WEATHER MODIFICATION - A MAJOR RESOURCE TOOL 1/ 620-77

By

Olin H. Foehner 2/

Introduction

Increased water supplies in both our dry western climate and in the eastern United States during periods of insufficient precipitation will have a critical role in developing and maintaining the quality of life most people strive for. Weather modification can be an important tool in the development of new water resources. Proving that new water supplies are being developed is an important key to the acceptance of cloud seeding. The shifting of natural precipitation from one area to another has only limited regional value.

Weather modification has been a center for controversy since its conception. During a period of drought such as we are now experiencing in the West, newspaper articles are frequently found which provide either an endorsement or a condemnation of weather modification. During drought periods the endorsements normally predominate. Some people believe this is because we find ourselves in either the concern or panic state as illustrated in the Hydro-Illogical Cycle shown in figure 1. Concerned decisionmakers are finding themselves in the position where they must either sit still and dry up or do something.

Since the options for doing something are fairly limited the question of initiating a drought relief weather modification program is usually given serious consideration. It is quickly realized that there can be no certainty about the outcome of cloud seeding. However, present knowledge can be applied with realistic expectations of an acceptable level of return.

Emergency drought relief weather modification projects are now going on in Washington, Oregon, California, Nevada, Utah, and Colorado. The projects, by necessity because of limited funding, are almost entirely directed at increasing precipitation with very little effort being expended on evaluation of results. There'are two major reasons for this: there are no simple methods known for evaluation, and the procedures commonly used are very expensive and time consuming. As reasearch now underway progresses, we expect the methods of evaluation will improve and the level of uncertainty will drop. But it will probably be a very long time before uncertainty about cloud seeding disappears completely.

Present Status

Progress in Research

Numerous attempts to change the weather have occurred throughout history. Only recently, however, have scientists developed the tools to measure and understand what goes on in the clouds. The major breakthrough in scientific understanding came from the work of Bergeron and Findeisen on ice crystal growth in the 1930's and the work of Scheafer, Langmuir, and Vonnegut on nucleation at the General Electric Research Laboratory in the 1940's.

A more general acceptance of the developing technology by the scientific community was withheld until 1966. At that time the National Academy of Sciences (NAS) published the National Research Council Publication No. 1350. One of the principal conclusions was that "there is increasing but still somewhat ambiguous evidence that precipitation from some types of cloud and storm systems can be modestly increased or redistributed by seeding techniques." The NAS position was elaborated in their 1973 report, Weather Climate Modification Problems and Progress, which includes the statement: "The Panel now concludes on the basis of statistical analysis of well-designed field experiments that ice-nuclei seeding can sometimes lead to more precipitation, can sometimes lead to less precipitation, and at other times the nuclei have no effect, depending on the meteorological conditions."

1/ Presented at the Western Snow Conference, April 18-21, 1977, Albuquerque, N.M.

2/ Division of Atmospheric Water Resources Management, Bureau of Reclamation, U.S. Dept. of the Interior, Denver, Colorado.

The Bureau of Reclamation's Colorado River Basin Pilot Project (CRBPP) was conducted over five winter seasons from 1970 to 1975. Aerometric Research, Inc., (ARI) performed the detailed analysis of the experiment. A number of significant results were identified. The most important conclusion is that the full potential from seeding was not realized because increases from seeding warm-top clouds were countered by decreases from seeding cold-top clouds. Two reasons have been identified which are of value in designing future programs: the inability to accurately forecast storm conditions for an entire experimental day up to 24 hours in advance, and the difficulties in targeting seeding material under certain wind and air-mass stability conditions.

The detailed data collection during the project has permitted extensive postanalysis of shorter time blocks within the seeded and unseeded storms. Analysis of these data has identified those conditions under which significant increases did occur. ARI's Executive Summary of Comprehensive Evaluation includes the statement:

> "The overall potential for seeding-produced increases in precipitation, provided only suitable clouds are seeded, is conservatively about ten percent, depending upon location over the barrier. The resultant potential increase in streamflow, calculated by a hydrologic computer model, is about 19 percent."

Research is continuing in Project Skywater on both summer cumulus precipitation in the High Plains Experiment (HIPLEX) program and on winter orographic precipitation in the Sierra Nevada. Planning and Coordination is also proceeding for a long-term demonstration program in the Colorado River Basin. Progress through research is being made at a reasonable pace considering the dollars and time expended versus the magnitude of the problems encountered.

Operational Use

The increasing acceptability of this technology can be partially attributed to the water users and particularly utility companies in the western United States. They have pioneered support for weather modification by their long-term use of winter orographic cloud seeding to increase inflow to reservoirs. The fact that rational business people are willing to continue annual expenditures over many years has convinced some of the public that the programs are continued because an acceptable return is obtained from the investment. An important related fact is the apparent lack of undesirable environmental effects attributable to the long-term programs. One operator has reportedly pointed out that if their program is halted because of the lack of an environmental report, it may be just as pertinent to require a report to determine the effect of no longer having the additional precipitation resulting from their program. The accompanying table 1 lists five California programs which have a collective history of over 100 years of operation. Reported results are unanimously positive.

Table 1. - Long-term operational programs in California

Sponsor	Area	Year began	Estimated results
Southern California Edison Company	Upper San Joaquin River Watershed	1950	Streamflow increase of 8% 1/
Pacific Gas & Electric Company	Lake Almanor Drainage Basin	1953	Significant increases from "cold-westerly" storms 2/
Kings River Conservation Dist.	Upper Kings River Watershed	1955	Streamflow increase of 6% 2/
Santa Clara Valley Water District	Santa Clara County	1955	Rainfall increases of 10-15% greater than average 3/
Sacramento Municipal Utility District	Upper American River Basin	1968	Described as successful with rewarding increases 1/

1/"Special Regional Weather Modification Conference, Augmentation of Winter Orographic Precipitation in the Western U.S.,"American Meteorological Society, 1975.
2/"Weather Climate Modification, Problems and Progress," National Academy of Sciences, 1973.
3/"Weather in the West from the Midcontinent to the Pacific," by Bette Rode Anderson, 1975.

Potential for Increased Use

With scientific and technological advancement, increased public acceptance, and a diminishing number of alternatives for new water supplies there is an expanding demand to develop the full potential from weather modification. The current drought is a catalyst for accelerating development.

Increased awareness of the capabilities and potentials of precipitation management has increased public concern about its effect on the environment and on man, himself. A significant part of the Bureau of Reclamation's Project Skywater research has been the related studies of the environment and society.

In November 1976, the Bureau hosted a SKYWATER IX Conference on Weather Modification and the Environment. The more than 60 natural, chemical, and social scientists determined that the most significant effects of the developing technology will be its influence on land use resulting from societal changes prompted by the availability of additional water. A group of 11 additional scientists, sponsored by the National Science Foundation, worked at the conference on just the problems related to seeding agents. "Based on purely environmental considerations (not considering relative economics and changes in delivery system capabilities)," the group said, "use of silver iodide as a nucleating agent should have an insignificant impact on the environment."

The Stanford Research Institute (SRI) was selected in 1971 by the National Science Foundation to do a technology assessment on the Bureau of Reclamation's proposal to augment the flow of the Colorado River by cloud seeding. The report compiled by Leo W. Weisbecker and published in 1974 titled The Impacts of Snow Enhancement concluded that: "WOSA (Winter Orographic Snowpack Augmentation) is an inexpensive method of augmenting the water supply in the Colorado River Basin."

During the same period as the SRI study, the Bureau of Reclamation contracted with North American Weather consultants for a comprehensive study of augmentation potential in 12 major mountain areas in the western United States. The Twelve Basin Investigation, published in 1973, provides information about potential increased water resources in both dry and wet years taking into account the frequency of occurrence of mountain precipitation and related key airmass parameters over a 20-year period. Table 2 summarizes the estimated average annual potential water supply increases for the 12 areas. The estimated range of potential annual increase for the Upper Colorado River Basin is 0.9-1.3 million acre-feet. Based on the 1952-1971 published record of Colorado River inflow to Lake Powell this represents a 9.1 to 13.2 percent increase in runoff. These estimates are supported by the most recent analysis of results from the Colorado River Basin Pilot Project.

The Westwide Study Report on Critical Water Problems Facing the Eleven Western States published by the Department of the Interior in 1975 includes an analysis of alternative methods of augmentation. The report concludes:

> "Weather Modification offers the greatest promise, both technically and economically, for augmenting the rivers in short supply. Subject to verification by major demonstration projects, precipitation management technology appears to be sufficiently advanced to offer an important source of new water supply * * *"

Future Impacts

Energy

The most critical problem facing our Nation and the World today is energy. And, no matter how the problem is viewed it is apparent that the availability of water is a dominant factor.

Table 2 - Twelve basin investigation estimated average annual potential water supply increases from weather modification (1,000 acre-feet)

Basin	(a) Conservative potential	(b) Total effect potential
Upper Colorado River Basin		
Colorado River inflow to Lake Powell	903 1/	1,3151/
Rio Grande Basin		
Rio Grande at Cochiti	88 2/	2092/
San Luis Valley	26	46
Truckee, Walker, Humboldt Basins		
Truckee River at Farad	99	129
Walker River total	66	82
Humboldt River near Carlin	98	98
Sacramento Basin		
Sacramento River at latitude of Sacramento	1,410	1,858
North Platte Basin		
Inflow to Seminoe Reservoir	155	164
Laramie River near Lookout	40	42
Gila River Basin		
Total Gila River	154	239
Snake River Basin		
Total Snake River	903	1,056
Upper Missouri Basin		
Total Upper Missouri Basin	1,408	1,837
San Joaquin Basin		
Total contribution to San Joaquin River	1,249	1,517
Deschutes Basin		
Deschutes River total above Culver	220	244
Bear-Wasatch Basin		
Total contribution to Bear-Wasatch	544	579
Yakima Basin		
Yakima River near Parker, Washington	283	352
Total of the 12 basins studied	7,646	9,757

1/ A 9.1 and a 13.2 percent increase in runoff based on 1952-1971 actual published runoff.
2/ An 11.0 and a 26.1 percent increase in runoff based on 1952-1971 actual published runoff. (These are unadjusted).

Translation of energy production into water needs is dependent on specific site locations, processes used, cooling methods, and other parameters. However, to measure the relative water for energy needs, the following unit factors were assumed except where specific plans and water contracts are already firm.

Coal fired electric generating plant	- 15 acre-feet/year/megawatt at 85 percent plant factor
Oil shale	- 17,400 acre-feet/year for a 1,000,000 barrel/day plant
Coal gasification plant	- 15,000 acre-feet/year for a 250 million cubic feet/day plant

These factors which include the estimated related municipal requirements to support the development came from the Report on Water for Energy in the Upper Colorado River Basin prepared by the U.S. Department of Interior in July 1974.

Weather modification has the potential for becoming a major tool in the reclamation of mined lands, the transport of coal through slurry pipelines and serving energy production complexes. The benefits from increased summer showers may make the difference between success and failure in restoring stripmined lands to productive range and croplands.

Increased runoff from weather modification also has the potential for improving the efficiency of the hydroelectric portion of a power system. In years of below normal riverflows, hydroelectric power capacity may be idle, and other sources of power such as thermal generation may be needed. When available, hydroelectric generation is the most economical power produced.

Hydropower's real value comes from its unique ability as a backup or energy storage operation for baseload energy systems. Because of the flexibility to increase or decrease output on short notice, hydroplants are particularly well suited to meet peak power demands. This ability to go online almost instantly offers other advantages as well in system regulation, emergency service, increasing the reliability of interconnected systems, and, perhaps in the future, stabilizing intermittent energy sources such as solar and wind power. Production of hydropower is a nonconsumptive use of water.

The Department of the Interior Water for Energy Management team concluded that "sufficient water in the Upper Basin (Colorado River) to meet energy developments and other anticipated needs to the year 2000 will not be available unless certain state and Federal actions are taken soon. These actions include strong state leadership in the resolution of water rights and water allocation actions and the attainment of efficiency in water use. Additional storage facilities will be required and augmentation of the supply will be needed through weather modification."

Agriculture

Agricultural water use dominates present water demands in the western United States. In the Colorado River Basin, agriculture accounts for 67 percent of depletions,

Areas of sparse and variable rainfall such as the High Plains show the greatest interest in increasing rainfall. The Bureau of Reclamation's HIPLEX program, a cooperative effort involving agreements with the state governments in Montana, Nebraska, Kansas, Colorado, and Texas, is well underway and will begin experimental seeding next summer. The object is to establish a verified, effective cloud seeding technology and a policy and management background for responsibly producing additional rain.

Increased rainfall would benefit dryland farming and would reduce the demand for irrigation water which frequently is pumped to the surface from dwindling ground-water supplies. The energy used in irrigation for pumping and distribution would be reduced; but even more important, crop reduction would be enhanced. Estimates made for HIPLEX indicate that crop value in the High Plains alone could be increased by up to $500 million a year just by adding 1 additional inch of water.

