BACKGROUND AND SUMMARY INFORMATION ON THE KINGS RIVER WEATHER MODIFICATION PROGRAM CONDUCTED DURING THE 19-YEAR PERIOD FROM 1954 THROUGH 1973

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I INTRODUCTION

The Kings River is one of several streams which originates in the high snowfields along the western slope of the Sierra Range in California and flows from its 1600 square mile 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 to a maximum of more than 4,300,000 acre feet. The average for the past 40 years has been approximately 1,600,000 acre feet.

The irrigation development on the Kings River has been extensive. More than 1,000,000 acres of irrigated land are in the areas served by the river and in years of normal runoff, no water is wasted over the flood plain or to the ocean. Present estimates indicate it takes nearly 135% of normal annual runoff before available water exceeds useful demand. This upper limit is dependent upon a number of agricultural aspects, the condition of the watershed, the amount of carry-over storage, the manner in which the water runs out of the basin, plus other hydrologic and meteorological factors governing the behavior of the watershed and the flow of the river.

There are presently three main dams in the watershed. Wishon and Courtright are storage reservoirs for power generation, built and operated by the Pacific Gas and Electric Company. Pine Flat Dam in the foothill area was built by the Corps of Engineers and has a storage capacity of about 1,000,000 acre feet. Value of the dam for both flood control and irrigation storage has been well demonstrated in past periods such as December 1955 when extensive damage was caused from flooding in the watersheds immediately south, but was completely minimized in the Kings River area.

Pine Flat Dam was dedicated on 22 May 1954, and until recent years, the Bureau of Reclamation acted as the administrator for the storage of water. The Kings River Conservation District (KRCD), acting as a public district and administrative group, has dealt with the Bureau of Reclamation under a number of lengthy interim contracts. This district is charged with developing and improving the water resources of the Kings River and was the negotiative force in the eventual enactment of the permanent contract with the Bureau of Reclamation.

The Kings River Water Association (KRWA), representing its 28 members including 12 irrigation districts, has acted as the administrative body dealing with the distribution of water below Pine Flat Dam. On 23 December 1963, the 28 members of this association individually signed permanent contracts with the Bureau of Reclamation, giving the people of the Kings River area the exclusive and perpetual rights to the use of storage space in Pine Flat Reservoir subject only to the use of this space for flood control purposes.

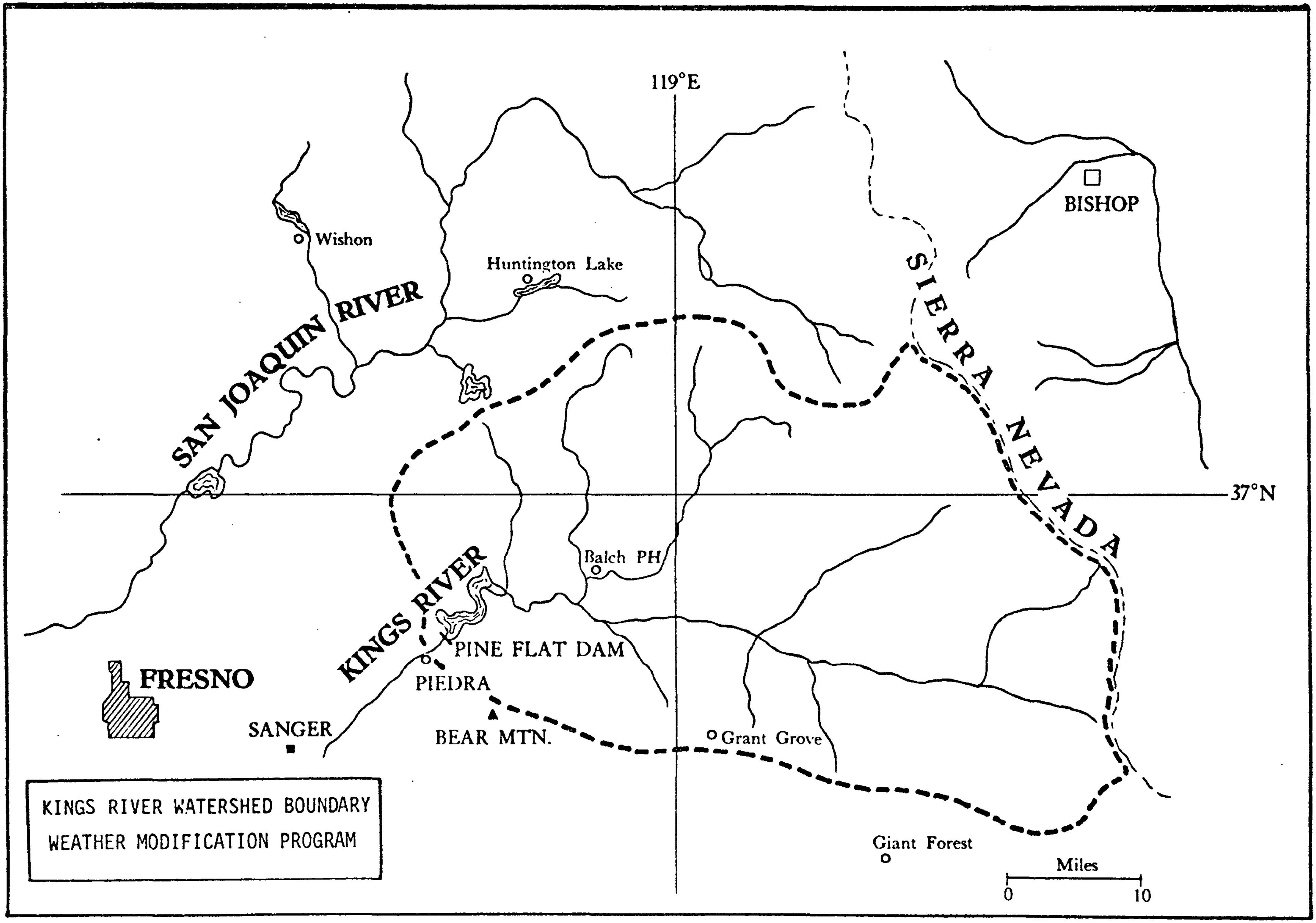
In the 1954/55 water year, following the basic cloud seeding discoveries at General Electric Research in 1947, the Kings River Conservation District initiated an operational research weather modification program designed to increase the annual flow of the Kings River into Pine Flat Reservoir. The program has been operated continuously since that time during the winter seasonal periods from October through April. In more recent years, as a result of a three-year summer cloud seeding research experiment, the Kings River Conservation District authorized the expansion of the cloud seeding program to include the remaining months of May through September in those years when the annual riverflow is forecast to fall below usable quantities.

