin to basin, even though widely distributed geographically. However, there is evidence of large variation in precipitation from area to area even in these general storms. Storms last for several days or more. A storm of this type occurred in September 1959. It was primarily concentrated in the area between the Stanislaus and Kings Rivers. This storm resulted in over 100 acre-feet per square mile or about 2 inches of runoff from North Fork of the San Joaquin River below Iron Creek, and about 1.4 inches on Fall Creek near Hetch Hetchy. During the same period, precipitation recorded at Huntington Lake, approximately 30 miles south of North Fork, was 5.45 inches.

       Less productive storms of this type might be difficult to distinguish from generalized thundershower activity by hydrograph analysis.
2. As basins become more widely separated geographically, the shapes of daily hydrographs become less comparable. It is interesting to note that annual volumes also become less comparable.
3. During the period after end of snowmelt, runoff is apparently increased substantially by a number of consecutive days of precipitation. This may have two causes, one hydrologic and the other meteorologic. First, with several days of precipitation, runoff efficiency increases as more precipitation falls without a "drying out" period between storms. Second, and this may merit further investigation, precipitation quantities and/or intensities could increase after several consecutive days of thundershower activity due to residual moisture from the earlier storms.
4. Even in the generalized thunderstorm situation, high correlation between quantities of runoff on two basins or between precipitation and runoff at two locations may be difficult to establish. An example of generalized thundershower activity is delineated on Figure 6. The figure shows runoff from three storm periods during August 1961 on North Fork of the San Joaquin below Iron Creek (38.0 square miles) and Bear Creek near Lake Thomas A. Edison (53.5 square miles), two basins located along the Sierra

TABLE I

RUNOFF ATTRIBUTABLE TO SUMMER PRECIPITATION
AND
PHYSICAL CHARACTERISTICS OF BASINS USED IN HYDROLOGIC STUDIES

Station Number and Name		Runoff Attributable To Summer Precipitation End of Snowmelt to September 30 Acre Feet/Square Mile: Average Runoff 1/	Median Runoff 2/	Range of Runoff: Min	Range of Runoff: Max	Watershed Area (Square Miles)
A-1	Cole Creek nr Mokelumne Peak	1.7	0.6	0.1	5.1	20.4
C-1	Clark Fork nr Dardenelles	4.8	4.8	2.3	10.1	67.5
D-1	Falls Creek nr Hetch-Hetchy	14.8	7.1	1.3	88.4	46.0
D-2	Middle Fork Tuolumne	2.0	1.3	0.4	6.1	73.5
E-1	Merced River at Happy Isles	12.4	8.2	3.8	36.3	181.0
E-2	So. Fork Merced nr Wawona e	4.0	2.3	0.9	17.9	100.0
F-1	Chiquito Creek nr Bass Lake	3.2	1.5	0.9	19.1	59.6
F-2	Jackass Creek nr Bass Lake 4/	2.1	0.9	0.3	16.8	12.8
F-3	Granite Creek nr Cattle Mountain	11.8	5.6	1.7	61.0	47.8
F-4	No. Fork San Joaquin blo Iron Creek	43.5	33.3	17.1	144.3	38.0
F-5	San Joaquin at Miller Crossing	16.5	13.2	5.9	48.6	254.0
F-6	Mono Creek at Vermillion Valley 3/	13.6	12.3	-	-	92.0
F-7	Bear Creek nr Lake Thomas A. Edison	19.4	17.6	5.7	44.8	53.5
F-8	San Joaquin nr Big Creek 3/	6.6	-	-	-	1050.0
F-9	Pitman Creek blo Tamarack Creek	2.5	1.9	0.5	8.0	22.7
G-1	Big Creek nr Pine Flat e	1.4	0.9	0.04	2.0	69.9
G-2	Post Corral Creek nr Blackcap e	6.9	6.2	0.6	31.0	27.9
G-3	Fleming Creek nr Blackcap e 4/	9.8	8.8	1.9	26.1	15.0
G-4	No. Fork Kings nr Meadowbrook e	16.1	14.4	3.3	43.6	37.7
G-5	No. Fork Kings nr Cliff Camp 3/	2.5	1.5	-	-	181.0
G-6	Kings River abv North Fork	8.9	8.2	1.9	16.9	952.0
H-1	Marble Fork Kaweah at Potwisha e	7.0	6.5	0.9	12.2	51.4
H-2	Middle Fork Kaweah nr Potwisha e	7.8	7.0	2.5	13.1	102.0
I-1	No. Fork of Middle Fork Tule e	3.5	3.3	2.0	5.1	39.3
J-1	Little Kern nr Quaking Aspen e	2.8	2.0	0.9	4.9	134.0
J-2	Golden Trout Creek nr Cartago e	3.8	3.1	2.1	7.7	23.4
J-3	Kern River nr Quaking Aspen e	~8	Insufficient Data		13.3	530.0
J-4	Kern River nr Kernville	4.6	4.1	1.1	10.0	848.0
J-5	So. Fork Kern nr Olancha e	1.6	1.3	0.1	5.2	146.0

TABLE I
(Continued)

Station Number	Station Elevation (Feet)	Mean Basin Elevation (Feet)	Mean Elevation of Basin Barrier (Feet)	Distance From Basin Centroid to Crest (Miles)	Percent of Vegatative Cover
A-1	6000	6,900	8,400	12	98
C-1	5507	6,400	9,800	5	70
D-1	5350	8,400	9,800	8	53
D-2	2800	6,800	8,200	24	85
E-1	4017	7,650	11,100	9	53
E-2	4030	8,150	9,800	25	77
F-1	4800	7,200	9,000	24	89
F-2	6900	8,150	8,400	18	80
F-3	6800	8,900	10,750	15	65
F-4	6800	9,680	11,750	3	16
F-5	4550	8,200	11,800	5	52
F-6	7400	9,250	12,400	7	58
F-7	7400	10,050	12,500	4	48
F-8	2400	—	—	—	—
F-9	7005	8,080	9,000	27	90
G-1	962	3,400	6,200	36	95
G-2	8145	9,750	10,500	15	52
G-3	8590	10,100	11,200	9	37
G-4	8145	10,250	11,900	11	44
G-5	6144	8,600	11,500	14	66
G-6	1004	—	—	—	—
H-1	2150	9,000	10,500	24	62
H-2	2100	6,400	11,500	20	61
I-1	2920	7,200	8,800	30	87
J-1	4682	7,400	10,400	24	86
J-2	8940	9,900	11,500	35	81
J-3	4693	—	—	—	—
J-4	3542	—	—	—	—
J-5	7840	9,000	10,000	3	93

1/ Average annual runoff volume for 13-year period 1952-1964. If record does not cover entire period, average is estimated using other basins in area.

2/ Median annual runoff volume for 13-year period 1952-1964. If record does not cover entire period, median is estimated using other basins in area.

3/ No record is used for periods after which reservoirs were constructed on these streams. Averages and medians are estimated from prior record.

4/ These stream basins are probably too small for adequate hydrograph analysis from mean daily discharge records.

e Record used in analysis is started after 1952. Average, median, minimum and maximum estimated from data available.

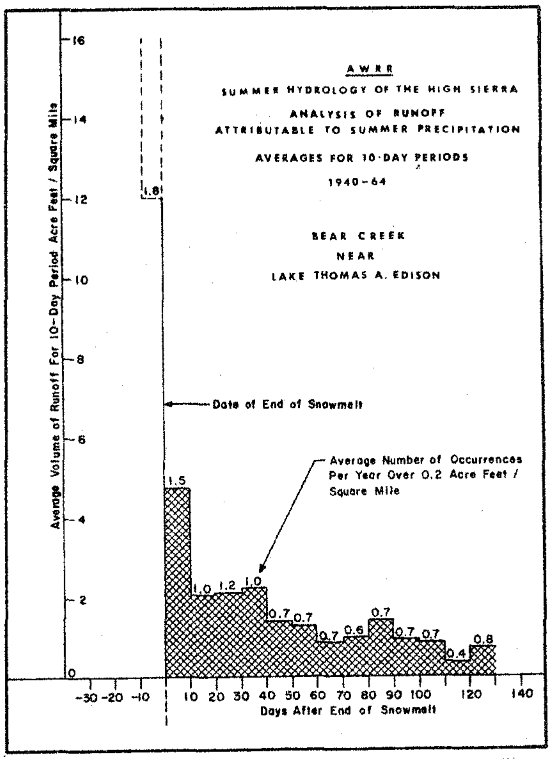
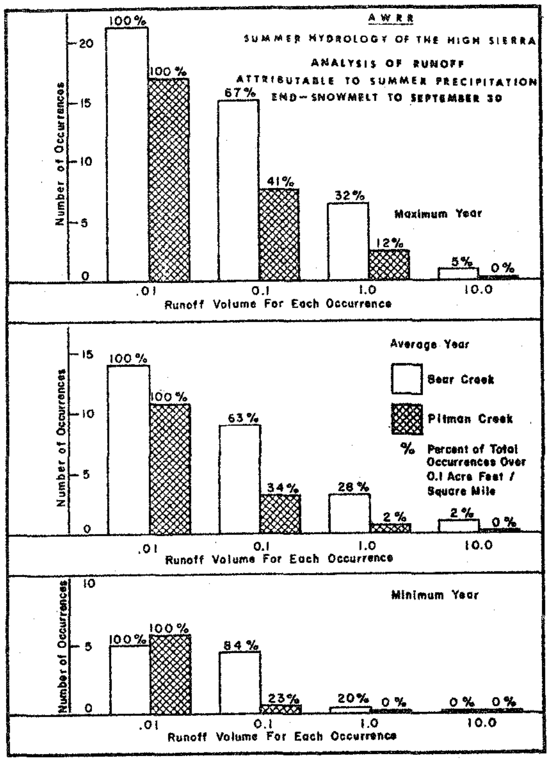


FIGURE 4



Size Distribution of Runoff Occurrences

FIGURE 5

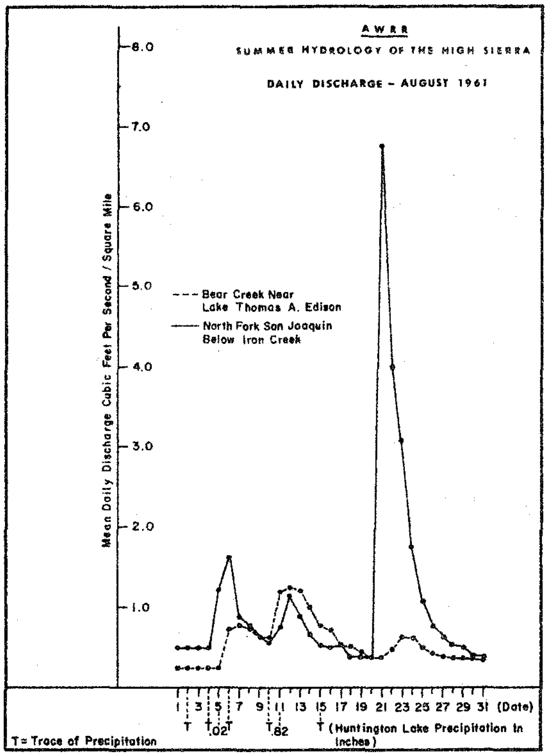


FIGURE 6

Crest and approximately 25 miles apart. Also tabulated is recorded precipitation at Huntington Lake. There is some evidence that on the upper Kern River, some 60 miles south of Bear Creek, the runoff is again increased substantially, with peaks of similar magnitude occurring on both the 12th and 23rd of August.

