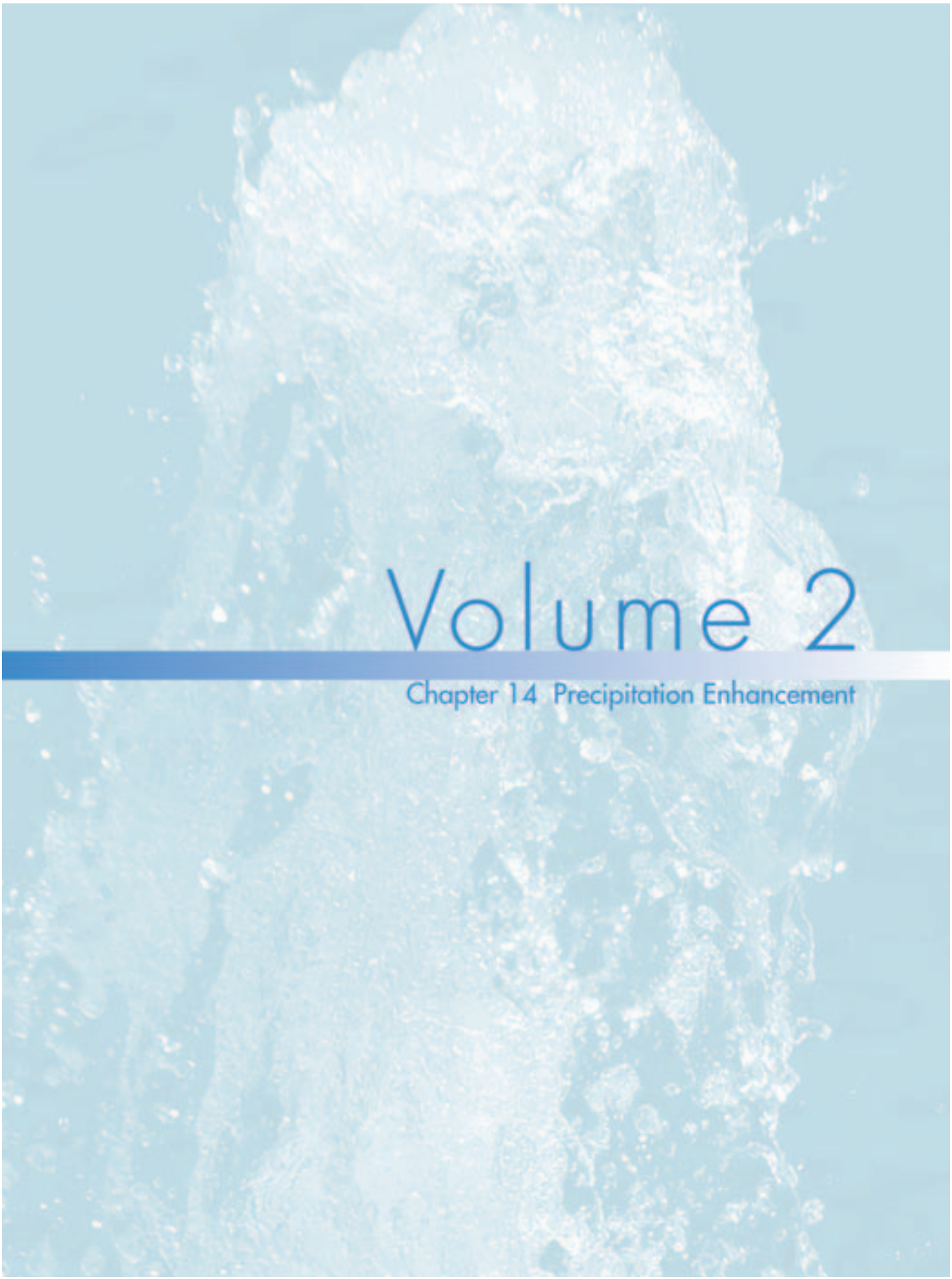

# Volume 2

## Chapter 14 Precipitation Enhancement

Cloud seeding has been practiced continuously in California since the early 1950s. Most projects are along the central and southern Sierra Nevada with some in the Coast Ranges. (DWR photo)