II KINGS RIVER PROJECT DESIGN

Within the early experiments at General Electric Research, silver iodide was found to be a most unique and effective ice nucleus. Other substances, such as solid carbon dioxide, dust particles, cupric oxide, metaldehyde, lead iodide and others were found to have similar properties but silver iodide has remained one of the most efficient. Once the artificial nuclei source has been chosen, the design of any weather modification program becomes a matter of organizing the professional level personnel, acquisition and deployment of equipment, coordinating the nuclei delivery system, monitoring the storm periods, maintaining appropriate operational safeguards, and establishing proper evaluation procedures.

On the Kings River Project, storm periods have been monitored through the use of 3cm and 5cm weather radar systems. Operating at 50,000 watts and 250,000 watts peak power, these systems identify the location, movement and intensity of storms as they move across the Valley and into the Kings River Watershed above Pine Flat Reservoir. Silver iodide nuclei are generated from both ground based units and pyrotechnic seeding devices attached to the aircraft. Voice communication between the radar system and the cloud seeding aircraft provides the information transfer necessary for proper application of material during each storm period.

Depending upon specific meteorological conditions, various numbers of ground generators are ignited in the Sierra foothill regions and aircraft flight paths are organized to provide a nuclei source in those areas where proper locations of ground generators are not available. Radar monitoring of the storm situation and the application of artificial ice nuclei to the system, continues until all weather activity has passed from the area. Built-in operational safeguards include the termination of seeding whenever flood threats are imminent or high water conditions suggest the possibility of damage to the watershed or irrigated land throughout the Kings River service area.



KINGS RIVER WATERSHED BOUNDARY
WEATHER MODIFICATION PROGRAM

The cloud seeding aircraft has always been operated from the Fresno Air Terminal on a 24-hour-a-day, 7-day-a-week basis during operational periods. Silver iodide ground generators are distributed in appropriate locations throughout the operational area with one line along Highway 180 up to the 6,000 ft. level. Another group is distributed further from the target area south of Highway 180, and a third group is installed northward from Piedra to the Trimmer and Shaver Lake areas, and northeastward to Balch Camp and Wishon Dam. Local people in the area operate some of the generators on command from the radar facility and others are operated by in-house field personnel.

III PROJECT OPERATIONS

Weather forecasts are produced on a daily basis from basic data provided by the National Weather Service at the Fresno Air Terminal. Each morning during the operational period, weather data are analyzed by AI personnel and the meteorologist determines the potential for cloud developments or storm situations suitable for treatment. If no suitable storm periods are imminent, project personnel are placed on a "standby" status awaiting results from the afternoon or evening forecast of that particular 24 hour period.

When appropriate storm periods or suitable cloud conditions are forecast to develop within the 24 hour period, operational personnel move to the "alert" status and await the movement of clouds into the area. As these clouds begin to develop over the watershed, radar monitoring is initiated and continues as long as the possibility of suitable cloud conditions remain.

Once the cloud conditions are determined to have satisfactory depth and water content, all personnel move to the "operational" status and the application of silver iodide begins from ground generators and/or aircraft sources depending upon the results from a continuous assessment of weather elements. As the storm period diminishes, personnel and equipment move back through the alert and standby categories until other storms or cloud developments move toward the area.

IV RESEARCH

The operational weather modification program as conducted over the Kings River Watershed has provided a sound platform for the development of several basic research and evaluation investigations during the past several years. In the early summer of 1961, Atmospherics Incorporated entered into a three-year cost sharing research contract with the National Science Foundation. Under NSF C-206, this research was designed specifically for physical studies of winter storms in the Sierra Nevada Range of California. The program was primarily focused on ice nuclei measurements, temperature profiles, photographic storm analysis and identification of silver iodide plumes.

