Precipitation Enhancement

Photo caption. Clouds over green foothills.

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Chapter 10. 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.

Winter orographic cloud seeding has been practiced in California since the early 1950s. Most of the projects are along the central and southern Sierra Nevada with some in the Coast Range. The projects generally use silver iodide as the active seeding agent, supplemented by dry ice if aerial seeding is done. Silver iodide can be applied from ground generators or from airplanes. Occasionally, other agents, such as liquid propane, are used. In recent years, some projects have been trying hygroscopic materials (substances that take up water from the air) as supplemental seeding agents. Figure 10-1 shows rain and snow enhancement programs which had operated at some time during the 2005-2007 seasons. (Most are long-term projects and were operated in all of the three years. A few, such as Monterey County, only ran in one or two seasons.) Historically, the number of operating projects has increased during droughts—up to 20 in 1991—but have leveled off at about a dozen in the more normal years. Most of the projects suspend operations during the very wet years once enough snow has accumulated to meet their water needs.

State requirements for sponsors of weather modification projects consist of filing a Notice of Intention (NOI) initially and every five years for continuing projects, some record keeping by operators and annual or biennial reports to the California Department of Water Resources. The items to include in the NOI can be obtained from DWR. In addition, sponsors need to comply with the California Environmental Quality Act (CEQA). Annual letter notices should also be sent to the board of supervisors of affected counties and to DWR. Activity reports are sent to the National Oceanic and Atmospheric Administration (NOAA) giving the number of days and hours of operation and the amount of seeding material applied.

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 (ASCE) has also shown interest with its Policy Statement No. 275 on Atmospheric Water Management in 2003 and a report (ASCE/EWRI 42-04) "Standard Practice for the Design and Operation of Precipitation Enhancement Projects" in 2004. This standards document was followed by a second edition of ASCE Manual No. 81, "Guidelines for Cloud Seeding to Augment Precipitation," published in 2006.

Figure 10-1 Rain and snow enhancement programs, 2005 through 2007 seasons

PROJECT	SPONSOR
1. Lake Almanor	Pacific Gas & Electric Company
2. Tahoe-Truckee	Desert Research Institute
3. Upper American River	Sacramento Municipal Utility District
4. Upper Mokelumne River	Pacific Gas & Electric Company
5. Carson and Walker Rivers	Desert Research Institute
6. Tuolumne River	Turlock and Modesto Irrigation Districts
7. San Joaquin River	Southern California Edison Company
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. Monterey County	Monterey County
14. North Fork Stanislaus River	Northern California Power Agency

For years weather modification supporters have faced a perceived negative bias in the scientific community. In June 2008, the international journal *Nature* advocated a renewed push for scientific research into weather modification activities. The editorial in a widely respected scientific journal may mark a turn in opinion. Massive weather modification efforts in China for the Olympics also lent support to the efficacy of the practice.

Cloud seeding has advantages over many other strategies for providing water. A project can be developed and implemented relatively quickly without multiyear lead times. In the snow zone, it can offset some of the loss in snowpack expected from global warming. This may be of benefit to mountain meadows and could delay the start of the fire season in the forest. As one of the resource strategies in California Water Plan Update 2005, precipitation enhancement can be considered as part of integrated regional water management in some regions in developing water management portfolios. Seeding opportunities tend to be greater in Northern California than in the south because of more frequent storms and cooler temperatures.

Since Update 2005, there have been several developments in weather modification. First, a new long-term project has been added on the North Fork of the Stanislaus River sponsored by the Northern California Power Authority. Its primary purpose is production of more hydroelectric power.

Pacific Gas and Electric Company (PG&E) is planning a new project on the Pit and McCloud rivers in Northern California at the headwaters of Shasta Lake. Since seeding opportunities tend to be greater as one moves north into colder winter weather and more frequent storms, this will likely be a fairly productive program. The plan is to increase precipitation recharge of the large volcanic aquifers that feed the Pit and McCloud Rivers year round and thereby increase hydroelectric power production. An added benefit would be water supply in the upper Sacramento River system at Shasta Reservoir. Projected yields, according to PG&E, could average 250,000 acre-feet (AF) per year, or about a 9 percent increase in runoff. The company plans to start seeding operations in the 2010-2011 water year. Once the aquifer is built up, the project is expected to produce 330 gigawatt hours (GWh) per year of additional hydroelectric energy.