# Chapter 14 *Precipitation Enhancement*

Precipitation enhancement, commonly called "cloud seeding," artificially stimulates clouds to produce more rainfall or snowfall than they would naturally. Cloud seeding injects special substances into the clouds that enable snowflakes and raindrops to form more easily. Precipitation enhancement is the one form of weather modification done in California; hail suppression (reducing the formation of large, damaging hailstones) and fog dispersal (when fog is below freezing temperature) projects are conducted in other states.

## Precipitation Enhancement in California

The first serious cloud seeding program in California began in 1948 on Bishop Creek in the Owens River basin for California Electric Power Co. Precipitation enhancement in the form of cloud seeding has been practiced continuously in several California river basins since the early 1950s. Most projects are along the central and southern Sierra Nevada with some in the coast ranges. The projects use silver iodide as the active cloud-seeding agent, supplemented by dry ice if aerial seeding is done. The silver iodide can be applied from ground generators or from airplanes. Occasionally other agents, such as liquid propane, have been used. In recent years, some projects have also been applying hygroscopic materials (substances that take up water from the air) as supplemental seeding agents. Figure 14-1 shows rain and snow enhancement programs for the 2002-2003 season.

Operators engaged in cloud seeding have found it beneficial to seed rain bands along the coast and orographic clouds over the mountains. The number of operating projects has tended to increase during droughts, up to 20 in 1991, but have leveled off to about 12 or 13 in recent years. The total area covered by these projects is about 13,000 square miles.

Policy statements by both the American Meteorological Society and the World Meteorological Organization support the effectiveness of winter orographic cloud seeding projects. The American Society of Civil Engineers has also shown interest with its Policy Statement No. 275 on Atmospheric Water Management in 2003 and a new report, ASCE/EWRI 42-04, "Standard Practice for the Design and Operation of Precipitation Enhancement Projects" in May 2004. This standards document will be a sequel to ASCE Manual No. 81, "Guidelines for Cloud Seeding to Augment Precipitation," published in 1995.

## Benefits from Precipitation Enhancement

In California, all precipitation enhancement projects are intended to increase water supply or hydroelectric power. The amounts of water produced are difficult to determine, but estimates range from a 2 to 15 percent increase in annual precipitation or runoff. A National Research Council (NRC) report on weather modification (Box14-1) has limited material on winter orographic cloud seeding, such as practiced in California and other western states. However, the report does seem to concur that there is considerable evidence that weather modification does work, possibly up to a 10 percent increase. A detailed study by the Utah Department of Natural Resources in 2000 showed an average increase in April 1 snowpack water content ranging from 7 to 20 percent from a group of projects which had been operating from 9 to 22 years. The overall estimated annual runoff increase was about 250,000 acre-feet, or 13 percent for the study area. Actual increases in annual runoff are probably significantly less in California than in Utah. One conservative estimate is that the combined California precipitation enhancement projects generate 300,000 to 400,000 acre-feet annually, which would be an average of about a 4 percent increase in runoff.[1]

[1] DWR staff analysis (2004).