In 1965, Atmospherics Incorporated negotiated another three-year cost-sharing contract with the National Science Foundation. Under NSF-C-402, this program was titled "Physical Studies of Winter Storm Mechanisms as Related to Cloud Seeding Efforts in the Sierra Range of California". The program was an extension of the original NSF supported investigation and included such items as freezing nuclei plume tracking, condensation nuclei measurements, surface windflow studies, physical changes in ice crystals during operational periods, radar scope and cloud photograph analyses, measurements of air potential as related to cloud seeding efforts, and evaluations of the long term Kings River Project. A final report was filed with the National Science Foundation in February 1968.

In 1967, the Research Foundation of California State University at Fresno, under funding from the Bureau of Reclamation, began a series of field experiments to determine the potential benefit from seeding summer cumulus clouds over the Southern Sierra Range. This program, called "Project Sierra Cumulus" was active for three years during the May-September periods. Single cumulus cells within pairs of cumulus clouds, were randomly chosen for treatment with silver iodide. The results from this experiment indicated that, (1) precipitation could be initiated from non-precipitating clouds, (2) precipitation could be significantly increased from those clouds already producing rainfall and (3) the increase in streamflow could be identified as resulting from the cloud seeding efforts. Based on these independent research results, the KRCD Weather Modification Program was expanded to include summer cloud seeding operations during those years when the annual flow of the river was forecast to be less than approximately 135% of normal.

Other research efforts and statistical evaluations of the Kings River Program have been independently conducted by such groups as the Bureau of Reclamation's Atmospheric Water Resources Research group formerly at Fresno, California; Colorado State University at Ft. Collins, Colorado; the National Science Foundation, Washington, D.C.; National Academy of Sciences and the National Weather Service. The results of all these investigations have been reported in numerous scientific papers and general publications. Each has confirmed the apparent statistical results that during the 1955-73 period, the Kings River Weather Modification Program has increased the water supply into Pine Flat Reservoir by a total of not less than 1,280,000 acre feet.

V EVALUATION PROCEDURES

The 1973-74 season completed the 20th consecutive year of weather modification operations over the Kings River Watershed. The program has probably been evaluated on more levels than any other operational weather modification project in the United States.

One of the early evaluation attempts dealt with the comparison of rain gauge figures. Lack of available data from the upper watershed areas above 9,000 ft. produced a severe limitation in this evaluation approach. As in many cases using rain gauge data, the available figures did not produce relationships with high significance levels. This difficulty, coupled

with the inadequate numbers of rain gauges at high altitudes, excluded the use of rain gauge data as a meaningful approach to the evaluations.

As part of these early evaluations, a compilation of all snow survey data was initiated. This investigation indicated a more significant relationship between the precipitation in seeded and unseeded areas. However, even though the analysis produced rather high positive indications of the success of cloud seeding on the Kings River, the statistical confidence levels were considered inadequate. While the snow survey data did provide strong clues pertaining to the positive effects of the seeding operations, the approach was abandoned in favor of other more significant techniques.

An examination of the streamflow records along the Western Slopes of the Sierra Range yields much basic data which are considerably more meaningful in this type analysis than either the snow survey data or the precipitation figures. Applications of statistical methods have been made to many of the streamflow figures from streams 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 the results from comparisons between the flow of the Kings River and combinations of flows from the Merced and Kern Rivers. The use of control streams from areas both north and south of the target area seemed appropriate in the search for methods of eliminating bias from years which may have contained a predominance of either northerly or southerly type storms.

The possible bias from persistent storm directions was not the only item investigated in these early analyses. For example, the total number of acres covered by forest fires in both control and target areas was tabulated, methods of streamflow measurements were examined, types of measuring devices and locations of measuring points were investigated and the historic record of streamflow itself was repeatedly checked. All the possible items which were thought to have had some abnormal effect on the flows of either the control or target streams were finally considered minimal or 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 developed to indicate any possible change in the flow of the Kings River during the seeding periods. No particular manipulation of these data has been made during the evaluation period, nor has there been any change in methodology since the first statistical decision was made during the early years of the seeding program.

The primary statistical formula which produced the highest confidence prediction of the annual flow of the Kings River in any single year was given by:

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

Where X_e equals the predicted unregulated annual flow of the Kings River as measured below Pine Flat Dam, C_1 equals the annual flow of the Merced River as measured at Pohono Birdge and C_2 equals the annual flow of the Kern River as measured near Kernville.

When this prediction formula was applied to the Kings River annual flow during the 19 years of seeding from 1954 through 1973, a significant positive effect from the weather modification program has been noted in 13 of these operational years. In 6 of the 19 annual periods, a positive effect was not identifiable by this statistical method. In statistical terms, the overall positive effect is significant at the 0.01 level.

Expressed in terms of water volume, the 13 positive years have produced a total of 1,280,200 acre feet of additional water, an average of more than 98,400 acre feet per year.

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