NEW ASSESSMENT OF THE ECONOMIC IMPACTS FROM SIX WINTER SNOWPACK AUGMENTATION PROJECTS

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ABSTRACT

California has the longest history of continuous operational cloud seeding programs of any area in the world. The technology was first applied by the California Electric Power Company beginning on February 2, 1948. As the years evolved, additional programs funded by water agencies, municipalities and hydroelectric interests were organized over many California locales. During the 2001/02 winter season, thirteen operational programs were active. A broad range of statistical evaluations have been applied to many of these programs. In addition to statistical methods applied to precipitation and streamflow data, these evaluations have also focused on substantial radar data collected by operational 3cm and 5cm weather radar systems. The combined benefits are explored using six programs in California which have been active for various periods since 1950. The results from this study strongly suggest that very beneficial increases in water supplies have been produced by these long-term cloud seeding programs.

1. HISTORIC BACKGROUND

For many years cloud seeding programs designed to enhance the mechanisms of rain and snow have been conducted at various sites in the California area (Dennis, 1980). One of these programs has operated almost every year for more than 47 of those years. Another has an unbroken record of 52 years of continuous operations. Evaluations have been extensive (Orville, 1967; Malone, 1973).

One of these programs in the Sierra which has received extensive evaluations is the Kings River Weather Resources Management Program. It has an operations background beginning in 1954. The evaluations have produced apparent positive results significant at the 0.05 confidence level (Henderson, 1966; Malone, 1966).

2. THE CLOUD SEEDING PROGRAMS

Six cloud seeding programs were chosen for inclusion in this study. All were active during some portion of the 2001/02 water year. The choices included such criterion as geographic location, design features, length of operations, available data, multiple water use aspects, previous evaluations, and the author's knowledge about the program. The names of the chosen programs, the primary supporting groups, and their individual years of operation are listed in Table 1.

Table 1. Cloud Seeding Projects - Basic Information.

Project Name	Primary Support Group*	Total Seasons of Cloud Seeding
Tuolumne River	TID/MID	12 (1990)
Eastern Sierra	DWP	25 (1977)
San Joaquin River	SCE	52 (1950)
Kings River	KRCD	48 (1954)
Kaweah River	KDWCD	27 (1975)
Kern River	NKWSD	25 (1977)
	TOTAL:	**189 Seasons**

TID/MID: Turlock and Modesto Irrigation Districts
DWP: Los Angeles Department of Water and Power
SCE: Southern California Edison Company
KRCD: Kings River Conservation District
KDWCD: Kaweah Delta Water Conservation District
NKWSD: North Kern Water Storage District

The major storage reservoirs, capacities and their relevant watershed areas, are listed in Table 2. It is worth emphasizing that the watershed areas total more than 9,000 sq.miles and the storage capacity of the major reservoirs alone is approximately 4.6 million acre feet.

Table 2. Cloud Seeding Programs, Major Reservoirs, Capacities, Watersheds

Project Name	Major Storage Reservoir	Capacity (AF)	Watershed Area (mi^2)
Tuolumne	New Don Pedro	2,030,000	1,500
Eastern Sierra	Crowley	321,000	2,000
San Joaquin	Millerton	521,000	1,600
Kings River	Pine Flat	1,000,000	1,500
Kaweah River	Terminus	143,000	680
Kern River	Isabella	568,000	2,100
	TOTAL:	**4,583,000**	**9,380**

3. EVALUATIONS

Because of the natural and artificial water courses in California, supplemental water from many cloud seeding programs has multiple uses and related benefits. For example, an acre foot of water in the higher snowpack above 10,000 ft. elevation may eventually move through several hydroelectric generating plants, then contained in downstream reservoirs for flood control and recreational purposes, move on to the valley floor for use by agricultural interests, industry and municipalities and sometimes finding its way to ponding basins for ground water recharge.

At present, there are no less than 260 references dealing with evaluations of cloud seeding programs in California. It is enough to say that data used in these historic and current evaluations have included files from (1) several rain gage networks, (2) various cooperative snow survey programs, (3) US Geological Survey published streamflow records and, (4) radar data sets obtained during many cloud seeding operations. For the benefit of the statistical community, the ranges of R^2 values within these evaluations are listed in the following Table 3.

It is worth emphasizing that the statistical analyses which produced the ranges of R^2 values in Table 3, and utilized with the four noted data sets, have ultimately indicated apparent increases in the range of 4% to 16%, significant at the 0.05 level.

Table 3. Cloud Seeding Program Evaluations - California

Data Set	Range of R^2 values
Rain gage networks	0.68 - 0.82
Snow survey programs	0.76 - 0.91
Streamflow compilations	0.87 - 0.98
Project radar data	0.83 - 0.92

4. BENEFITS

Based on the extensive statistical and physical evaluations, this study assumes that supplemental water has been derived from such cloud seeding programs and explores the potential benefits in terms of a range of effectiveness percentages and their values. In order to establish a broader view of these possible benefits on a cumulative scale in California, the average annual streamflow, hydroelectric generating capacity, and hydro production efficiency data were assembled and tabulated. These values are shown in Table 4 for each of the six programs included in the study.

Table 4. Cloud Seeding Projects - Hydro Generation

Project Name	Average Annual Flow (AF)	Hydro-electric Capacity (MW)	Efficiency Kwh/AF
Tuolumne	1,656,000	195	350
River	435,000	214	2,000
TID/MID			
Eastern Sierra			
Bishop	68,000	29	3,530
Creek	35,000	11	1,270
Rush Creek	26,000	11	1,045
Lee Vining			
San Joaquin River	1,776,000	1,190	8,630
Kings River			
PG&E	1,670,000	1,547	6,076
KRCD	1,311,000	165	310
Kaweah River	444,000	7	1,760
Kern River	716,000	90	2,100
TOTALS:	**8,137,000**	**3,459**	**27,071**

Taken as a whole, the totals shown in Table 4 tend to minimize any error ranges associated with basic data from individual projects, and probably come somewhat closer to establishing realistic benefits. It is enough to emphasize that the totals are large, and represent a remarkable and extremely valuable resource in California.

The study now moved to the actual economic benefits, which are derived by assuming the cloud seeding programs actually increase the average volume of available water by some range of percentages. For purposes of reaching some meaningful conclusions, the chosen percentages were 2%, 4%, and 6% increases, rather conservative figures when compared with the higher values concluded from more recent physical and statistical studies. A fourth column showing a 9% increase in runoff volume was added as a sort of personal speculative figure because of the results shown by the extensive statistical evaluation focused on the historic Bishop Creek Program as published in 1953 (Hall, Henderson, Cundiff, 1953).

The results from this range of percentage streamflow increases as applied to the average annual streamflow through the individual basin-related hydro powerplants are shown in Table 5.

Table 5. Cloud Seeding Projects - Increases in Streamflow

Average Annual Flow Increases from Cloud Seeding (AF)				
	2%	**4%**	**6%**	**9%**
Tuolumne River				
TID/MID	33,120	66,240	99,360	149,040
Holm-Kirkwood	8,700	17,400	26,100	39,150
Eastern Sierra				
Bishop Creek	1,360	2,720	4,080	6,120
Rush Creek	700	1,400	2,100	3,150
Lee Vining Creek	520	1,040	1,560	2,340
San Joaquin River	35,520	71,040	106,560	159,840
Kings River				
PG&E	33,400	66,800	100,200	150,300
KRCD	26,220	52,440	78,660	117,990
Kaweah River	8,880	17,760	26,640	39,960
Kern River	14,320	28,640	42,960	64,440
TOTALS:	**162,740**	**325,480**	**488,220**	**732,330**

Before moving on to the estimates of dollar values, the remaining calculations involved the conversion of average annual streamflow increases in acre feet to the total megawatt hours of generation. These amounts are shown in Table 6.

The historic average annual streamflow totals, as calculated for the benefit study period, include only the flows which originate in the areas affected by the cloud seeding programs, then move downstream through various hydroelectric plants. These figures show the additional MwH produced by each of the four chosen apparent increases in streamflow due to the cloud seeding programs. The assumption is made that all generating units are operating at full capacity for an entire year.

Table 6. Cloud Seeding Projects - Increases in Generation

Average Annual Mwh ($x10^3$) Increases from Cloud Seeding				
	2%	**4%**	**6%**	**9%**
Tuolumne River				
TID/MID	11.6	23.2	34.8	52.2
Holm-Kirkwood	17.4	34.8	52.2	78.3
Eastern Sierra				
Bishop Creek	4.8	9.6	14.4	21.6
Rush Creek	0.9	1.8	2.7	4.0
Lee Vining Creek	0.5	1.0	1.5	2.2
San Joaquin River	306.5	613.-0	919.5	1,379.3
Kings River				
PG&E	202.9	405.8	608.7	913.0
KRCD	8.1	16.2	24.3	36.4
Kaweah River	15.6	31.2	46.8	70.2
Kern River	30.1	60.2	90.3	135.5
TOTALS:	**598.4**	**1,196.8**	**1.795.2**	**2.692.7**

Because the supplemental water provides multiple-use benefits, the total average annual volume of water attributed to the six cloud seeding programs was also required for estimating the benefits to agriculture, municipalities and the environment. These totals are again shown in Table 7.

Table 7. Average Annual Volume of Water Attributed to Cloud Seeding

Total average annual flow from six programs (AF)	2% Increase (AF)	4% Increase (AF)	6% Increase (AF)	9% Increase (AF)
8,137,000	162,740	325,480	488,220	732,330

5. CONCLUSIONS

The added power generation and values have been calculated for each of the percentage increases in streamflow due to the cloud seeding programs. Conservative estimates of supplemental water values to Agriculture, Municipalities and Environmental interests have also been compiled. These data are shown in Table 8.

Table 8. Total U.S.$ Value (x 1,000) of Supplemental Water for the Six cloud Seeding Programs in California.

	2%	4%	6%	9%
MWh	598.4	1,196.8	1,795.2	2,692.7
$20/Mwh	$11,968	$23,936	$35,904	$53,854
Agri/Municipal / Environment ($60 /AF)	$9,764	$19,529	$29,293	$43,940
TOTAL VALUE	$21,732	$43,365	$65,197	$97,794
BENEFIT/ COST RATIO	13:1	27:1	40:7	61:1

Additionally, the stated value of electrical energy at $20/Mwh is very conservative. During dry seasons, the actual value of supplemental water for hydro generation may be many times that figure depending upon modes of operation within specific projects. The total dollar values of supplemental water for agriculture, municipal and environmental uses are equally difficult to estimate. The $60/AF figure used in this study is considered very conservative, but can be adjusted depending upon the values in any given area.

The total values of the supplemental water produced by the six cloud seeding programs each year in California is in the range of about $22 million to U.S.$98 million. Based on a private sector estimated total annual operational cost of $1,600,000 for the six cloud seeding programs, the benefit/cost ratios for the four percentage increases are in the range of 13:1 to 61:1.

The estimated annual cost of $1,600,000 to operate six of the programs for each season includes full-time assigned personnel, in-house satellite derived weather data acquisition and weather forecasts, ground-based radar systems, aircraft seeding capabilities, ground seeding generator networks plus evaluations and reports.

6. REFERENCES

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