**Figure 14-1 Rain and snow enhancement programs in California, 2002-2003 season**


| | Project | Sponsor |
|---|---|---|
| 1. | Lake Almanor | Pacific Gas & Electric Co. |
| 2. | Tahoe-Truckee | Desert Research Institute |
| 3. | Upper American River | Sacramento Municipal Utility District |
| 4. | Upper Mokelumne River | Pacific Gas & Electric Co. |
| 5. | Carson and Walker Rivers | Desert Research Institute |
| 6. | Tuolumne River | Turlock and Modesto Irrigation Districts |
| 7. | San Joaquin River | Southern California Edison Co. |
| 8. | Eastern Sierra | City of Los Angeles |
| 9. | Kings River | Kings River Conservation District |
| 10. | Kaweah River | Kaweah Delta Water Conservation District |
| 11. | Kern River | North Kern Water Storage District |
| 12. | Santa Barbara County | Santa Barbara County |
| 13. | San Gabriel Mountains | Los Angeles County |

There were 12 rain and snow enhancement programs for the 2002-03 season. Most projects are along the central and southern Sierra Nevada with some in the coast ranges. The total area covered by these projects is about 13,000 square miles.

Another 300,000 to 400,000 acre-feet per year may be available. Many of the best prospects are in the Sacramento River basin, in watersheds that are not seeded now. The Lahontan regions are already well covered by cloud seeding projects, except for the Susan River. With the exception of the upper Trinity River watershed, and perhaps the Russian River, there is little new potential in the North Coast region because not much extra rainfall could be captured due to limited storage capacity. There is also potential to increase water production by more effective seeding operations in existing projects.

Precipitation enhancement should not be viewed as a remedy for drought. Cloud seeding opportunities are generally fewer in dry years. It works better in combination with surface or groundwater storage to increase average supplies. In the very wet years, when sponsors already have enough water, cloud seeding operations are usually suspended.

## Potential Costs

Costs for cloud seeding generally would be less than $20 per acre-foot per year. State law says that water gained from cloud seeding is treated the same as natural supply in regard to water rights.

It is estimated that about $3 million is being spent on operations. Realizing the additional 300,000 to 400,000 acre-feet of potential new supply could require about $7 million, which would be about $19 per acre-foot. An initial investment of an estimated $1.5 million to $2 million in planning and environmental studies would also be required. Over the next 25 years, precipitation enhancement costs are expected to total about $177 million.[2]

## Major Issues for Precipitation Enhancement

### Reliable Data

No complete and rigorous comprehensive study has been made of all California precipitation enhancement projects. Part of the reason is the difficulty in locating unaffected control basins for the standard target and nearby control area comparisons since wind variations would cause spillover into adjoining basins. Some studies of individual projects have been made in the past years on certain projects, such as the Kings River, which have shown increases in water.

### Operational Precision

It is difficult to target seeding materials to the right place in the clouds at the right time. There is an incomplete understanding of how effective operators are in their targeting practices. Chemical tracer experiments have provided support for targeting practices.

### Concern over Potential Impacts

Questions about potential unintended impacts from precipitation enhancement have been raised and addressed over the years. Common concerns relate to downwind effects (enhancing precipitation in one area at the expense of those downwind), long term toxic effects of silver, and added snow removal costs in mountain counties. The U.S. Bureau of Reclamation did extensive studies on these issues. The findings are reported in its Project Skywater programmatic environmental statement in 1977 and in its Sierra Cooperative Pilot Project EIS in 1981. The available evidence does not show that seeding clouds with silver iodide causes a decrease in downwind precipitation; in fact, at times some of the increase of the target area may extend up to 100 miles downwind (Ref. 1981 SCPP EIS). The potential for eventual toxic effects of silver has not been shown to be a problem. Silver and silver compounds have a rather low order of toxicity. According to the Bureau of Reclamation, the small amounts used in cloud seeding do not compare to industry emissions of 100 times as much into the atmosphere in many parts of the country or individual exposure from tooth fillings. Watershed concentrations would be extremely low because only small amounts of seeding agent are used. Accumulations in the soil, vegetation and surface runoff have not been large enough to measure above natural background. A 2004 study done for Snowy Hydro Limited in Australia has confirmed the earlier findings cited above. In regard to snow removal, little direct relationship to increased costs was found for small incremental changes in storm size because the amount of equipment and manpower to maintain the roadway is essentially unchanged. That is, the effort is practically the same to clear a road of 5.5 inches compared to 5 inches.

