"REVIEWED"

WEATHER RESOURCES MANAGEMENT ON THE KINGS RIVER WATERSHED

Thomas J. Henderson
Atmospherics Incorporated
Fresno, CA 93727

In 1954 a cloud seeding program designed to increase precipitation in the form of rain and snow was initiated over the watershed of the Kings River in the Sierra Range of California. The project has been funded by the Kings River Conservation District, Fresno, California, and operated continuously each season during the seven-month October-April period. In recent years, operations have been expanded to include the total annual period except in those years when riverflow forecasts indicate annual flows will exceed about 135% of normal. At the end of the first three-year period, a multiple regression analysis was developed utilizing the unregulated historic flow of the Kings River and the flow of adjacent rivers presumed to be unaltered by cloud seeding activities. This statistical analysis has been applied to the flow of the rivers. During the 25-year seeded period 1954-1979, the analysis shows an apparent increase in flow amounting to 6% of the total predicted by the regression analysis. This apparent increase is significant at the 0.001 level.

1. INTRODUCTION

The Kings River is one of the several streams which originates in the high snowfields along the western slope of the Sierra Range in California and flows from its 1600 mi^2 (4144 km^2) watershed to the rich San Joaquin Valley. Emerging from the foothills east of Fresno, the total annual flow has ranged from a minimum of less than 400,000 acre feet (4.934×10^8 m^3) to a maximum of more than 4,000,000 acre feet (4.934×10^9 m^3). The average for the past 50 years has been near 1,500,000 acre feet (1.85×10^9 m^3).

Irrigation development on the Kings River has been extensive which explains, in part, why Fresno County remains the richest agricultural county in the United States and probably one of the richest farming areas in the world. There are presently about 1,200,000 acres of irrigated land in the area served by the Kings River. In years of normal runoff, no water from the river reaches the ocean. Present estimates indicate it takes nearly 140% of normal runoff before surplus water would reach the coast. Of course, this depends on the condition of the watershed, the amount of carry-over storage, the manner in which the water runs out of the basin and other hydrologic and meteorological factors governing the flow of the river.

There are three main dams in the watershed. Two of these, Wishon and Courtright, are storage reservoirs for power generation, built and operated by the Pacific Gas and Electric Company. The other is Pine Flat, a five million cubic yard concrete dam built by the Corps of Engineers. The dam itself is 440 ft. high, providing a reservoir storage of about 1,000,000 acre feet.

The Kings River Conservation District (KRCD) is a political subdivision of the State of California. The District was formed by the California legislature in 1951 with the passage of the "Kings River Conservation District Act" (Stats. 1951, c. 931, p. 2463). In general, the administrative structure and method of operation of the KRCD are similar to those of irrigtion districts. In the 1954-55 water year, the KRCD initiated an operational research weather resources management program designed to increase the annual flow of the Kings River into Pine Flat Reservoir. The program has been operated continuously since that time during the winter seasonal periods from October through April. In 1971, as a result of a three-year summer cloud seeding research experiment, the District authorized expansion of the cloud seeding program to include the remaining months of May through September. The entire weather modification program is conducted by Atmospherics Incorporated, Fresno, California, under contract with the District.

This report summarizes in some detail the operation of the weather resources management program and presents the results of the evaluation for the total 25-year period. The location of the Kings River operational area is shown in Figure 1.

