Precipitation Enhancement Resource Management Strategy

CALIFORNIA WATER PLAN UPDATE 2023

October 2024

Precipitation Enhancement Resource Management Strategy

CALIFORNIA WATER PLAN UPDATE 2023

Lead Author: Ramesh Gautam

Contents

Figure

Acronyms and Abbreviations

CEC	California Energy Commission
DWR	California Department of Water Resources
NAWC	North American Weather Consultants
NOI	notice of intent
NOAA	National Oceanic and Atmospheric Administration
Reclamation	U.S. Bureau of Reclamation

Precipitation Enhancement Resource Management Strategy

Introduction

Precipitation enhancement, commonly called "cloud seeding" or "weather modification" is a scientific method to artificially stimulate clouds to produce more rainfall and snowfall than would be produced naturally. The primary mechanism is to inject substances, such as silver iodide or ice crystals (cloud seeding agents), into the clouds that enable snowflakes and raindrops to form more easily. Various cloud seeding programs have been operational since late 1950s. Most programs continue for a number of years during winter months and as conditions warrant. The following is a summary on previous cloud seeding programs in California.

Cloud Seeding in California

Winter orographic cloud seeding (cloud seeding where wind blows over a mountain range, causing clouds and rain or snow by lifting the air) has been practiced in California since early 1950s. Most of the projects are along the central and southern Sierra Nevada, with some in the Coastal Ranges. 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, have been used. In recent years, some projects applied hygroscopic materials (substances that take up water from the air) as supplemental seeding agents.

North American Weather Consultants (NAWC) performed a cloud seeding operation in the northern part of the Feather River and portions of the Pit River and McCloud River watersheds during February and April of 1989 (North American Weather Consultants 1989). NAWC conducted cloud seeding operations in the Kings River watershed during 2010-2011 (North American Weather Consultants 2011). The report indicates the effect of cloud seeding was between +1.5percent and +8.8 percent. The corresponding benefit:cost ratio of 3:1 to 10:1 was estimated. In 1992, one of the historically dry years in California, the California Department of Water Resources (DWR) evaluated the average value of new water from the Feather River basin to be approximately $30 per acre-foot (Reinking et al. 1995). The drought water bank in 1992 paid $50 per acre-foot for real, new water at the Delta in the Sacramento Valley and marketed it for $70–$75 per acre-foot in the same location