All operating projects have suspension criteria designed to stop cloud seeding any time there is flood threat. Moreover, the type of storms that produce large floods are naturally quite efficient in processing moisture into rain anyway. In such conditions, seeding is unlikely to make a difference.

### Box 14-1 NRC Report on Weather Modification

In the fall of 2003, the National Research Council released a report entitled "Critical Issues in Weather Modification Research", which examined the status of the science underlying weather modification in the U. S. One conclusion widely reported by the press was that convincing scientific proof of the efficacy of weather modification was lacking and the authors proposed that a large sustained research program be developed to reduce the uncertainties of this technology. Progress in seeding agent formulation and targeting was noted, although there is need for more research on these aspects.

[2] Cost estimated = $0.2 billion, as follows: ($7 million/year for cloud seeding activities) x (25 years until 2030) + ($2 million for initial environmental studies) = $177 million.

### Concern about Continuance of Hydroelectric Utility Seeding Operations

Four of the existing cloud seeding projects in California are sponsored by hydroelectric utilities. These four projects probably account for about a third of the estimated statewide water production by cloud seeding. There is some concern that if these power plants are sold, either as part of deregulation or for other reasons, new owners may not be interested in continuing cloud seeding. This would result in some loss in water supply for downstream users who have been indirectly benefiting from the added water. The State Public Utilities Commission is aware of this possibility and has tried to ensure, as a condition of transfer, that weather modification would continue.

### Funding

Little federal research funding for weather modification has been available in the past 15 years. The Bureau of Reclamation had some funding in 2002 and 2003 in the Weather Damage Mitigation program. Desert Research Institute of Nevada did obtain a grant of $318,000 from this source early in 2003 to evaluate its seeding in the eastern Sierra.

### Inadvertent Weather Modification

There is evidence that human activities such as biomass burning, transportation, and agricultural and industrial activities modify local and sometimes regional weather. The effects of aerosols on clouds and precipitation are complex. Recent studies by Ramanathan and Rosenfeld suggest suppressed precipitation formation in affected clouds due to pollution and dust. Some aerosols can enhance precipitation and some, especially the very fine aerosols in diesel smoke, can reduce precipitation. Much more research is needed to evaluate the air pollution effects on precipitation processes and the amount of impact as well as possible effects on cloud seeding programs. It is possible that some of the California cloud seeding projects have offset a potential loss in precipitation from air pollution, which may have obscured a more positive signal from the weather modification projects.

## Recommendations to Increase Precipitation Enhancement

1. The State should support the continuation of current projects as well as the development of new projects and help in seeking research funds for both old and new projects.
2. DWR should collect base data and project sponsor evaluations of existing California and other western states precipitation enhancement projects, independently analyze them, and perform research on the effectiveness of this technology to supplement water supplies while minimizing negative impacts.
3. DWR should investigate the potential to augment Colorado River supply by cloud seeding, in cooperation with the Colorado River Board, the other Colorado River Basin States, and the U.S. Bureau of Reclamation.
4. DWR should support research on cloud physics and cloud modeling being done by the National Oceanic and Atmospheric Administration labs and academic institutions. With improvement, these models may become tools to further verify and test the effectiveness of cloud seeding activities.
5. DWR should support efforts by California weather modification project sponsors, such as that proposed in 2002-03 by Santa Barbara County Water Agency, to obtain federal research funds for local research experiments built upon their operating cloud seeding projects.

## Selected References


ASCE Manual No. 81 "Guidelines for Cloud Seeding to Augment Precipitation", 1995

ASCE Policy Statement No. 275, "Atmospheric Water Resources Management", 2003

ASCE/EWRI 42-04 "Standard Practice for the Design and Operation of Precipitation Enhancement Projects", 2004.

National Oceanic and Atmospheric Administration

Desert Research Institute, Reno, Nevada

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World Meteorological Organization

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