2. GENERAL OPERATIONS

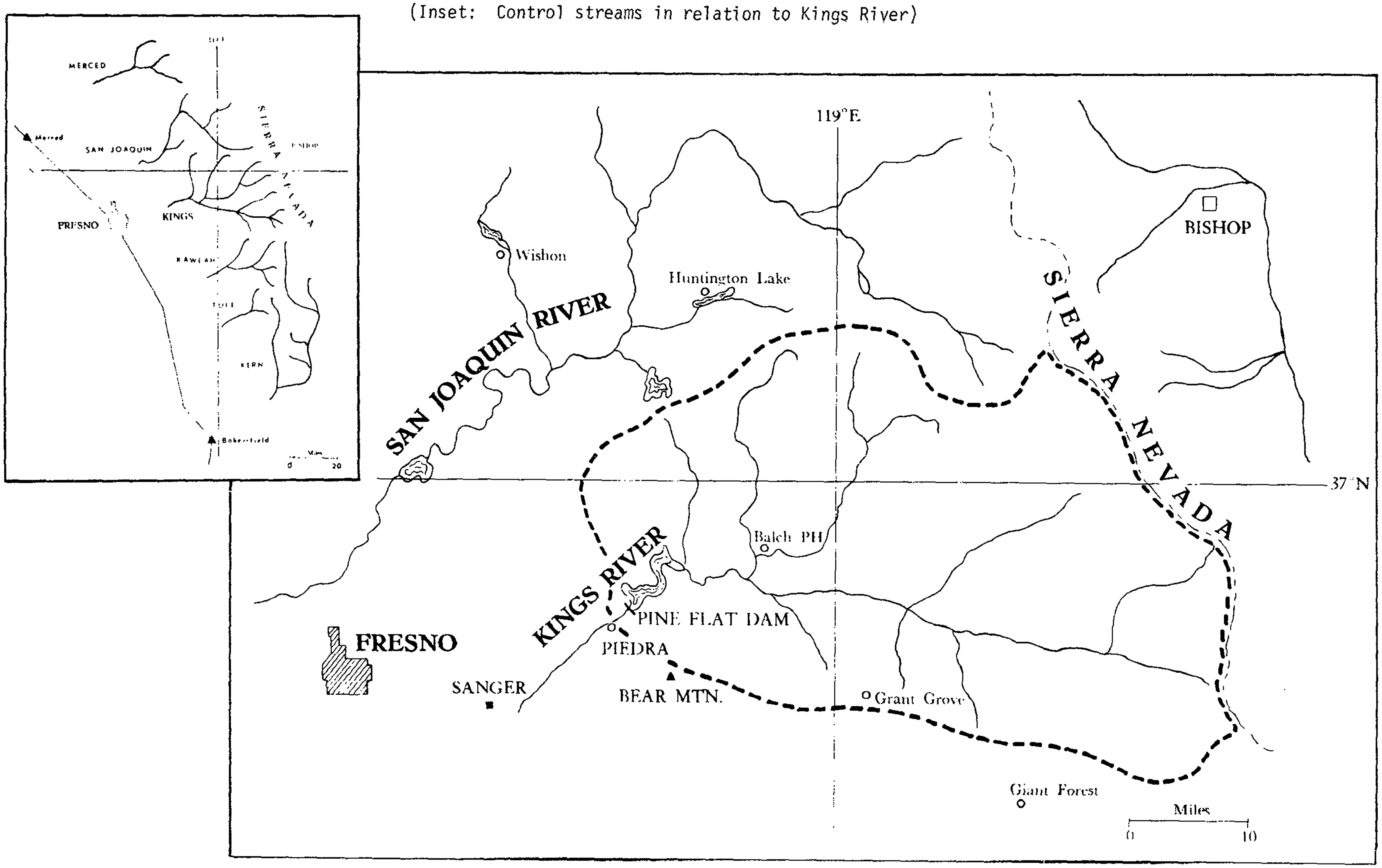
2.1 Meteorology

The normal winter storm meteorology, if there really is any such thing along the western slopes of the Sierra, involves a low pressure center positioned off the Washington coast with an associated frontal system trailing southwestward into the Pacific. As the system moves southeastward over Oregon and California the activity in the frontal zone diminishes. The Kings River watershed usually marks the southern boundary of any intense weather activity. Precipitation amounts usually diminish rapidly south of this area.

A second weather pattern, one which is less common but produces very large amounts of precipi-

FIGURE 1.

TARGET AREA - KINGS RIVER CLOUD SEEDING PROJECT
(Inset: Control streams in relation to Kings River)



tation in the southern Sierra, is associated with a high pressure center in British Columbia which shunts the low center further south off the coast of northern or central California. In this situation the freezing levels move upward from the usual 4,000 ft. level to around 8,000 ft. asl.

A third and rather unusual weather pattern in the southern Sierra is associated with the low pressure center located off the southern California coast. This produces easterly to southeasterly flow along the Sierra crest with the eastern slopes being favored for the larger precipitation amounts. This pattern usually produces large amounts of precipitation in the Los Angeles Basin and far lesser amounts in the downslope regions along the western portions of the Sierra.

Troughs at the 500 mb level are usually associated with all these weather patterns and exert a variety of influences on the total precipitation amounts resulting from each system. However, in each precipitation period there is a tendency toward "bands" of precipitation to move across the valley area and seldom does the radar show long periods of unbroken continuous precipitation. These "bands" are most evident up to the foothill areas but usually merge into areas of solid cloud cover and more homogeneous precipitation areas at the higher altitudes throughout the higher mountain areas.

Through the years, storm typing has been a fashionable exercise with 10 or 12 different types now accepted as reasonably identifiable. The numbers of storm types in these sub-sets seem to increase as additional forecasting uncertanties are expressed with each "newly discovered storm type".

At the moment, a feeling still persists on the operational level that the most pronounced seeding effects can be found during storm periods when supercooled liquid water is high and ice crystal concentrations are low. Radar photographs and aircraft penetrations within the general storm systems continue to support this view. By these same observations, there is further indication that seeding is ineffective or may even produce negative results when 500-mb temperatures are colder than about -24^{o}C. However, the 500 mb temperature is only a guide to seedability because there are extreme variations in the ratio of supercooled liquid water to ice crystals even when the 500 mb temperature is colder than any specific number.