The third area is the Colorado River Basin where a lengthy drought has caused the seven states through which it and its headwaters flow to look at all potential options. The best hope of augmenting Colorado River water supply is wintertime cloud seeding in the headwater states of Colorado, Utah, and Wyoming. Many seeding programs are in place. However, the basin states have agreed to work together in a program for implementing new programs and to designate new areas for seeding and possibly longer seasons of operation for existing projects. Fifteen projects are operating in the upper Colorado River region; there may be a potential for up to 15 more in the basin, including four in Arizona. A 2006 study by North American Weather Consultants estimated the combined potential yield of the new programs could average 800,000 AF per year. This is based on a 10 percent increase in precipitation. Additional amounts could be obtained by augmenting the existing programs. As a starter, the Lower Basin states added about $400,000 in the three years from 2006 through 2008 for Upper Basin cloud seeding efforts to enhance and extend the operating season.

On a discouraging note, Nevada's budget shortfalls in summer 2009 have greatly reduced the scope of the Desert Research Institute weather modification activities in California. Support has found to continue the Tahoe-Truckee project, but cloud seeding

in the Carson-Walker project has been discontinued, except possibly on a few ground seeding sites in the Walker River Basin.

Much more research in weather modification is desirable. The equipment required to conduct research is unaffordable for independent project sponsors, although much can be gained from piggybacking research onto existing programs. To this end, legislation was introduced in the 110th Congress by Senator Kay Hutchison of Texas and Congressman Mark Udall of Colorado for weather modification research and to increase the effectiveness of existing programs through applied research.

In California, proposals have been made to the California Energy Commission's Public Interest Energy Research (PIER) program for additional research into cloud seeding to evaluate the effectiveness of existing programs in the state and optimize their effectiveness. This approach would survey the latest scientific advances in cloud physics, remote sensing, atmospheric science, and seeding technologies; evaluate strategies; and recommend the best course of action to maximize the contribution of operational cloud seeding programs for the state's water and energy supplies. Research could also be conducted on the potential effect of global warming and atmospheric pollution on seeding practices and capabilities. DWR recommends that PIER include and fund research on cloud seeding in their activities.

The State of Wyoming has undertaken a major weather modification research program, which is entering its 5th year (2009-2010). The objective is to evaluate, with help from scientists at the National Center for Atmospheric Research, the potential for increased snowpack in the Sierra Madre and Medicine Bow Mountains with a randomized experimental design. Some storms will be seeded and some will be left unseeded with extensive measurements of moisture tracking in the air and results on the ground. Another three years will be needed after the current one to gain the 120 to 150 cases needed to detect with confidence a 10 percent increase in snowpack due to seeding. A full operational program might yield 250,000 AFY on average.

Benefits from Current and Potential Precipitation Enhancement

In California, all precipitation enhancement projects are intended to increase water supply or hydroelectric power. The amount of water produced is difficult to determine, but estimates range from a 2 to 15 percent increase in annual precipitation or runoff. A National Research Council (NRC) 2003 report on weather modification suggested that there is considerable evidence that winter orographic weather modification does work, possibly up to a 10 percent increase. A detailed study by the Utah Department of Natural Resources in 2005 showed an average increase in April 1 snowpack water content ranging from 2 to 18 percent from a group of projects that had been operating from 2 (High Uintas) to 27 (Central/Southern Utah) years. The overall estimated annual runoff increase for the state was about 230,000 AF, or 7 percent for the study

Box 10-1 Acronyms and Abbreviations

AF	acre-feet
ASCE	American Society of Civil Engineers
CEQA	California Environmental Quality Act
DWR	California Department of Water Resources
GWh	gigawatt hours
NOAA	National Oceanic and Atmospheric Administration
NOI	Notice of Intention
NRC	National Research Council
PG&E	Pacific Gas and Electric
PIER	Public Interest Energy Research
S.	US Senate bill
TAF	thousand acre-feet
USBR	US Bureau of Reclamation

area. Actual increases in annual runoff are probably less in California than in Utah. A conservative estimate made for Water Plan Update 2005 by DWR staff is that the combined California precipitation enhancement projects generate 300 to 400 thousand AF annually, which would be an average of about a 4 percent increase in runoff. Nearly half of the projects are conducted by utilities, so there is also a substantial incremental benefit to hydroelectric power generation.

Although the planned Pit River project occupies one of the most favorable areas for cloud seeding, another 200 to 300 thousand AF per year may yet be available. Many of the best prospects are in other parts of the Sacramento River Basin, in watersheds that are not now seeded. The Lahontan region is 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, however, 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 are generally less than $20 per AF 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 to $4 million is spent now on

yearly operations. Achieving an additional 200 to 300 TAF of potential new supply (beyond the planned Pit-McCloud project) could require an initial investment of around $7 million for planning, reports, and initial equipment, plus around $4 million in annual operating costs. Over the next 25 years, that would total $107 million, an average of nearly $20 per AF.

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. Some studies of individual projects have been made in the past on certain projects, such as the Kings River, that have shown increases in water.

Operational Precision

It is difficult to accurately target the location and time of cloud seeding. There is an incomplete understanding of the effectiveness of current targeting practices. Chemical tracer experiments have provided support for some targeting practices. New atmospheric measuring tools (currently being employed by the NOAA hydrometeorological test bed experiments) can be used in studies of new seeding agents, transport, and diffusion to improve operational precision.

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 US Bureau of Reclamation (USBR) did extensive studies on these issues. The finding is reported in its Project Skywater programmatic environmental statement in 1977 and its Sierra Cooperative Pilot Project environmental impact statement in 1981. The available

Photo Image of ground-based seeder. Image courtesy of Pacific Gas and Electric Company

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.

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 USBR, 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. Some recent silver accumulation testing by PG&E on the Mokelumne River and Lake Almanor watersheds was reported at the 2007 annual meeting of the Weather Modification Association. Both watersheds have been seeded for more than 50 years. Sampling at Upper Blue Lake and Salt Springs Reservoir showed very low to nondetectable concentrations in water and sediment. Similar results were found at Lake Almanor in testing water, sediment, and fish samples during the 2000 to 2003 period. Amounts were far below any toxic levels, and there was little to suggest bioaccumulation. Therefore, continued operations should not result in any significant chronic effect on sensitive aquatic organisms.

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 as it is to clear 5 inches.

All operating projects have suspension criteria designed to stop cloud seeding any time there is a flood threat. Moreover, the types 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.

Funding

Little federal research funding for weather modification has been available in the past 15 years. USBR 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.

As noted earlier, bills were introduced in the 110th Congress which would re-establish federal support for more weather modification research, some of which would provide research support on existing operating projects. The legislation was supported by the Western States Water Council, the seven Colorado River Basin states, the Colorado River Board of California, DWR and others. The bill was reintroduced in 2009 as S. 601 in the 111th Congress and was remolded into the Weather Mitigation Research and Development Act which would establish a Weather Mitigation Research Office within

the National Science Foundation with a budget of $ 25 million a year. Prospects of passage do not appear bright.

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 effect of aerosols on clouds and precipitation is 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. Research work in Israel has demonstrated such effects.

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 seek research funds for both old and new projects. Operational funding support for new projects may be available in the integrated regional water management program.

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. Specifically, DWR staff should monitor progress and research results of the Wyoming Weather Modification Pilot Program, a major research program which is costing Wyoming about $1 million dollars a year.

3. DWR should support efforts to investigate the potential to augment Colorado River supply by cloud seeding, in cooperation with the Colorado River Board, the other Colorado River Basin states, USBR, and Metropolitan Water District of Southern California.

4. DWR should support research on cloud physics and cloud modeling being done by NOAA labs and academic institutions. With improvement, these models may become tools to further verify and test the effectiveness of cloud seeding activities.

5. The State should support research on potential new seeding agents, particularly ones that work at higher temperatures. Global warming may limit the effectiveness

of silver iodide, the most commonly used agent, which requires cloud temperatures well below freezing, around -5º C, to be effective.

6. 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 and State research funds for local research experiments built upon their operating cloud seeding projects. In this regard, DWR recommends that the California Energy Commission PIER program includes research studies on weather modification.

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