

## TOOL IN WEATHER MODIFICATION 1/

By

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Introduction and Background

Weather modification projects representing a wide range of effort and capability have been conducted in California's southern and central Sierra Nevada since the late 1940's. The major objective of this study was to prepare a regional hydrologic analysis of the entire southern and central Sierra, extending from the latitude of Bakersfield, Calif., to the latitude of Reno, Nevada, to identify trends in runoff and to identify which of these trends might reasonably be associated with weather modification activities. The analysis was not intended in any way to evaluate the relative effects of specific projects on specific targets, nor was it intended to evaluate statistically specific increases in runoff resulting from weather modification activities. Instead, the analysis was designed to (1) outline areas of increased runoff resulting from weather modification activities and to provide general information on the probable magnitude of increases, (2) to identify changes in runoff in terms of target and/or generator locations, and (3) to investigate possible downwind or side effects, and possible interproject effects of major magnitude which might exist in the area of regional analysis.

The Sierra Nevada creates a meteorologic barrier some 400 miles long, with elevation ranging from near sea level in the San Joaquin Valley to over 14,000 feet along the crest. This is an area in which accumulation of snow during the winter months stores water for release during spring and summer snowmelt. Inaccessibility of the snow covered area during the period of accumulation has limited the amount of data available. Although snow measurements are made throughout the area, these measurements are made only at monthly intervals. Only within recent years have major strides been made in obtaining telemetered data from the high country. As a consequence of paucity of detailed precipitation and snow-pack data, streamflow data have become perhaps the most valuable source of information for estimating climatologic and hydrologic trends throughout the Sierra.

Three major weather modification projects have been carried on in the southern and central Sierra, although many smaller projects have been attempted during the same period of time (Figure 1). The southernmost project considered in this paper is intended to increase the runoff of the entire 1,600 square mile Kings River Watershed. The project is conducted for the Kings River Water Association by Atmospheric, Inc., of Fresno. This project has been continuously operated from the 1955 water year to present. Predecessor companies may have carried on some activity in the area prior to 1955. The second project is in the San Joaquin drainage and is conducted for the Southern California Edison Company, a power generating utility, by North American Weather Consultants. This project has been conducted continuously from the 1951 water year to the present. The target area of this project is somewhat smaller than that of the Kings River project, as it includes only the up-stream tributaries above Southern California Edison diversion, storage and generating facilities. The third project was conducted on the Stanislaus and Molelumne River watersheds at the northern end of the central Sierra for the Pacific Gas and Electric Company by North American Weather Consultants. This project lasted from 1953 to 1961. Note that there is a general overlap of periods of operation.

Exploratory Work

The first step in exploratory work on this project was to select basic data for

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use in analysis, recognizing that some basins may have trends resulting from works of men, differences in measurement techniques, change in location of gaging stations, etc. It was reasoned that careful selection of control basins and analysis of numerous test basins would tend to minimize unreal trends.

Initial analysis consisted of double-mass plotting (Linsley, Kohler and Paulhus, 1958) of annual streamflow for the 40-year period 1925 to 1964. At the time the project was initiated, corrections for impairments at many stations could be made only through the 1963-1964 water year. Recording gage-height instruments came into common use in the early 1920's, and it was anticipated that the entire 40-year period would be suitable for use in hydrologic analysis. However, double-mass plotting quickly showed that many of the stations with long period records did have inconsistencies in the early portion of that period. Rather than attempt to correct the early period record, the first 10 years of the period were eliminated so that the final period of the analysis was 1935 through 1964.

Double-mass plotting also uncovered an apparent north-south trend in runoff. Within recent years of record, northern stations have apparently had more runoff than expected compared to southern stations. Analysis of this problem, which extended as far north as the Sacramento and Feather River basins and the north coastal area, indicated that the trend apparently persists throughout the area investigated. To verify that this was not strictly a runoff phenomenon, groupings of precipitation stations were also analyzed, disclosing the same basic trend (Figure 2). If any specific break in this time trend could be pinpointed, it would be in the middle 1940's.