2.2 Ground Generators

During the early years of the project, the silver iodide ground generator progressed from the use of a chemical-propane mixture dispersed through a standard paint spray nozzle to a modified Wells Fuquay aspirator type in which the solution was drawn from a 10-gallon storage reservoir by the passage of a propane jet across the tip of a hypodermic needle. This finely divided mixture was burned in a three-inch diameter flame chamber at a temperature of about 980^{o}C which produced some 5 x 10^{15} nuclei per gram of silver iodide effective at -20^{o}C. In recent years the ground generator configuration has returned to the more sophisticated stainless steel spray nozzle and the flame chamber temperature reduced to about 850^{o}C.

The silver iodide chemical solution strength has ranged between 1½% and 4% silver iodide by weight in acetone. Each generator consumes about 15 grams of silver iodide per hour depending upon solution use rate. Propane use rate is 2.0 liters per hour when the pressure is regulated at 10 psi.

The total number of silver iodide ground generators installed each season during the past 25 year period has ranged from as few as 15 to the present level of 25 units. From year to year the actual locations of the individual generators have been shifted in a number of cases. These modifications have resulted from studies of windflow characteristics throughout the watershed and from ground and airborne silver iodide plume tracking during operational periods. In general, the present silver iodide ground generator network is reasonably well fixed. The main line of units is along the southwest border of the target boundary with additional units scattered in certain sections of the western and northwestern areas for use during changing wind directions.

The total number of ground generators used during any individual storm period has ranged between 2 and 24. The number is dependent upon the intensity and duration of the particular storm. Insofar as possible, the general method of operation involves ignition of units located along a path perpendicular to the surface windflow. Every storm period is seeded provided certain public safety criteria are fulfilled and supercooled liquid water is present. No ground generators are used during the summer months of May through September.

In the 24-year operational period a total of 3512 generators have been operated during the 607 storm periods. Total time logged as 40,913 hrs. Total amounts of silver iodide consumed during this period was 574,382 gms (1265 lbs.) an average of about 14 grams hr^{-1}.

Silver iodide ground generator operations during the individual seasons are shown in Table 1.

2.3 Aircraft

In the past 25 years of operation there have been nine types of seeding aircraft used on the Kings River Project: P-40 (War Hawk), F-51 (Mustang), F8F (Bear Cat), T-28 (trainer), Cessna 180, Piper Twin Comanche, Piper Apache, Piper Aztec, and Piper Navajo. Since 1970 the Aztec PA23-250T) and the Navajo (PA31-310) have been the primary seeding aircraft. These aircraft are equipped with turbochargers, complete deicing equipment, and all normal navigational aids. Under flight configuration the altitude capability is in excess of 25,000 ft. msl. These aircraft have performed well and have served as reasonably good platforms for both nuclei dispensing equipment and research instruments.

The seeding aircraft has two main functions. It has first served as supplemental equipment to the overall ground generator network. Secondly, it has provided a platform for certain research equipment provided within the structure of the total program. Terrain features, locations of National Park boundaries, and specific windflow patterns make it impossible to place silver iodide ground generators in locations suitable for com-

TABLE 1.

SUMMARY OF SILVER IODIDE GROUND GENERATOR OPERATIONS

- 25-year Period 1954/55 through 1978/79 -

Year	Storm Periods	Number Generators Operated	Total Hrs.	Silver Iodide dispensed (gm)
1954-55	16	87	783	9,788
1955-56	23	277	2694	30,981
1956-57	18	241	1715	25,725
1957-58	23	258	2064	26,832
1958-59	15	145	1276	17,226
1959-60	26	275	3221	35,431
1960-61	26	225	2677	26,770
1961-62	23	195	3212	32,120
1962-63	24	184	2401	24,010
1963-64	18	120	1597	22,360
1964-65	21	145	1964	26,202
1965-66	21	111	1710	20,521
1966-67	21	103	1561	20,080
1967-68	22	81	281	6,730
1968-69	29	70	1012	15,488
1969-70	23	84	1145	17,187
1970-71	29	94	1311	19,666
1971-72	25	94	1242	19,125
1972-73	37	128	1969	29,658
1973-74	38	146	1659	33,208
1974-75	32	141	1807	36,138
1975-76	28	89	782	13,646
1976-77	26	67	573	11,708
1977-78	23	107	1654	33,080
1978-79	20	45	603	20,702
TOTAL	607	3512	40,913	574,382
AVERAGE	24	140	1,637	22,975

plete nuclei coverage in all areas of the Kings River watershed. Silver iodide plume tracking, under a program funded by the National Science Foundation, indicates the seeding capability of the aircraft is essential on this particular program.

In most winter storm situations, both aircraft and ground generators are operated. In these cases it is difficult, and no attempt has been made, to separate the effects from the individual sources. However, there have been a number of cases throughout the period when the aircraft was used on cumulus clouds (post frontal and summer orographic) which were not producing precipitation. In some of these cases the only clouds which produced precipitation were those which were seeded. These continue to be substantial evidence that the aircraft is essential for any full-scale efficient cloud seeding program in this particular mountain area.

Silver iodide seeding is accomplished from the aircraft by ignition of flare devices each containing 20 grams of AgI. Burning time of each unit is about 10 minutes and 24 are carried on racks mounted aft of the wings. The flares can be ignited individually or in groups. The efficiency of these pyrotechnic seeding devices has been checked at Colorado State University and found to be about 2.5×10^{15} nuclei per gram of silver iodide effective at $-20^{o}C$.

Auger type dry ice equipment has been carried on the aircraft with dispensing rates available in the range of 1-30 lbs. per minute. Silver iodide seeding is accomplished at the $-5^{o}C$ level and dry ice is dispensed at cloud tops or near $-15^{o}C$.

A total of 987 aircraft seeding flights have been made during the 25 years of operation. Total silver iodide dispensed from the aircraft during the 25-year period has been 92,846 grams (205 lbs.). During the four year period 1961-1965 a total of 8,393 lbs. of dry ice was dispensed mainly in post-frontal cumulus clouds over the upper portions of the Kings River watershed. In addition to the flights conducted primarily for cloud seeding purposes, a total of about 80 additional flights have

"REVIEWED"

been conducted as part of basic research efforts.

A summary of aircraft operations during each year may be found in Table 2. Total nucleating agents dispensed each year from all sources is shown in Table 3.

2.4 Radar

The original radar system used on the Kings River Project was a modified APS-15 military surplus system. It operated on a frequency of 9375 MHz and a peak power of 50 Kw. The antenna was a 30-inch parabola with 3^{o} pencil beam radiation. The system had a maximum range of 200 miles and a scope presentation of the 7-inch Plan Position Indicator type.

In 1960 a new radar system was designed and built by Atmospherics Incorporated for use on the Kings River Project. This 3.2 cm system also operated in the 9375-9400 MHz range, producing a peak power of 50 Kw. The system included two indicator presentations of the 7-inch PPI type. One of the indicators was used for general viewing and data procurement as necessary for the direction of both ground generator and aircraft operations. A second indicator was used exclusively for 16mm time-lapse scope photography of precipitation echoes. The installation site for this system was moved westward to a point about 14 miles NNE of Fresno at an elevation of 350 ft. msl. The site provided an unobstructed view of the total Kings River watershed and made it possible to view in considerable detail precipitation echoes as the storms moved

TABLE 2.

SUMMARY OF AIRCRAFT SEEDING OPERATIONS

- 25-Year Period 1954/55 through 1978/79 -

	Aircraft Operations (winter)					Aircraft Operations (summer)			
Year	Storm Periods	Total Flts.	Total Hrs.	AgI Dispensed (gm)	CO_2 Dispensed (lb.)	Storm Days	Total Flts.	Total Hrs.	AgI Dispensed (gm)
1954-55	16	9	16	450	-	-	-	-	-
1955-56	23	41	58	1300	-	-	-	-	-
1956-57	18	66	153	3750	-	-	-	-	-
1957-58	23	49	118	2950	-	-	-	-	-
1958-59	15	31	68	1750	-	-	-	-	-
1959-60	26	29	56	1430	-	-	-	-	-
1960-61	26	46	69	-	2065	-	-	-	-
1961-62	23	34	70	-	2234	-	-	-	-
1962-63	24	44	52	37	2658	-	-	-	-
1963-64	18	32	27	387	1109	-	-	-	-
1964-65	21	54	52	948	300	-	-	-	-
1965-66	21	24	25	695	-	-	-	-	-
1966-67	21	21	30	1290	-	-	-	-	-
1967-68	22	23	45	3210	-	-	-	-	-
1968-69	29	21	41	3156	-	-	-	-	-
1969-70	23	15	32	2385	-	-	-	-	-
1970-71	29	27	38	3008	-	40	40	104	24,602
1971-72	25	21	33	2505	-	52	62	82	5,239
1972-73	37	36	59	3376	-	-	-	-	-
1973-74	38	34	67	3678	-	-	-	-	-
1974-75	32	35	81	6631	-	29	54	98	1,334
1975-76	28	25	40	2963	-	25	27	63	4,631
1976-77	26	24	39	2841	-	27	27	32	2,280
1977-78	23	29	38	3240	-	-	-	-	-
1978-79	20	7	12	2780	-	-	-	-	-
TOTAL	607	777	1319	54760	8393	173	210	379	38,086
*AVERAGE	24	31	53	2381	1679	35	42	76	7,617

*Averages are based on the actual number of years in which an entry is made.

TABLE 3.

SUMMARY OF TOTAL NUCLEATING AGENTS

- 25-Year Period 1954/55 through 1978/79 -

Year	Storm Periods	Silver Iodide (gm)	Carbon Dioxide (lb)
1954-55	16	10,238	-
1955-56	23	32,281	-
1956-57	18	29,475	-
1957-58	23	29,782	-
1958-59	15	18,976	-
1959-60	26	36,861	-
1960-61	26	26,770	2065
1961-62	23	32,120	2234
1962-63	24	24,047	2635
1963-64	18	22,747	1109
1964-65	21	27,150*	300
1965-66	21	21,216*	-
1966-67	21	21,370*	-
1967-68	22	9,940*	-
1968-69	29	18,644	-
1969-70	23	19,572	-
1970-71**	69	47,276	-
1971-72**	77	26,869	-
1972-73	37	33,034	-
1973-74	38	36,886	-
1974-75**	61	44,103	-
1975-76**	53	21,240	-
1976-77**	53	16,829	-
1977-78	23	36,320	-
1978-79	20	23,482	-
TOTAL	780	667,228	8,393
AVERAGE	31	26,689	1,679

*Includes ignition of pyrotechnic units utilized on the ground as a supplement to the liquid fuel ground generators.