Edward Ackerman, in Water and Agriculture, Publication No. 62 of the American Association for the Advancement of Science, reached the conclusion that:

"Among all the future possibilities of increasing water receipts in the West, weather modification appears to be the only indubitably cheap source of water where it is applicable. There is no doubt water cheap enough for irrigation can be produced by this means."

Water Quality

New water supplies developed from augmenting high mountain snowpacks are one of the best sources available for high-purity water. Snowmelt runoff occurs from areas that normally have high precipitation rates and correspondingly good vegetative cover. The impact of snow on the soil mantle does not dislodge soil particles such as rain on dry barren ground from which much of the stream sediment in western states originates. Meltwater from the snowpack occurs during a period of maximum ground saturation; therefore, it normally travels over the ground surface with little opportunity for dissolving solids.

The Westwide study concluded that the most promising approach to reducing salinity is through a program of construction of salinity control projects and implementation of measures to prevent large quantities of salt from entering the river. However, the alternative to salinity control is augmentation of the river to achieve a degree of dilution. Weather modification is considered the most desirable source of augmentation when compared to such programs as large-scale diversions from other river basin systems or geothermal desalting.

Municipal and Industrial

Water shortages and poor quality water plague many communities throughout the West. The stability and well being of communities and rural areas can be adversely influenced by inadequate water supplies. Weather modification can provide some help in those areas where the municipal and industrial users obtain their supply from surface or ground-water sources that have wide fluctuations between wet and dry years and where dilution would improve the water quality.

During periods of drought many large cities have turned to weather modification as a source for increased water supplies. New York, Denver, and Los Angeles each have had a program. The diversity of locations demonstrates the interest across the entire U. S.

Potential benefits to the energy industry have been discussed. Many water dependent industries will benefit from more reliable or increased streamflows.

Recreation

Winter snowpack augmentation has been used by numerous ski areas in California, Colorado, Wyoming, and Vermont to establish and maintain a good base for skiing. Developing the snow base earlier has also been attempted to increase the length of the season. Jackson Hole, Wyoming, ski area officials credit cloud seeding efforts this past winter with increasing snowfall to near normal levels.

Snowmobiling and cross country skiing are growing winter sport activities which also benefit from more stable levels of snow cover.

Adequate moisture levels in forest recreation areas are required before campfires or overnight use are permitted. Increases in precipitation may make the difference in marginal periods.

Stream fisherman benefit through maintenance of flows suitable for fish habitat over longer periods and longer reaches of the stream. Fish also benefit from having sufficient snow cover on mountain lakes to prevent freezing to severe depths. Increased runoff in low flow years also permits whitewater boaters and rafters longer periods of use.

Conclusion

No attempt has been made to list or detail the problems which remain to be overcome before weather modification becomes the major resource tool described in this paper. The objective has been to present a picture of what is possible and to demonstrate that the rewards justify overcoming many obstacles.

The following conclusion appeared in the Working Document of the Western U.S. Water Plan titled Augmentation Potential Through Weather Modification in February 1975. It still is appropriate:

> "The advantages of using weather modification as a means of water supply augmentation are: (1) a source of high-quality water that does not deplete water supplies in other areas, (2) no known major ecological disadvantages, (3) increased water at high elevations permitting maximum hydropower generation, and (4) water supply enhancement at a relatively low initial investment and low annual operating cost. Taking into consideration availability, quantity, quality, and cost of the augmentation alternatives, weather modification is recommended as the promising source of new water supply. Figure 1.

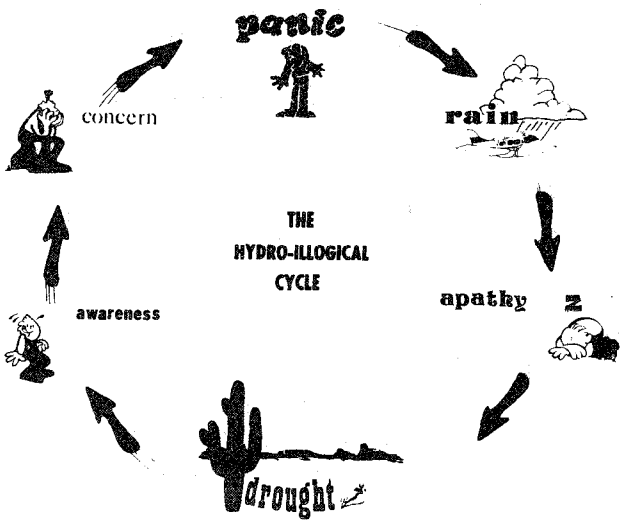

Figure 1