In order to further analyze possible trends, several streams with extremely long periods of record were plotted back to the turn of the century. Similar apparent trends are discernible in this early record. Studies conducted by the U. S. Geological Survey in Southern California (USGS, 1963) indicate that precipitation data in the southern portion of the state shows a time trend similar to that indicated in the southern Sierra, further verifying the effects noted in runoff data.

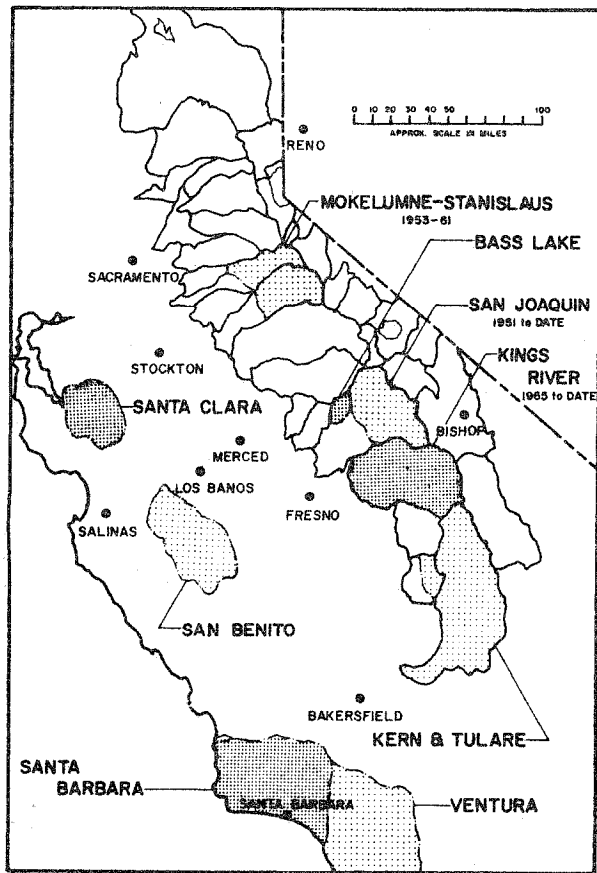
Evidence of apparent north-south time trends in the records dictated that any model created for analysis of the data would have to include comparative data both to the north and to the south of the test basin under analysis. The assumption made was that some linear relationship exists between the two control basins and that the intermediate test basin being analyzed would fit into the overall pattern. Further statistical analysis of basic data tended to bear out this assumption. For example, a linear regression between discharge of the Kings River and the Merced River at Pohono Bridge, located approximately 85 miles to the north, gave a correlation coefficient of approximately 0.88. On the other hand, a similar multiple linear regression to estimate discharge of the Kings using the Merced on the north and the Kern River near Kernville on the south gave a correlation coefficient of over 0.98. Poor correlations tend to make detection of trends more difficult and statistically less reliable.

#### Analysis Technique

After the decision to use a dual control type model was made, the most reasonable approach for preliminary analysis appeared to be a computerized multiple regression. During analysis more than 300 multiple regressions were run on this project. The computer analysis was to be used only for preliminary work, leaving more detailed analysis to a method which permitted visual inspection of data.

The unit time interval used in the final analysis was the water year. The water year discharge in acre feet was selected as the unit of analysis because it most nearly represents the length of the snowmelt hydrograph in the Sierra. Carry-over from sources other than snowmelt represent a minor portion of the annual runoff (Hannaford and Williams, 1967) on most basin.

In order to simplify detection of the effect of weather modification, if this effect does exist on a particular basin, a modification variable was taken as zero in years where no modification activity occurred and plus one in years where modification programs were active. A separate set of weather modification data was prepared for each of the three projects. That set of data was applied to all streams where seeding effects might be detected. It should be pointed out that since these projects overlapped in time and in fact