**Includes summer aircraft seeding operations.

eastward across the San Joaquin Valley and into the higher mountain areas.

In 1971 a Decca II Weather Radar System was added to the program and all radar equipment was moved a few miles further west to the Atmospherics Incorporated headquarters building near the Fresno Air Terminal. This Decca system operated on a frequency of 9380 MHz with a peak power of 40 Kw and a range of approximately 144 nautical miles.

In 1973 the first 5-cm type radar built by Enterprise Electronics was installed for the Kings River Project. This system operated on a frequency of 5,550 MHz, a peak power of 250 Kw and a range of 250 nautical miles. An L-band interrogator/transponder unit also became a part of the radar system.

Throughout the history of the Kings River Project the radar systems have provided two important functions within the application of the total cloud seeding program. As an operational tool, they have provided the meteorological information necessary for proper direction of aircraft and ground generators. Routine weather forecasting procedures by individuals and agencies have not been sufficient for direction of a full-scale cloud seeding operation and the radar has provided the necessary supplemental information. Secondly, the radar systems have provided a significant input to the various basic research and evaluation efforts which have played an important part in this total weather resources management program.

2.5 Research

Beginning in 1960 the National Science Foundation provided modest funding for supplemental instrumentation considered essential to the total Kings River Program. The actual equipment procured in this research effort, such as time-lapse cameras, temperature measurement devices, calibrated portable cold boxes, microscopes, potential gradient recorders, small particle detectors, and miscellaneous laboratory equipment, permitted a more definitive examination of storms and seeding effects within and beyond the boundaries of the Kings River watershed.

In 1964, a continuing cost-sharing contract between Atmospherics Incorporated and the National Science Foundation provided another three-year period for "Physical Studies of Winter Storms Mechanisms as Related to Cloud Seeding Efforts in the Sierra Range of California". Under this research activity particular emphasis was placed on an expanded area of interest including the watersheds of the Kern, Tule, Kaweah, Kings, San Joaquin and Merced Rivers. Of particular importance was the inclusion of certain watersheds along the eastern slopes of the Sierra for purposes of determining some of the downwind effects of cloud seeding activities further to the west.[1]

During the eleven year period 1966 through 1977, Atmospherics Incorporated conducted a number of research efforts sponsored by the Naval Weapons Center, China Lake, California. These investigations were largely related to the field application of pyrotechnic nuclei generators and measurements of related parameters. Additionally, certain airborne investigations were conducted on the distribution of small particulates which act as freezing and condensation nuclei in precipitation mechanisms. These research programs focused on the development and use of pyrotechnic seeding devices as sponsored by the Naval Weapons Center were instrumental in major modifications to the manner in which silver iodide nuclei were generated and dispensed by aircraft over the Kings River area.

In 1966 Atmospherics Incorporated became part of a weather modification research program conducted by Atmospheric Water Resources Research, Fresno State College Foundation, under a contract with the Bureau of Reclamation. This particular research effort, referred to as Sierra Cumulus I, II and III, was designed to investigate the possible initiation and enhancement of precipitation from summer orographic cumuli which develop over the Southern Sierra Range in California and to measure the resultant effects. The Atmospherics Incorporated input to this research program involved the aerial application of silver iodide to single randomly chosen cumulus within a pair of selected cells, the identification of any possible seeding effects within high altitude sub-basins in the Sierra, and the operational seeding of portions of the upper Kings River watershed in order to supply supplemental water during a very low water year. The results from this particular summer orographic cumulus research effort led the Kings River Conservation District to expand their program over the summer months of May through September.

[1] Cost-sharing contracts NSF C-206, C-402.

The numerous historic research efforts over the Kings River and adjacent watersheds as sponsored by the National Science Foundation, Department of the Interior (WPRS) and the Naval Weapons Center, have produced an enormous amount of information used to enhance our overall understanding of precipitation mechanisms and the application of cloud seeding technology to both winter and summer cloud systems over the Sierra Range of California.

3. STATISTICAL EVALUATIONS

The 1978-79 season completed the 25th consecutive year of weather modification operations on the Kings River watershed. During this period, many months have been spent attempting to identify a "most significant" evaluation procedure.

One of the early attempts at evaluation dealt with the comparison of raingauge figures. As in many cases using raingauge data, particularly in mountain areas, the figures did not produce relationships with high significance levels. In addition, the network of established raingauges over the Kings River and adjacent areas is too small to provide adequate sampling of the areas inside and beyond the target boundaries.