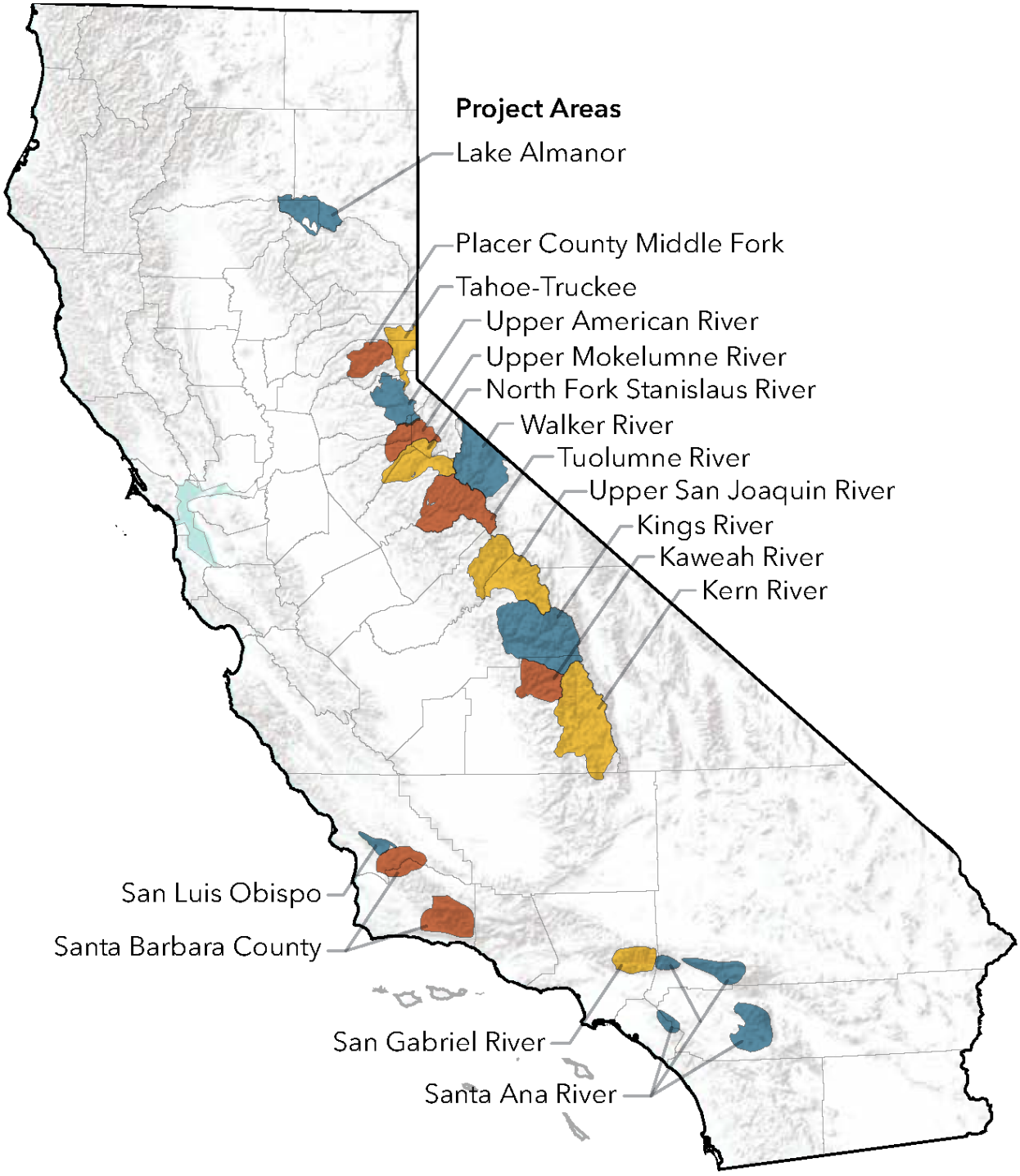
after accounting for conveyance losses and other charges. The study conducted by Henderson in 2003 reported the benefit:cost ratios of six long running programs in California that ranged from 13:1 to 61:1, based on precipitation increase of 2 percent to 9 percent (Henderson 2003). The study concludes that the average cost of producing a 6 percent increase in stream flow was $3.27 per acre-foot for these six programs.

Figure 1 shows precipitation enhancement operational programs in California during 2022. Most weather modification projects are long-term projects that operate in all or most years. Historically, the number of operating projects has increased during droughts, but has leveled off at approximately a dozen in wet or normal water years. Most of the agencies or districts conducting precipitation enhancement projects suspend operations during wet years after enough snow has accumulated to meet their water needs. The Santa Ana Watershed Project Authority began its cloud seeding program in 2020 with its first testing phase. It is now a pilot project spanning four winter seasons. The focus of this project is on seeding four mountain ranges surrounding the watershed with an emphasis on increasing snow and rain precipitation.

State requirements for sponsors of weather modification projects consist of filing an initial notice of intent (NOI), and then every five years after, for continuing projects; some record keeping by operators; and annual or biennial reports to DWR. The information to include in the NOI can be obtained from DWR. In addition, sponsors need to comply with the California Environmental Quality Act and should send annual letter notices to the boards of supervisors within affected counties and to DWR. The National Oceanic and Atmospheric Administration (NOAA) also requires activity reports, which give the number of days and hours of operation and the amounts of seeding material applied.

Policy statements by the American Meteorological Society in 1998 and the World Meteorological Organization in 2007 support the effectiveness of winter orographic cloud- seeding projects, although they acknowledge that results may be uncertain because of the high degree of background variability of weather. A more detailed treatment of weather modification capabilities, position statements, and the status of the discipline is in *Guidelines for Cloud Seeding to Augment Precipitation*.