Summary and Conclusions

As a consequence of computer analysis of basic data, results can be analyzed and assembled in virtually any form desired. As of the present date, not all possible analyses of the data have been completed. However, summary of and reflection upon the major findings to date might be in order at this point.

Average (1952-1964) runoff from summer storms from end of snowmelt through September 30 in terms of percentage of annual runoff varies from over 2% on the higher, rocky basins to less than 0.1% on the lower, more timbered basins.

North Fork San Joaquin below Iron Creek	2.2%
Bear Creek near Lake Thomas A. Edison	1.7%
Pitman Creek below Tamarack Creek	.2%
Cole Creek near Mokelumne Peak	.07%

Runoff produced as a result of summer precipitation is quite variable with respect to both volume and timing. Variation in volume from year to year is on the order of 10 to 1, even on the most dependable producing basins.

Highest production, natural or otherwise, may be expected from high elevation basins with high relief and little vegetation, located adjacent to major ridges or barriers. Runoff production capability of a given basin is possible through analysis of the physical characteristics of the basin, for which preliminary analysis has been completed.

The number of occurrences producing runoff over 0.2 acre-feet per square mile on the most productive basins varies from year to year from about 5 to 15. In many cases an "occurrence" is the result of several days of precipitation. Consequently, the number of occasions upon which weather modification activities may have to be carried out could be quite large.

Although very moderate amounts of increase in summer precipitation will show substantial percentage increase in summer runoff, only in a few selected areas will potential for increasing volume of runoff be comparable to that of winter operations. For example, it would take a four- or five-fold increase in runoff attributable to summer precipitation on the most productive basins before a mid-summer program would be able to provide increased volumes comparable to those reported from well organized effective winter programs.

From a hydrologic standpoint, the most effective times to modify summer-type storms would be 1) early season (that is, before end of snowmelt), 2) during general thundershower activity, and 3) during any general storms which might occur during the snowmelt season or summer. Strictly isolated storms probably offer least potential for good runoff production from larger sized areas.

An interesting sidelight from the water supply forecaster's point of view is the effect that variations in high-elevation, largely unmeasured precipitation from cumulus activity occurring during the snowmelt period may have upon runoff during the April-July period. From initial hydrograph analysis, it is conservatively estimated that runoff resulting from cumulus activity occurring prior to end of snowmelt which is unrecorded as precipitation elsewhere, may be from two to ten times as great as that resulting from precipitation during the mid-summer period, dependent upon the basin.

Using the Kings River above North Fork (952 square miles) as an example, the maximum variation in runoff resulting from summer precipitation over the last 25 years is approximately 16,000 acre-feet. Assuming a variation three times as great during the snowmelt period this would be approximately 50,000 acre-feet. Interestingly enough, this is in the same order of magnitude as the standard error of snowmelt forecast procedures in current use. This is not to imply that all of the remaining relationship error is the result of unmeasured precipitation but it is apparent that significant contributions could be made in improvement of forecast accuracy with more adequate high-elevation precipitation data.

Future Work

A research project of this nature generally opens up more new questions than it answers. In this case, most of the new questions center about hydrology of the period prior to the end of snowmelt and the character of summer-type, particularly cumulus-associated, precipitation including intensities, geographical distribution, and similar parameters.

Listed below are suggestions for further analysis work on this project:

1. Extend analysis to Sierra east side in study of basin characteristics, to further delineate the effects of summer precipitation along the crest of the Sierra.
2. Extend detailed study of daily hydrograph data, particularly on the larger basins, where contributions from many minor, high elevation tributaries make up the flow of the stream.
3. Look for suitable basins with some precipitation record to try to get some idea of magnitude of precipitation amounts and thus secure a better understanding of losses from summer precipitation.
4. Study separation of hydrographs before end of snowmelt in more detail probably through analysis of diurnal hydrograph fluctuation, determination of precipitation occurrences by radar and finally by field measurement of high elevation precipitation.

References

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