In the early stages of the program an investigation of all snow survey courses and compiled data was initiated. These investigations indicated a more significant relationship between seeded and non-seeded areas and the precipitation comparisons. However, even though these analyses produced rather high positive indications of the success of cloud seeding on the Kings River, the confidence levels were considered inadequate. It is important to note that many of these snow survey data comparisons served as strong clues pertaining to the effects of seeding operations within certain areas of the program and were not ignored during the investigations of specific local effects.

An examination of the streamflow records along the western slopes of the Sierra Range yielded additional basic data which were considerably more meaningful than either the snow survey data or precipitation figures. Furthermore, it seemed more appropriate at the time to deal directly with the amount of water available for irrigation, and the numbers dealing with acre feet of water were more meaningful to the actual water users.

Applications of statistical methods have been applied to many of the streamflow figures from rivers along both the western and eastern slopes of the Sierra. The results of these analyses indicate a very high confidence level may be placed on results from comparisons between the flow of the Kings River and combinations of flows from the Merced River to the north and the Kern River to the south. The use of control streams from areas both north and south of the target area seemed appropriate in any search for methods of eliminating bias from years which contain a predominance of either northerly or southerly type storms.

The possible bias from persistent storm directions was not the only item investigated in these original analyses. For example, the total numbers of acre covered by forest fires in both control and target areas was tabulated, methods of streamflow measurements were checked, types of measuring devices and locations of measuring points were investigated, and the historic record of streamflow itself was repeatedly checked. All of the possible items which may have had some abnormal effect on the flows of either the control or target streams were eventually considered insignificant.

It was thought desirable to keep any statistical analysis as simple as possible without resorting to complex transformations of the basic data or to controversial methodology. Consequently, a straightforward multiple regression analysis was used to indicate any possible change in the flow of the Kings River. No peculiar manipulation of these data has been made during the evaluation period nor has there been any change in methodology since the initial choice was made in 1957.

Combinations of possible control streams were examined and these included the Merced, San Joaquin, Kern, Kaweah, Tule and Owens. The combination of streams which resulted in the highest correlation with the Kings River was found to be the Merced River measured at Pohono Bridge and the Kern River measured at Kernville. Mathematical analysis tells us the combination of these control streams which best minimizes the departure during the base period prior to any cloud seeding activity. The analysis also gives us the correlation coefficient between the target stream and this best combination of the two control streams.

A study of this analysis follows:

Let X = flow of the Kings River for any water year

C_1 = flow of the Merced River for any water year

C_2 = flow of the Kern River for any water year

Averages over the base period were denoted by bars and standard deviations by S. Thus:

$\overline{X}$ = mean annual flow (unregulated) of the Kings River at Piedra during the base period and

S_1 = standard deviation of the annual flow of the Merced River during the base period, etc.

The correlation coefficients were denoted by R. Thus,

R_{X1} = correlation coefficient between the annual runoff of the Kings and Merced Rivers for the base period, etc.

R_{12} = correlation coefficient between the annual runoff of the Merced and Kern Rivers for the base period.

The correlation coefficients were defined by the standard formula,

$$R_{X1} = \frac{\overline{XC_1} - \overline{X}\overline{C}_1}{S_X S_1}$$

where $\overline{XC_1}$ is computed by averaging the products of the streamflow of the Kings and Merced Rivers over the base period.

The result of the computations are as follows where all values except the correlation coefficients are expressed in thousands of acre feet.

$\overline{X}$ = 1509.4	S_X = 662.0	R_{X1} = 0.947
$\overline{C}_1$ = 421.1	S_1 = 153.7	R_{X2} = 0.967
$\overline{C}_2$ = 497.0	S_2 = 226.6	R_{12} = 0.876

These results indicated that the chosen control streams have a very high relationship to the flow of the Kings River and will produce a formula which will predict the Kings River flow with a high degree of confidence.

According to statistical theory, the correlation coefficients between the best possible combination of the two control streams and the Kings River runoff is given by:

$$R^2 = \frac{R_{X1}^2 + R_{X2}^2 - 2R_{X1}R_{X2}R_{12}}{1 - R_{12}^2}$$

Substitution of numerical values leads to:

$$R^2 = 0.978$$

To see what improvement this represents over the better of the individual controls, we computed the standard error for each case. For the Kern River alone, the standard error (thousands of acre feet) is given by:

$$S_E = S_X \sqrt{1-R_{X2}^2} = 661.9 \text{ X } 0.255 = 168.8$$

For the combination control figure,

$$S_E = S_X \sqrt{1-R^2} = 661.9 \text{ X } 0.15 = 99.3$$

The use of the combination control figure reduces the standard error by approximately 70,000 acre feet.

The control figure calculated from the Merced and Kern Rivers can be denoted by X_E. Then,

$$X_E = b_o + b_1C_1 + b_2C_2$$

$$\text{where } b_o = \overline{X} - b_1\overline{C}_1 - b_2\overline{C}_2$$

$$b_1 = \frac{S_X}{S_1}\left[\frac{R_{X1} - R_{X2}R_{12}}{1 - R_{12}^2}\right]$$

$$b_2 = \frac{S_X}{S_2}\left[\frac{R_{X2} - R_{X1}R_{12}}{1 - R_{12}^2}\right]$$

Substituting numerical values we found

$$X_E = 1.85C_1 \text{ (Merced)} + 1.72\ C_2 \text{ (Kern)} - 124.4$$

Using the proportions of the Merced and Kern control streams as indicated, a formula was re-solved which gave us a relatively high confidence prediction of the flow of the Kings River in any single year. A tabulation of all streamflow figures during the base period 1925-26 through 1949-50 is presented in Table 4. A tabulation of all streamflow figures during the cloud seeding operational period 1954-55 through 1978-79 is shown in Table 5.

TABLE 4

STREAMFLOWS IN ACRE FEET*

- 25-Year Historic Record 1925/26 through 1949/50 -

WATER YEAR	KINGS RIVER	MERCED RIVER	KERN RIVER + #3
1925-26	1,036,200	343,700	299,000
27	1,984,200	537,800	616,000
28	970,900	370,600	303,000
29	849,400	255,600	287,000
30	862,800	277,800	299,000
1930-31	465,800	144,700	177,000
32	2,083,500	506,700	585,000
33	1,180,900	289,900	390,000
34	658,800	187,300	220,000
35	1,621,300	527,200	421,200
1935-36	1,876,500	504,400	634,100
37	2,340,800	493,200	858,500
38	3,275,100	849,300	1,015,000
39	974,400	252,600	388,900
40	1,790,400	499,500	608,400
1940-41	2,542,800	616,800	946,000
42	2,005,300	599,300	618,600
43	2,026,600	537,800	802,500
44	1,168,200	327,700	443,500
45	2,062,400	478,300	665,700
1945-46	1,612,000	497,900	528,200
47	1,107,300	309,700	355,500
48	996,200	387,700	301,400
49	960,700	332,600	271,800
50	1,281,000	399,700	399,100
TOTAL	37,734,500	10,527,800	12,425,500
AVERAGE	1,509,400	421,100	497,000

*From Surface Water Records -- Annual Reports, U.S. Dept. of Interior, Geological Survey, Sacramento, California.

TABLE 5.

STREAMFLOW RECORDS IN ACRE FEET*

- 25-year Cloud Seeding Period 1954/55 through 1978/79 -

Water Year	Kings River (incl. Mill & Hughes)	Merced River (Pohono Bridge)	Kern River +#3 (near Kernville)
1954-55	1,143,000	296,200	331,400
1955-56	2,695,000	783,700	766,000
1956-57	1,259,000	361,700	387,200
1957-58	2,615,000	613,100	810,700
1958-59	823,700	241,700	246,000
1959-60	718,900	252,000	246,400
1960-61	571,500	186,900	165,300
1961-62	1,871,850	461,700	550,400
1962-63	1,902,000	501,200	628,500
1963-64	877,900	254,900	273,800
1964-65	1,980,000	640,500	575,100
1965-66	1,219,430	328,900	335,100
1966-67	3,332,000	758,600	1,192,600
1967-68	843,200	230,900	388,300
1968-69	4,386,200	882,800	1,547,000
1969-70	1,330,600	422,200	491,500
1970-71	1,175,000	402,500	359,600
1971-72	859,600	325,200	235,000
1972-73	2,135,400	519,600	740,300
1973-74	2,095,900	566,800	638,100
1974-75	1,583,300	492,300	447,800
1975-76	540,700	157,000	209,100
1976-77	396,000	91,700	171,500
1977-78	3,453,800	724,600	1,138,000
1978-79	1,729,820	468,500	504,800
TOTAL	41,539,700	11,689,800	14,517,500
AVERAGE	1,661,588	467,592	580,700

*From Surface Water Records -- Annual Reports, U.S. Dept. of Interior, Geological Survey, Sacramento, California.

4. CONCLUSIONS -- 25 YEAR PERIOD

The details of many investigations, oriented toward the measurement of the flows of rivers both along the eastern and western slopes of the Sierra, will not be covered in this paper. These investigations have established that the figures, as submitted by the U.S. Geological Survey are reasonably accurate and do reflect a true picture of the unregulated flow of all streams used in this analysis.

The flow of the Kings River, as published by the U.S.G.S. is the result of measurements at their gaging station below Pine Flat Dam, plus the gain and loss in the upstream reservoirs, plus an evaporation factor applied to the surface of these reservoirs. Two streams, Mill and Hughes Creek, enter the Kings River between the dam and Piedra. These streams are measured by the Kings River Water Association and their flows added to the U.S.G.S. figures. A sound reconstruction of the historic and unregulated flow is obtained.

If these unregulated flow figures of the Kings River are used in the statistical formula, then the apparent change in Kings River flow during the 25-year cloud seeding period is noted as shown in Table 6.

The figures appearing in the last column are the probability that the observed departure is a chance fluctuation as given by application of the standard statistical t-test to the observed departures. The one-tailed t-test has been employed.

The indicated total increase in Kings River flow from those years which have indicated a positive departure is 1,884,930 acre feet over the 25-year period representing an overall increase of approximately 6%. The probability that this total increase was due to chance is 0.001.

"REVIEWED"

TABLE 6.

SUMMARY OF APPARENT CHANGES IN KINGS RIVER FLOW

- 25-Year Cloud Seeding Period 1954/55 through 1978/79 -

Water Year	Unregulated Flow in A.F.	Predicted Flow from Formula	Apparent Change A.F.	Apparent Change %	Flow Change In Standard Errors	Probability of Increase
1954-55	1,143,000	993,600	+149,400	+15.0%	+1.50	93.3%
1955-56	2,695,000	2,643,000	+ 52,000	+ 2.0%	+0.50	69.9%
1956-57	1,259,000	1,210,700	+ 48,300	+ 4.0%	+0.49	68.8%
1957-58	2,615,000	2,404,200	+210,800	+ 8.8%	+2.12	98.3%
1958-59	823,700	745,800	+ 77,900	+10.4%	+0.78	78.2%
1959-60	718,900	765,600	- 46,700	- 6.1	-0.47	31.9%
1960-61	571,500	505,700	+ 65,800	+13.0%	+0.66	74.5%
1961-62	1,871.850	1,676,450	+195,400	+11.7%	+1.97	97.6%
1962-63	1,902,000	1,883,800	+ 18,200	+ 1.0%	+0.18	57.1%
1963-64	877,900	818,100	+ 59,800	+ 7.3%	+0.60	72.6%
1964-65	1,980,000	2,049,700	- 68,800	- 3.5%	-0.69	25.0%
1965-66	1,219,430	1,060,400	+159,030	+13.0%	+1.60	94.5%
1966-67	3,332,000	3,330,300	+ 1,700	+ 0.5%	+0.02	50.8%
1967-68	843,200	970,600	-127,400	-15.1%	-1.28	10.0%
1968-69	4,386,200	4,169,600	+216,600	+ 4.9%	+2.18	98.5%
1969-70	1,330,600	1,502,100	-171.500	-12.9%	-1.72	4.3%
1970-71	1,175,000	1,238,700	- 63,700	- 5.4%	-0.64	26.1%
1971-72	859,600	881,400	- 21,800	- 2.5%	-0.22	41.2%
1972-73	2,135,400	2,110,200	+ 25,200	+ 1.2%	+0.25	59.9%
1973-74	2,095,900	2,021,700	+ 74,000	+ 3.5%	+0.75	77.3%
1974-75	1,583,300	1,556,570	+ 26,730	+ 1.7%	+0.27	61.3%
1975-76	540,700	531,975	+ 8,725	+ 1.6%	+0.09	53.6%
1976-77	396,000	340,225	+ 55,775	+16.4%	+0.56	71.2%
1977-78	3,453,800	3,173,470	+280,330	+ 8.8%	+2.83	99.8%
1978-79	1,729,820	1,610,580	+119,240	+ 7.4%	+1.20	88.5%
TOTAL	41,539,700	40,194,470				
AVERAGE	1,661,588	1,607,780				

5. ACKNOWLEDGEMENTS

A sincere note of appreciation must go to the Kings River Conservation District of Fresno, Calif. for its continued support of the total cloud seeding program. The early Board of Directors, under President Philip A. Gordon, and Cloud Seeding Chairman Edward E. Harper, displayed an unusual understanding of the uncertainties connected with this effort. The philosophy underlying the operation of this program has been continued under the current direction of the Board President Edward H. Howe and Cloud Seeding Committee Chairman Raymond W. Lambrecht. The District is to be commended for its insistence that the project be operated on a professional level and that the resultant data be made public information.

Notes of appreciation must also go to Dr. Earl Droessler during his earlier tenure with the National Science Foundation; Dr. Archie M. Kahan, who was Chief of the earlier Bureau of Reclamation's Atmospheric Water Resources Management group, and to both Dr. Pierre St.-Amand and Dr. William G. Finnegan of the Naval Weapons Center during that period when the Earth and Planetary Sciences Division provided such a strong insight to the fundamentals of applied cloud seeding and the useful devices which have become the foundation of our operations program.

Of course, a special note of thanks must go to Dr. Vincent J. Schaefer who started all of us along this path and during the ensuing years provided much of the strong enthusiatic support and knowlegable advice for the continuing Kings River Program.

REFERENCES

Hall, F., T. J. Henderson, and S. A. Cundiff, Cloud Seeding in the Sierra near Bishop, CA. Bulletin of the AMS, Vol. 34, #3, Mar., 1953.

Henderson, T. J., A Ten-Year Non-Randomized Cloud Seeding Program on the Kings River in Calif. Journal of Applied Meteor., Vol. 5, #5, p. 697-702, Oct. 1966.