Figure 1 Cloud-Seeding Project Areas in California



In California, proposals were made to the California Energy Commission's (CEC's) research funding program for additional research into cloud seeding to evaluate the effectiveness of existing programs in the state and optimize their effectiveness. Justification would be the potential effect on hydroelectric energy production. This approach would survey the latest scientific advances in cloud physics, remote sensing, atmospheric science, seeding technologies, and evaluating strategies and would recommend the best course of action to maximize the contribution of operational cloud-seeding programs to California's water and energy supplies. Researchers could also study the potential effect of climate change and atmospheric pollution on seeding practices and capabilities. DWR recommends that the CEC's research funding program(s) include and fund research on cloud seeding in its activities.

Coud seeding done along the Colorado River Basin, particularly in Utah may benefit California, if it raises the inflow to Lake Mead. In turn, this would increase the allocation of Colorado River resources to California. In recent years a major California water agency partially supports orographic cloud seeding in Utah for this reason. Other western State governments, such as Nevada and Utah, support precipitation enhancement cloud seeding.

Benefits of Precipitation Enhancement

In California, all precipitation enhancement projects are geared toward increasing water supply or hydroelectric power. The amounts of water produced are difficult to determine, but estimates range from a 4 percent to 15 percent increase in annual precipitation or runoff. A feasibility study conducted by DWR in 2014 indicated the benefit:cost ratio of potential cloud-seeding projects in the Feather River, Pit and McCloud River, and Trinity River basins ranged from 12:1 to 20:1. Similar previous studies indicate that the projects were implemented with benefit:cost ratio as low as 3:1. An update to a publication of the American Society of Civil Engineers (American Society of Civil Engineers 1995) published in 2006 recommends a ratio of approximately 5:1 to consider a program feasible. A 2003 National Research Council report on weather modification had limited content on winter orographic cloud seeding, such as is practiced in California and other western states. But the report did seem to concur that there is considerable evidence that winter orographic weather modification works, with as much as a 10 percent increase. A 2012 study by the Utah Department of Natural Resources (updating a 2005 study through the 2010 season) showed an average increase on April 1 snowpack water content ranging from 3 percent to 15 percent from a group of projects that had been operating from seven years (high Uinta Mountains) to 32 years (central and southern Utah). The

overall estimated annual runoff increase for Utah was approximately 180,000 acre-feet, or about 6 percent for the study areas. Estimated costs in 2010 were $2.27 per acre-foot from these ground seeding programs. A recent study carried out by the RHS Consulting firm in upper American River basin shows that the streamflow increases during Water Year 2020 increased by 13 percent over the entire basin and 20 percent in the primary cloud seeding target area (Sacramento Municipal Utility District 2020).

Cloud seeding has advantages over many other strategies of providing water. A project can be developed and implemented relatively quickly without multi-year lead times. After the infrastructure and permitting is set up, the kickoff of the program does not take a large investment other than general operation costs. In areas where it snows, it could offset some of the loss in snowpack expected from climate change. This may benefit mountain meadows and would delay the fire season in forests. As a resource management strategy, precipitation enhancement would qualify as part of integrated regional water management. Seeding opportunities tend to be greater in Northern California than in Southern California because Northern California has more frequent storms and cooler temperatures. But, because of ongoing drought, agencies in Southern California are working together to operate the cloud seeding program over Santa Ana River watershed for multiple years beginning in 2023.

Costs of Implementation

Ground-based cloud seeding comprises installation of ground-based generators and permitting for access and operation. Aerial-based cloud seeding includes the use of airplanes to disperse materials (silver iodide or ice crystals) in the air. Other costs include labor and material supply. Overall, the total cost of cloud seeding ranges from $20 to $40 per acre-foot, depending on the location of watershed and type of cloud seeding. Regarding water rights, additional water obtained from cloud seeding is considered the same as natural supply. Approximately $5 million to $7 million is being spent on annual cloud seeding operations in California. An additional 500,000 to 700,000 acre-feet of potential water supply could require an investment of approximately $18 million for planning, reports, and initial equipment, plus approximately $8 million for annual operation and maintenance costs. Over the next 30 years, that would add up to approximately $210 million.