HISTORICAL SEEDING PROJECTS  
CENTRAL PORTION OF CALIFORNIA  
1951-1967

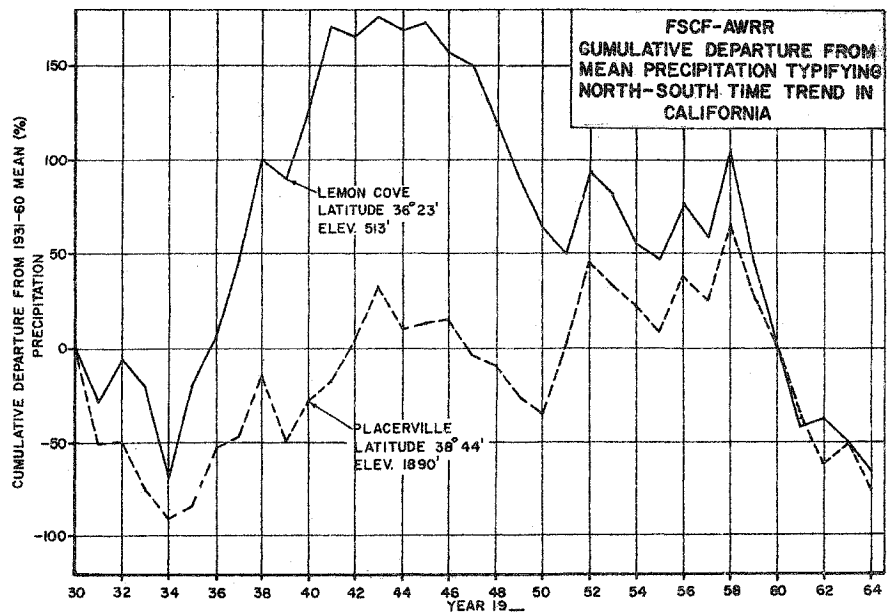


FIG. 2

covered almost the same period of record, the results obtained using data from one weather modification project were generally very similar to results using data from either of the other two projects.

#### Basic Runoff Data

In an analysis of this type, there is always a question concerning the effects of nature or man upon hydrologic records. Increased consumptive use, construction of major storage or diversion works, change in gaging station location or the method of measurement, improved measurement techniques and weather modification activities may have an effect on the runoff from any given basin. Each of the records used in this study was analyzed in order to avoid or minimize these effects. The problem of attempting to develop a group of consistent records where the very item which is under study will be manifest in a record-inconsistency can readily be visualized.

The first step in analysis of the basic data was to select groups of control basin records which would be as free of the works of man as possible. However, it is difficult to find a major basin in the central and southern Sierra that is completely uncontaminated by weather modification projects. (Figure 1).

Control basin criteria were set up as follows:

1. No major works of man were to be placed above the gaging station during the period of analysis. This obviously eliminated a large portion of the watersheds in the Sierra almost immediately. With the exception of one watershed, no new work was done above the control gages within the period of analysis, and in that particular instance, correction was made for trans-basin diversions for two years on the end of the record.
2. Pre-existing effects of man were to be accurately and consistently recorded to make corrections for such items as reservoir storage.
3. The full period of record was to be taken at the same location or completely correctible to the same location.
4. Elevations, topography and physical characteristics of the basins selected were to be representative of the Sierra at that latitude.
5. A United States Geological Survey streamgage reliability rating of "good" or "excellent" was required (USGS 1964).
6. The basin was to be located in an area where there was no probable effect of weather modification activities, or at least the effect was thought to be very minor.

Double mass plots were run on all proposed control basins against out-of-target area precipitation and out-of-target area runoff. Final selection of control basins included the following from north to south along the Sierra:

<u>Name of Gaging Station</u>	<u>Average Annual Runoff <sup>1/</sup></u>	<u>Location and Study Area</u>
Middle Fork of American River near Auburn	1,057,600 AF	Northern
Tuolumne River near Hetch Hetchy	769,100 AF	Central
Merced River at Pohono Bridge	535,000 AF	Central
Kern River near Kernville	4,450,800 AF	Southern

Historically some of these controls have been used by others in hydrologic evaluation in the southern Sierra. Henderson (1964) has used the Kern River near Kernville and the Merced River at Pohono Bridge to evaluate runoff on the Kings River, Inflow to Pine Flat Reservoir. Markovic (1966) used the Merced River at Pohono Bridge alone to evaluate the Kings River, Inflow to Pine Flat. Elliott and Lang (1967) have used the Merced River at Pohono Bridge for evaluation of projects in the area. It is interesting to note that the U. S. Geological Survey has designated "the Merced River in the Sierra Nevada . . . as one of . . . a group of stations in diverse environments throughout the nation that are not

<sup>1/</sup> Average is for the period 1935 to 1966.

likely to be affected by the works of man, but will vary solely as the result of natural causes. These stations will serve as a network of benchmarks with which other stations can be compared to provide a measure of the effect of man's activities on hydrology." (USGS, 1967). The Tuolumne River near Hetch Hetchy is located in Yosemite National Park. There is storage above the gaging station that has been operating in the area since 1923. A major portion of the Kern River above Kernville, California, also lies within a national park. However, at the point of measurement, a portion of the water is diverted through a power canal. The summation of the flow in the stream and the power canal has been used as the record for Kern River near Kernville since 1923. Unlike other streams selected as controls, the Middle Fork of the American River near Auburn does not lie within a national park. Drainages of several hundred square miles or more in the northern Sierra without the works of man are becoming increasingly difficult to find. This record was corrected for minor diversions which have occurred in the past and for storage which has been developed in the past few years in the upper portions of the basin.

Criteria for selection of other basins used in the analysis were not as stringent as for control basins. The requirement for no change in impairment during the period of record would have left too few stations for a regional analysis. All stations were corrected as nearly as possible to the same physical conditions throughout the entire period of record. It should be borne in mind that the results can be influenced by changes in measurement methods. Inter-basin diversions might make apparent changes in the characteristics of the runoff. There are any number of other problems which could influence the basic data. The point of a regional analysis is that it takes into account all records which are available, and biases, linked to weather modification or not, may be considered in analysis.

#### Analysis and Interpretation

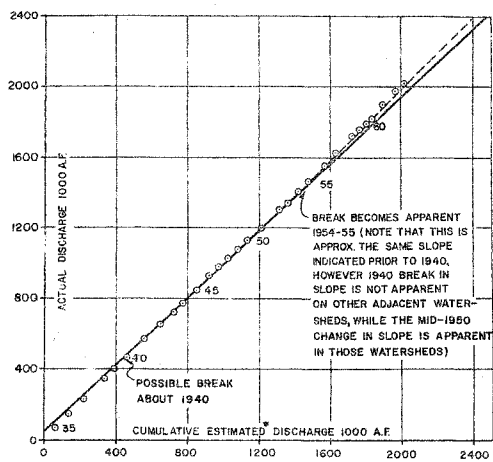
In each case where computer analysis indicated results suitable for additional work, further analysis was done to obtain a more graphic representation of any apparent trends. Double-mass diagrams were plotted of the actual annual discharge from the test basin versus discharge from the test basin estimated from two control basins (Figure 3).

In analysis of the plots, an attempt was made to establish or identify the following:

1. Did any break in the double mass line coincide with the approximate date when weather modification activities began in an area which might influence the particular test basin? In some cases computer analysis showed an apparent change in runoff related to the period of weather modification activity, even though plotting indicated that the actual point of break was before or well after the date when weather modification activity began. In many cases results were eliminated from this study because of insufficient evidence that an apparent increase in runoff could be directly associated with the time period of weather modification activity in the area. The material represented on the map (Figure 4) shows an apparent change in runoff coincident with the period of weather modification of one or more of the Sierra projects.
2. Did more than one break point occur? If more than one major break did occur, then was variation in slope the result of change in runoff characteristics of the basin in wet or dry periods, or could it be traced through station histories? Results were adjusted or ignored, depending upon the information available.
3. What was the magnitude of the change in slope? The magnitude of the apparent change in runoff during the period of weather modification activity was estimated both from the regression analysis and from the plotted data. Generally the plotted data controlled as the effect of trends could be more readily observed visually than numerically.

Figure 3 shows a typical double-mass plot prepared from the computer analysis in the San Joaquin target area. Results of all of the analyses appear in Table 1.

Figure 3



\* EST. FROM COMPUTER ANALYSIS USING:  
 +.0297 X MERCED RIVER AT HAPPY ISLES  
 +.0935 X KERN R. NEAR KERNVILLE  
 +.9281  
 ALL IN 1000 A.F.

AWRR  
 DOUBLE MASS DIAGRAM  
 BEAR CREEK NEAR LAKE T.A. EDISON  
 ACTUAL DISCHARGE  
 VS  
 DISCHARGES ESTIMATED  
 FROM COMPUTER ANALYSIS

TABLE I  
 AMOUNTS AND DATES FIRST NOTED FOR APPARENT INCREASES  
 COINCIDENT WITH WEATHER MODIFICATION

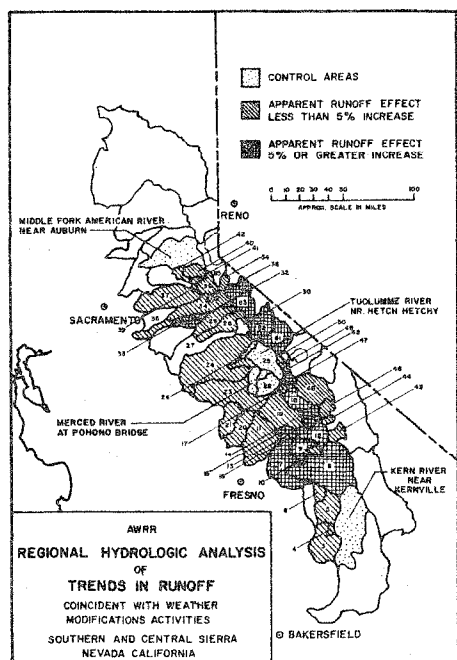
STATION	MRP <sup>1/</sup>	DATE <sup>2/</sup>	PLOT	DATE	REMARKS
1 Kern River nr Bakersfield	-3%	1955	-	1942-43	Only change in slope of DMP <sup>3/</sup> prior to any activity
2 Kern River, infl Isabella	-1%	1955	Nil	-	No visible change in slope of DMP
3 Tule River, infl Succasa	-12%	1955	Nil	Abt 1945	Change in DMP doubtful, if any
4 NP MF Tule River	-	-	Nil	-	No change in slope of DMP
5 Kaweah River nr Three Rivers	+4%	1955	Nil	Abt 1943	Change in DMP doubtful, if any
6 NP Kaweah	-	-	Nil	-	No obvious trends
7 Kings River, infl Pine Flat	+7%	1955	+7.5%	1955	Checks with project
8 Kings River abv North Fork	+7%	1955	+6%	1954-55	-
9 NP Kings River nr Cliff Camp	+0%	1955	+12%	1954	Two reservoirs built during period of seeding 1922-35, 1957-64
10 NP Kings River blo Meadowbrook	+6%	1955	+3%	-	Appears consistent
11 San Joaquin River, infl Friant	+2%	1951	+5.5%	1952-53	-
12 SF San Joaquin River nr Florence Lake	+5%	1951	+8%	1952	-
13 Bear Crk nr Lake Thomas A. Edison	0	-	+6%	1954-55	Break in early 1940's masks out MRP
14 Mono Crk blo Lake Thomas A. Edison	+6%	1951	+6%	1954	Includes an estimate of increase for evaporation from reservoir
15 Big Creek blo Huntington Lake	+9%	1951	+11%	1955	Break in 1940 causes problem with MRP
16 Pitman Crk blo Tamarack Creek	+3%	1951	+12%	1958	1958 break masked by MRP 1951 estimate of change in slope
17 NP San Joaquin blo Iron Creek	Not run	-	+4%	-	1922-28, 1959-65
18 San Joaquin at Miller Crossing	Not run	-	+7%	-	1922-28, 1933-64 by summation of data
19 San Joaquin at Mammoth Pool	+2%	1951	+7%	1957-58	Coincident with increases in number of generators & beginning of storage in Mammoth Pool
20 Fresno River at Knowles	-9%	1951	-	-	Decreases apparently real but not coincident with weather modification
21 Chowchilla River at Buchanan Dam	-5%	1951	-	-	caused multiple breaks in plots
22 Merced River at Happy Isles	-1%	1951	-	-	-
23 Merced River at Exchequer	-3%	1951	-4%	1946	Only break in slope of DMP about 1947
24 Tuolumne River, infl Don Pedro	+1%	1951	Nil	-	-
25 Tuolumne River nr Hatch Hatchy	-1%	1951	+3%	1955	-
26 Falls Creek nr Hatch Hatchy	-3%	1951	+3%	1950	Date of change in slope uncertain
27 Stanislaus River, infl Melones	+2%	1953-61	Nil	-	No discernible change on DMP
28 Stanislaus River at Sand Bar Flat	+1%	1953-61	-	-	-
29 NP Stanislaus River nr Avery	-	-	+4%	1953	No apparent return to original slope of DMP after 1961
30 MF Stanislaus Riv. at Kennedy Meadow	-	-	+6%	-	Only partial return of slope of DMP after 1961
31 Cosgrove Creek	Nil	-	-	-	Wet and dry effects
32 SF Mokelumne River nr Westpoint	+9%	1953-61	+10%	-	Dubious transfers on both basins
33 MF Mokelumne Riv. nr Westpoint	+11%	1953-61	+16%	1953-61	-
34 NP Mokelumne Riv. nr Westpoint	-1%	1953-61	Nil	-	-
35 Mokelumne Riv., infl Pardee	+1%	1953-61	-	-	-
36 Cole Creek nr Mokelumne Peak	+4%	1953-61	+6%	1954-60	-
37 Cosumnes Riv. nr. Michigan Bar	-2%	1953-61	Nil	-	Plot shows negative effect but multiple breaks wet & dry mask out probable effects
38 SF American River nr Kyburz	+1%	1953-61	Nil	1959	-
39 Alder Creek	+2%	1953-61	Nil	1956	Multiple breaks in slope of DMP
40 Silver Creek nr Union Valley	+2%	1953-61	Nil	1958	Data has been affected by construction
41 SF Silver Creek at Icehouse	-4%	1953-61	Nil	1958	Data has been affected by construction
42 Silver Creek nr Placerville	Nil	1953-61	Nil	1958	Data has been affected by construction
43 Bishop Creek	Nil	1951	Nil	-	No break in slope of DMP discernible
44 Pine Creek	+1%	1951	-	-	-
45 Owens River blo Long Valley	-2%	1951	-	-	-
46 Rock Creek	-10%	1951	-	-	-
47 Rush Creek	-1%	1951	+5%	1958	Difference due to date of break in slope of DMP
48 Parker Creek	Nil	1951	-	-	Flows too small to be meaningful
49 Walker Creek	+4%	1951	-	-	Flows too small to be meaningful
50 Lee Vining Creek	-8%	1951	Nil	1955	Plot too erratic to be meaningful. Does show positive trend after 1955
51 East Walker	+13%	1951	+12%	1952	Apparently real trend
52 West Walker	+8%	1951	+7%	1952	Apparently real trend
53 East Carson	+9%	1951	+4%	1952	Apparently real trend
54 West Carson	-	-	+6%	1954	Data questionable
55 Truckee at Tahoe	+3%	1953-61	Nil	-	-