Challenges to Implementation

Agencies face multiple challenges while implementing cloud-seeding projects. The primary challenges are funding, program reliability, data validation, permitting, potential adverse implications, operational precision, and the public's perception.

Funding

State funding opportunities for cloud seeding programs are restricted to certain conditions. DWR does not directly fund the projects but does track and record the number of ongoing cloud-seeding projects in California. Recently, CEC released a grant funding opportunity to fund short-term research that will support the advancement of the science and practice of precipitation enhancement for augmenting hydropower generation. Local agencies bundle together and try looking for funding resources either through the local bond fund or with the increase in water pricing. From the federal side, very little funding has been available for the last 25 years. Desert Research Institute obtains funds partly from the U.S. Bureau of Reclamation and partly from other sources, such as local agency's direct funding for the program, and in some cases from the States of Nevada and Colorado.

Data Validation

Because of the nature of this program, it is difficult to validate the quantification of excess water supply before and after implementing the program over a watershed or over several watersheds. Although several reports published by RHS consulting firm and North American Weather Consultants claim to have water supply augmentation ranging from 4 percent to 15 percent, the scientific validation of such claims by independent research or organizations is yet to be confirmed. The difficulty in validation is caused by the natural variability of weather and difficulty in locating unaffected control basins and wind speed and direction during the seeding windows that may have additional influence on the adjacent watersheds. Nevertheless, it is generally understood among scientific communities that the fresh water supply augmentation can range from 4 percent to 15 percent because of cloud seeding.

Operational Precision

It is difficult to target seeding materials at the right place in the clouds and at the right time. Moreover, the timing, duration, and weather events influence the seeding zone and consequently affect the excess precipitation over the study area. Likewise, the ground-based seeding assumes that the wind direction should happen in certain ways during the seeding events, but practically, this is not the case. As a result, there

is an incomplete understanding of how effective cloud seeding attributes to corresponding water supply within a given water year. Likewise, the relative merit of new seeding materials is yet to be justified through in-depth scientific research.

Potential Impacts

Potential impacts from precipitation enhancement projects were raised in the past. In general, concerns have been heard from local communities or specific groups who have a negative perception of the weather modification program. Common concerns relate to downwind effects, long-term toxic effects of silver, and added snow removal costs in mountain counties. Other concerns were the effect of excess water supply during flood events caused by the uncertainties of specific water year conditions and the nature of the cloud seeding program and its timing for launch. The U.S. Bureau of Reclamation (Reclamation), North Dakota Atmospheric Resource Board, and North American Weather Modification Council did extensive studies on these issues. The evidence does not show that seeding clouds with silver iodide causes a decrease in downwind precipitation or adverse implications to human health. In addition, a seminar specifically on downwind effects, held in Las Vegas during the 2012 annual meeting of the Weather Modification Association, confirmed earlier findings of no loss to downwind areas; often adjacent downwind areas also showed some increase in precipitation.

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, and the tracer study confirmed that the silver samples obtained from the study watersheds are equal or less than the background silver element already available naturally in the watershed. According to 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 to individual exposure from tooth fillings. Watershed concentrations would be extremely low because only small amounts of seeding agents are used. Accumulations in soil, vegetation, and surface runoff have not been large enough to measure above natural background levels.

Some silver accumulation testing by PG&E on the Mokelumne River and Lake Almanor watersheds was presented 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 undetectable concentrations in water and sediment. Similar results were found at Lake Almanor upon testing water, sediment, and fish samples from 2000 through 2003. Amounts were far below any toxic levels, and there was little to suggest

bioaccumulation. As a result, continued operations should not result in any significant chronic effect on sensitive aquatic organisms.

Regarding 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. In other words, the effort to clear a road of 5.5 inches of snow is practically the same as the effort to clear a road of 5 inches of snow. All operating projects have suspension criteria designed to stop cloud seeding anytime if there is a flood threat. Moreover, the type of storms that produce large floods are naturally quite efficient in processing moisture into rain. In such conditions, seeding is unlikely to make a difference.

Costs if Not Implemented

Weather modifications projects are vital resources to enhance fresh water supply for communities within their watersheds. Additional surface water supply helps to cope with the ongoing droughts and to suppress wildfires.