1/ Multiple Regression Program

2/ This date fixed in computer analysis by period of weather modification activity.

3/ Double Mass Plot

Figure 4



## Results of Analysis

Target Area Effect The results of the analysis delineated on the map of the southern and central Sierra (Figure 4) indicate that, for the most part, apparent increases have occurred in the intended target areas.

In the Kings River basin, (Kings River, Inflow to Pine Flat), an increase of about 7 percent was detected starting about 1954 or 1955 and continuing through 1964. The method of recording flows at this station has been altered over the years, leaving ample reason to doubt an increase in runoff from statistical analysis. Pine Flat Dam went into operation within a very few years of the date when a major weather modification project was initiated in the basin. Differences in measurement procedures necessitated by Pine Flat Dam may have resulted in an apparent change in the runoff from the basin. However, inspection of increases at a number of sub-basins within the major Kings drainage verifies increased runoff in the 5 to 10 percent range. Highest increases in this basin are on the North Fork which may be consistent with seeding generator locations and storm wind direction in the Kings River basin. However, even the southern portion of the Kings basin suggests some increase in runoff. Inspection of records at these up-stream points reinforces the validity of the increase detected at the Pine Flat station. Of the stations analyzed in the Kings River basin, only the Kings River above North Fork (South and Middle Forks of the Kings River) has had no interruption in record or construction during the period of analysis.

In the San Joaquin project area, increases similar to those on the Kings were noted. Previous investigators have reported an 8 percent increase in runoff for the target of the San Joaquin project as a whole. (Elliott and Lang, 1967) This regional study substantiates their results, even though variation from sub-basin to sub-basin has been noted. The drainage of Big Creek below Huntington Lake has an increase over 10 percent. It is interesting to note that this particular basin probably has the greatest concentration of seeding generators likely to have potential influence on precipitation in that basin. However, a majority of the water passing through the basin is diverted from other target basins in the area. Even small discrepancies in computation of the full natural flow in the Big Creek basin could result in substantial apparent increases of runoff. However, any consistent error made in the record for Big Creek below Huntington Lake would probably be the result of a similar consistent error with the opposite sign made in one or more of the other target areas in the project.

South Fork of the San Joaquin River above Florence Lake, Bear Creek and Mono Creek show apparent increases in the 6 to 8 percent range, which are comparable to increases detected on the North Fork of the Kings River. Bear Creek, a high elevation watershed lying between the South Fork of the San Joaquin and Mono Creek, shows little or no apparent effect in the computer analysis, but plotting discloses an increase of approximately 6 percent beginning 1954 or 1955. A break in slope in the early 1940's apparently masks out any increase coincident with weather modification in the computer analysis.

While not the primary target on the Southern California Edison project, the northern portion of the San Joaquin basin has at least been considered a secondary target. Data which covers the entire period of analysis is not available on the North and Middle Forks of the San Joaquin River. A few records were started about 1922 and continued through 1928. Annual records were reinitiated in 1952 or later. Remote location and severe winter conditions affected the early records at these stations so that only two stations were thought to have record satisfactory for analysis. These records were analyzed using a comparison of slopes between the early record and the late record. The San Joaquin River at Miller Crossing shows an apparent increase in runoff of approximately 7 percent, which is comparable to that on the primary target area. North Fork of the San Joaquin below Iron Creek, which is adjacent to the Merced River basin, shows an apparent increase of 4 percent. The reliability of this increase may be very low, but it seems to fit into the pattern developing in Figure 4.

In the Stanislaus-Mokelumne area, only on three watersheds were significant increases detected. Although data problems may be in part responsible for the results found, the pattern suggests storm wind movement and targeting problems. The South Fork of the Mokelumne River near West Point, the Middle Fork of the Mokelumne River near West Point, and Cole Creek near Mokelumne Peak all had increases in the 5 to 10 percent range. The two Mokelumne River stations have an inter-basin diversion and certain uses which make

the data somewhat questionable, but the effect is apparently quite real and closely related to the period of weather modification activity. North Fork of the Stanislaus River near Avery shows a small apparent increase. The break in slope occurs about 1950 and there is no reduction in slope after 1961 when seeding activities ceased on the local project. Other Stanislaus tributaries showed little effect. Minor positive effects have been noted in watersheds located to the north of the target area, but these effects, although consistent in sign, could by no means be termed statistically significant. Construction starting in this area about 1959 has affected records considerably.

Control Area Effect Analysis using various combinations of control basins suggests that some control basins may be experiencing effects from weather modification. As an example, the Merced River at Pohono Bridge shows a slight positive effect when compared with a lower station, Merced River, Inflow to Exchequer. This situation suggests a minor positive effect of weather modification in the upper portion of the Merced River watershed. This is understandable considering that the Merced basin is adjacent to the North and Middle Forks of the San Joaquin, which are secondary target areas in the San Joaquin project, but results are far from conclusive. Positive effects on a control may tend to decrease the apparent effect on the test basin.

If the Merced is affected by the projects to the south, it is entirely possible the same condition may be found on the Tuolumne. Though little evidence of such effect appeared in these studies, the map of Figure 4 suggests the effect may be there.

There is a possibility that the Kern River above Kernville may have also been affected by weather modification activities in the past. In spite of this possibility, analysis of the Kern was far from conclusive.

Downwind Effects Controversy has ranged far and wide on the effects of weather modification activities outside the target area. Apparent effects identified in this study are delineated on Figure 4.

Observers commenting on the direction of storms as they pass over the Sierra Nevada (Elliott, 1967c) indicate that winds approaching the range from the southwest are deflected as they meet the range, travel to the north and eventually cross easterly over the range somewhere to the north of the original point of intersection of the Sierra. This factor would indicate that downwind effects could be expected to the north of existing seeding projects. Analyses of streamflow records along the east side of the Sierra indicate no really significant effects in the Owens Valley region south of Bishop. In the Owens Valley area, watersheds do tend to be grouped by positive and negative effects, but these effects could not be termed significant from a statistical view-point.

On the east side watersheds adjacent to the Tuolumne and Stanislaus watersheds, an area of substantial apparent increase was detected. All analysis indicates that this increase is actual and timed to coincide with the weather modification projects in the southern portion of the west slope of the Sierra. Apparent increases in the 5 to 10 percent range were noted on the Walker and Carson Rivers, being generally larger in the southern portion of the area and smaller in the north. This pattern tends to confirm Elliott's (1967b) findings. It should be noted that the timing of these increases is such that it nearly coincides with the beginning of all three of the major projects discussed. However, the slope of the double-mass plots showing this increase does not return to its pre-seeded value following termination of the project on the Mokelumne-Stanislaus basins in 1961.

Areas of Negative Effect Negative effects were noted on some stream basins (i.e., there was an apparent decrease in runoff within recent years). In each of these cases, the test basin either had diversion for consumptive use above the gaging station or major construction within the basin during the period of analysis. Presumably consumptive use may have increased with time, thus producing an apparent decrease in the runoff with time. In no case did a basin with a significant apparent decrease show the beginning of that decrease coincident with the beginning of the weather modification operations in the area.

## Conclusions

In conclusion, this regional hydrologic study has provided important background information concerning weather modification projects conducted in California's Sierra Nevada.



First, most target areas have shown apparent increases in runoff during a period coincident with weather modification operations in the area. The pattern is clear even though increases may only be in the 5 to 10 percent range. This certainly implies that, for the most part, Sierra weather modification projects have been successful, being historically well targeted and effective. Even though the Stanislaus-Mokelumne project did not appear to target the desired area, some apparent increases were detected in the immediate area of the project.

Second, there is an apparent area of downwind effect showing increases in runoff of a magnitude similar to that in the target areas. However, the mechanisms for these effects and the point of origin will require more analysis before specific conclusions can be drawn. The pattern on Figure 4 appears consistent with Elliott's (1967b) findings, and no reason has yet been found to reject these results, although considerable effort has been expended to seek out causes other than weather modification for the observed trends. It is anticipated that additional work will be done to investigate downwind effects in the Nevada desert region and in the Sierra north of Lake Tahoe, where effects of the Stanislaus-Mokelumne project might be detected if the apparent southern Sierra pattern prevails.

Third, no peripheral or downwind effects indicating decreases in runoff were found which could be associated with the period of weather modification activity. If any negative effects do exist, they are either too small to be detected or we have not explored far enough afield to find them.

It is recognized that rigorous statistical proof with the data in this analysis is a virtual impossibility. Apparent effects are small when related to overall discharge and potential measurement errors, so that detection with a suitable degree of statistical reliability on many individual basins may not be possible. However, as indicated on Figure 4, an overall pattern is developing which appears consistent with findings of others in this and other areas. It is believed that this study has given valuable insight as to the effects and mechanics of weather modification operations in California's Sierra Nevada.

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