Recommendations

- Because of California's variable climate, the State should support existing cloud-seeding projects and help facilitate local agencies to initiate new cloud-seeding projects. Thus, the State should provide funding to help agencies and other parties conduct additional research on cloud seeding and support ongoing local cloud-seeding projects.
- Through the Division of Planning, DWR should support weather modification projects, such as the 2023 program in Southern California launched by Santa Ana Watershed Project Authority.
- DWR should establish staff positions dedicated to tracking local cloud-seeding programs in California, provide mechanisms for funding, and collaborate with the federal partners to conduct additional research and development in California. The new staff positions at DWR would collect data and project sponsor evaluations of existing California precipitation enhancement projects and projects of other western states, independently analyze them, and perform research on the effectiveness of this technology to supplement water supply while minimizing negative impacts.
- DWR should develop pilot projects in coordination with other State agencies (e. g., the CEC), to formally fund the program on a state level.

- DWR should support existing efforts underway to augment Colorado River supply by cloud seeding, in cooperation with the Colorado River Board of California and its member agencies, the other Colorado River basin states, and Reclamation.
- DWR, in partnership with Reclamation, and seeking cooperation from PG&E, should produce an environmental impact report/environmental impact statement on a Pit River–McCloud River project similar to the one proposed several years ago, because this area has one of the best potential yields. This could benefit the Central Valley Project and the State Water Project (which share in-basin use north of, and in, the Sacramento-San Joaquin Delta), and there would appear to be multiple statewide benefits from augmenting recharge of the huge northeastern California volcanic aquifer.
- DWR should support research on cloud physics and cloud modeling being done by the NOAA labs and academic institutions. With improvement, these models may become tools to further verify and test the effectiveness of cloud-seeding activities.
- The State should support research on potential new seeding agents, particularly ones that would work at higher temperatures. Climate change may limit the effectiveness of silver iodide, the most commonly used agent, which requires cloud temperatures well below freezing, approximately -5 °C, to be effective. Additionally, the increasing costs of silver are a detriment to some ongoing projects.
- DWR should support efforts by California weather modification project sponsors, such as that proposed in 2002–2003 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 CEC's research funding program(s) include research studies on weather modification.

Related Resource Management Strategies

Forest Management: Much of California's cloud seeding takes place over the forested western side of the Sierra Nevada.

Watershed Management: Upper watersheds in the Sierra Nevada are the catchment for enhanced precipitation from cloud seeding.

Useful Web Links

California Energy Commission's Electric Program Investment Charge Program
https://www.energy.ca.gov/programs-and-topics/programs/electric-program-investment-charge-epic-program

Desert Research Institute Cloud Seeding Program
https://www.dri.edu/cloud-seeding-program/projects/

Guidelines for Cloud Seeding to Augment Precipitation
https://ascelibrary.org/doi/book/10.1061/9780784408193

References

American Society of Civil Engineers, 1995. Guidelines for Cloud Seeding Augment Precipitation. ASCE Manuals and Reports on Engineering Practice No. 81.

Henderson, T. J. 2003. New Assessment of the Economic Impacts from Six Winter Snowpack Augmentation Projects. WMA, Journal of Weather Modification, 35, pp. 41-44.

North American Weather Consultants 1989. Operations Report on the Northern California Drought Relief Program, NAWC Report No. WM-89-2., Salt Lake City, UT.

North American Weather Consultants 2011. Summary and Evaluation of 2010-2011 Winter Cloud Seeding Operations for the Kings River Watershed, California, Report Submitted to California Department of Water Resources, June 2011.

Reinking, R. F., Berg, N. H., Farhar, B. C., and Foehner, O. H., Jr. 1995. Section 2 of Manual 81, "Economic, Environmental, and Societal Aspects of Precipitation Enhancement by Cloud Seeding", Guidelines for for Cloud Seeding to Augment Precipitation, ASCE, Reston, VA, pp. 9-47.

Sacramento Municipal Utility District 2020. Upper American River Basin Weather Modification Program. Report submitted by RHS Consulting, Ltd., Final Report 2020 Winter Season.


DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA