Snowpack Augmentation by Cloud Seeding in Colorado and Utah

By

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PREFACE

Weather modification is nothing new. Rain dancers reach into antiquity and the craft is still practiced today. The science of weather modification, however, is a relatively new matter kicked off after World War II with the experiments of Langmuir and Scheafer in dry ice cloud seeding near Pittsfield, Massachusetts. Langmuir and Scheafer triggered more than a snowshower with their first cloud-seeding experiment. They triggered a great interest in the possibilities of a variety of weather modification programs, including precipitation augmentation, fog dissipation, lightning suppression, hail suppression and weather as a weapon.

These programs, however, are only a drop in the bucket compared to what might lie ahead. A major effort in modern atmospheric research is now being brought to bear on large-scale atmospheric modification on a global basis. For example, consider the speculation of Dr. Walter Orr Roberts,[1] Director of the National Center for Atmospheric Research, Boulder, Colorado. "I have suggested . . . that small energies may suffice to trigger high-level cirrus clouds over large areas of the Gulf of Alaska, during winter. If so, I have speculated, substantial amounts of radiant energy may be trapped in the atmosphere, and prevented from escaping to space. Then, perhaps, the energies will prove sufficient to kick off large alternations in the storm tracks and jet streams over North America in the two week subsequent."

While large-scale weather modification is still only in its pioneering stages development, the magnitude of potential effects staggers the mind, and therefore, it is the opinion of the authors of this paper that it is not too soon to begin thinking about weather modification as it applies to water resources management and planning. In this vein, examination of the weather modification program that is currently upon us in the water resources field serves as a ground floor level of understanding of what appears to be a future of significant proportions.

INTRODUCTION

The natural characteristics of water and its use make water resources development and management an uncertain matter. First, water occurs in three physical states - liquid, solid and gas, depending on its position in the hydrologic cycle. Because of these different physical forms, water compared to other natural resources may be considered as a "fugitive resource" in terms of management. Second, an uncertainty exists in both supply and demand for water. Inputs to a water resources management system are variable over time in quality, quantity and spatial distribution. Knowledge of future hydrologic events is limited by the past record, which represents a sample of the possible variability of future events. Water and water related products depend on estimates of future population, production, technology, political decision and so on. The further ahead the demands are projected and the smaller the area for which the demands are made, the more uncertain the estimates of demand become.

Realization of these characteristics of water have had at least three major implications for water resources management. First, water resources development must be a continuous process to allow for unpredicted and unpredictable changes in future conditions. Second, management must be flexible so that a mix of outputs from the system can be changed if conditions change over time. And last, the organizational structure of water resources administration should be flexible to adapt to changing conditions.

The importance of the above is that traditional water resources development, meaning regulation of surface flows by means of large-scale reservoirs and other structural works is beginning to become outmoded. This is reflected in the current trends in water resource planning of finding alternative ways of meeting needs for water and water related products, such as flood plain zoning, wastewater recycling, redistribution of existing supplies and finding new supplies. In other words, it appears that water resources management in the future will be weighted more towards manipulation of developed surface and groundwater supplies and the development of new supplies in ways other than what has been the traditional approach.

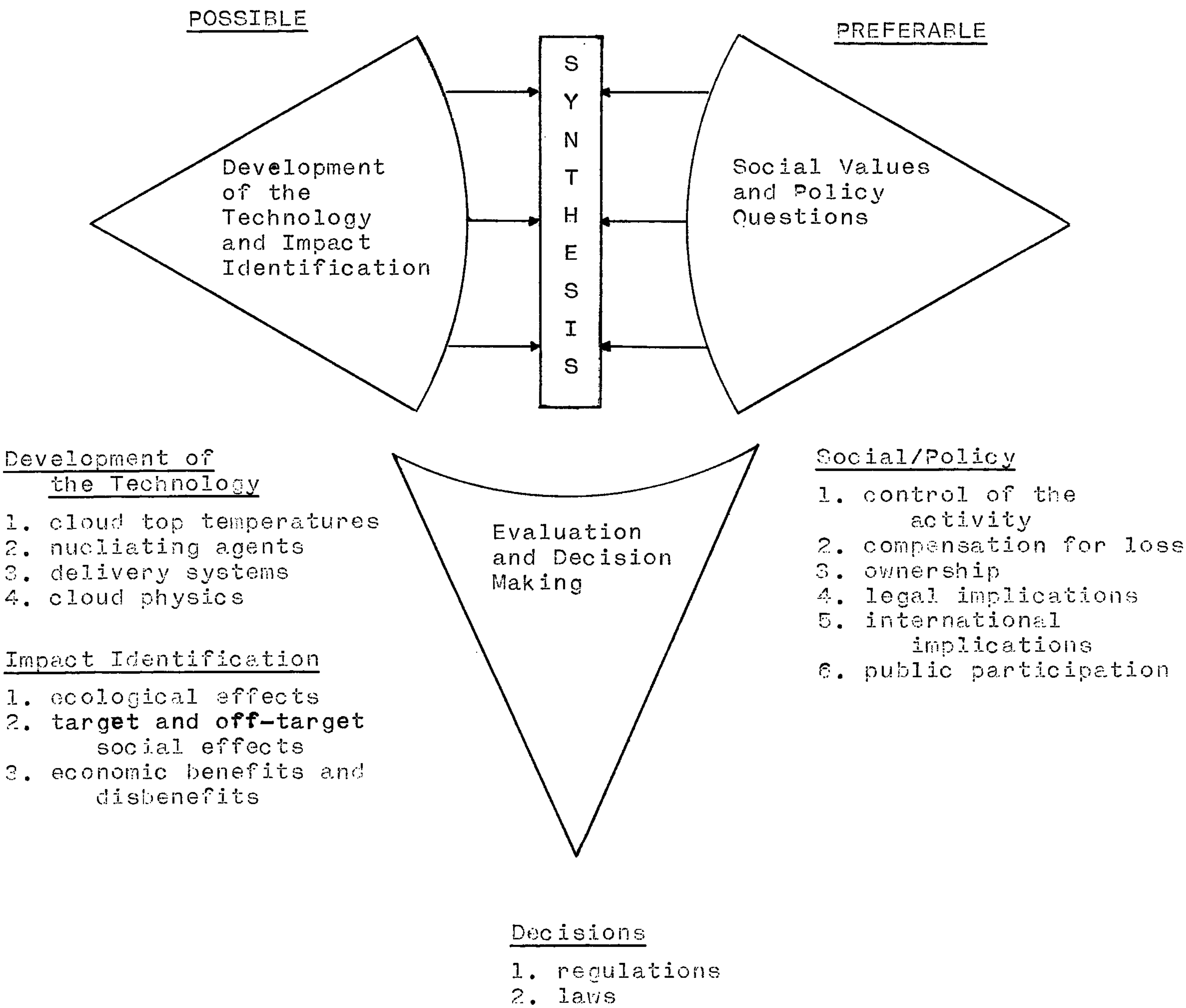
Precipitation augmentation is considered one way of developing new supplies of water. The flow of atmospheric water across the skies can be viewed as an untapped water resource. These rivers in the sky transport moisture evaporated from the oceans and deliver water vapor above the land where it may fall as precipitation. Rather than rely exclusively on nature, which deals in extremes (i.e. at times too much precipitation, but more often not enough), to tap this great resource; man is attempting to develop his own taps of this resource through atmospheric science technology.

Just as the development of surface and ground waters have been accompanied by tangible and intangible problems, precipitation augmentation is beginning to show some of the same problems. Apart from the purely meteorological problems of precipitation augmentation, there are many important considerations which involve the reactions of society to this newest effort to alter the environment. Figure 1 provides a general framework by which the problems of precipitation augmentation might be analyzed.[2] As can be seen from Figure 1, the problems are both ontological and teleological in nature. On the ontological side is the fanning out of problems in the development of the technology, i.e. knowing when to seed and when not to seed, and the identification of magnitude and moment of the impacts resulting from technology. On the teleological side is the fanning out of the normative problems of the values and needs of society. The interaction between these two problem fields is viewed as a synthesis process which ultimately, through the politics of choice, funnels the technology into the future.

This report will examine the current status of precipitation augmentation as it relates to the States of Colorado and Utah. Its purpose is to provide the reader with a feel for the general direction in which precipitation augmentation is headed as far as the Upper Colorado River Basin is concerned. The primary reason that an explanation of precipitation augmentation is of particular interest in the Upper Basin is that this is an area where supply is truly limited and demands are extraordinary. According to Dr. Lewis Grant of the Department of

FIGURE 1

Precipitation Augmentation Problem Analysis



Atmospheric Sciences, Colorado State University (personal communication, 1979); the only real source of new water for the Upper River Basin is the atmosphere. This is contrasted against other regions both east and west of the Upper Basin where alternative sources of water, such as groundwater or desalinized water or water from interbasin transfer are at least engineeringly feasible. The extraordinary demand for Upper Basin water is the result of rapid growth within the service region (with the prospect of even greater demand if oil shale mining becomes a reality) and the commitments by compact of Upper Basin water to the Lower Colorado River Basin uses.

SCOPE OF STUDY

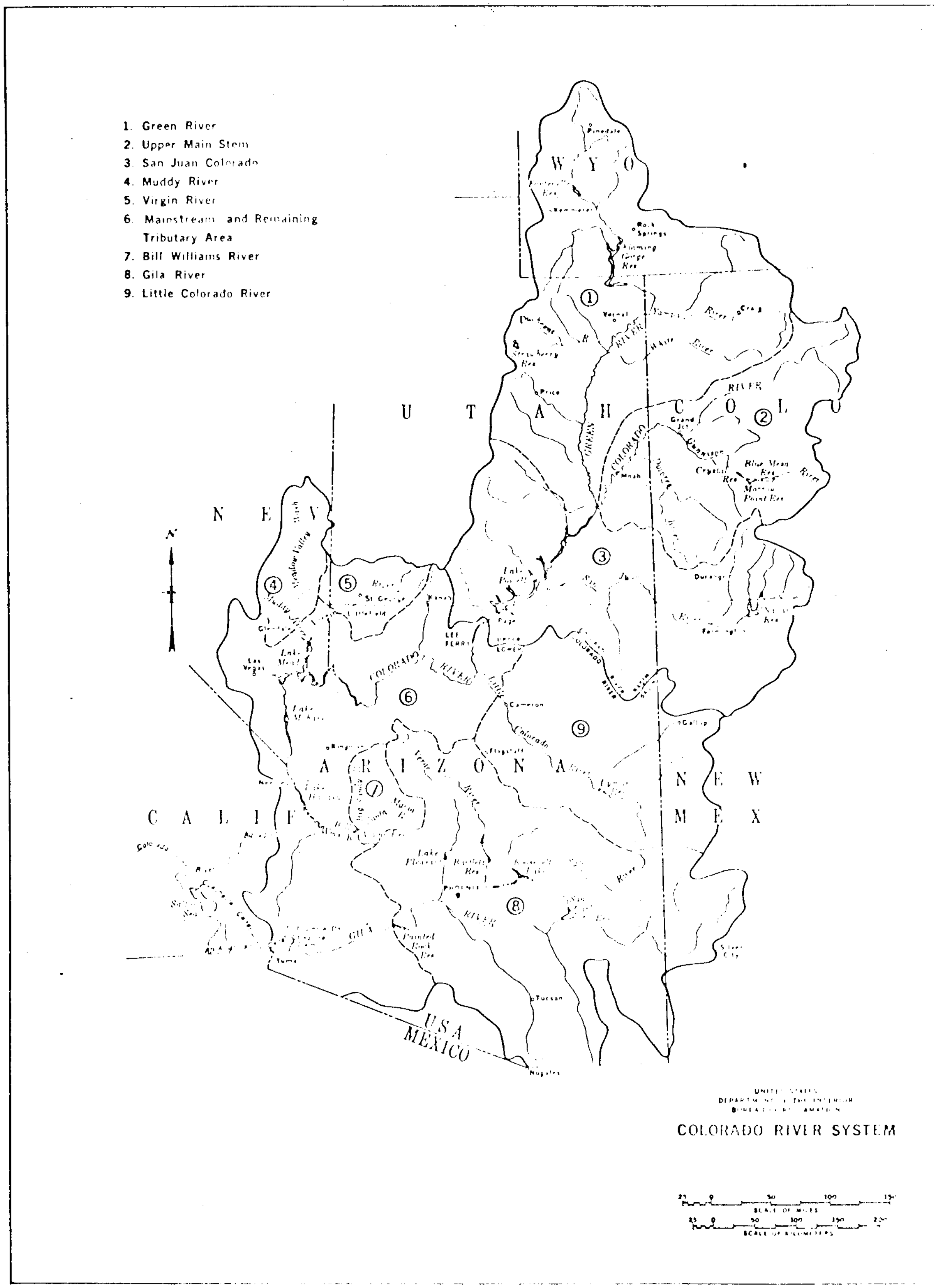
The Study Area

As indicated above, the geographical limits of this paper will be the Upper Colorado River Basin, primarily that portion of the Basin occupied by the State of Colorado and Utah. The reasons that this region was selected for study are: (1) about 85% of water in the Colorado River originates in Colorado and Utah; (2) Colorado and Utah appears to have two of the most aggressive precipitation augmentation programs in the United States; (3) the topography of the Colorado and Utah is ideal for precipitation augmentation, especially for winter orographic seeding programs, and (4) Colorado and Utah are the major users of water in the Upper Colorado River Basin.

The Colorado River Basin (Figure 2) drains an area of approximately 244, 000 square miles of seven states. Most of the runoff comes from the melt of snow in the higher elevations of the headwaters of the Colorado River and its major tributaries, the Green and San Juan Rivers. The drainage area of these rivers has been historically referred to as the Upper Colorado River Basin. The Upper Colorado River Basin drains an area of approximately 109, 600 square miles of four states, Colorado, Utah, Wyoming and New Mexico.

The topography of the Upper Colorado Basin is dominated by high mountain ranges and most of its periphery except along the southern

FIGURE 2


1. Green River
2. Upper Main Stem
3. San Juan Colorado
4. Muddy River
5. Virgin River
6. Mainstream and Remaining Tributary Area
7. Bill Williams River
8. Gila River
9. Little Colorado River
W Y O
U T A H
C O L
N E V
A R I Z O N A
C A L I F
N E W
M E X
GREEN RIVER
COLORADO RIVER
GILA RIVER
USA
MEXICO
COLORADO RIVER SYSTEM

border and a relatively low saddle on the northeast border. Table I (Rasmussen 1968) lists the percent distribution of surface area of the Basin in various elevation classes.

TABLE I

Percent of the Area of the Upper Colorado River Basin by Elevation Above Sea Level

Elevation range (feet)	11, 000	8, 000-11, 000	5, 000-8, 000	5, 000
Percent area	3	24	63	10

A major climatological feature of the Upper Colorado River Basin is the large variability in precipitation. Marlatt and Riehl (1963)[3] have shown that the annual precipitation over the Upper Colorado River Basin varied by a factor of 2 over the period 1930 to 1960. Moreover, over most of the region the potential for evaporation greatly exceeds the precipitation. These two factors underscore the semi-arid nature of the region.

Since the evaporation potential exceeds the precipitation, the resulting stream flow from small local watersheds is ephemeral, lasting only a short time after precipitation. Only in the high elevations is the precipitation great enough and the evaporation potential low enough to sustain streamflow continuously. But this precipitation is seasonal and therefore the flow of the rivers in the basin vary greatly from month to month year to year.

Mineral production and agricultural form the economic base for the Upper Colorado River Basin. Agricultural development is centered around livestock production. There is somewhat more diversification of crops in the Upper Main Stem, however, with some major land areas devoted to sugar beets, beans, potatoes, table vegetables and fruit. Oil, natural gas, coal as well as molybdenum, uranium, lead, zinc and soda ash are the most important minerals produced. Thermal electric power production is becoming an increasingly important industry in the Basin.

Irrigation consumptive use accounts for approximately 80 percent of the total water use in the Upper Basin area. Nearly 1,480,000 acres of land are irrigated in an average year. In the Colorado Main Stem drainage area, however, considerable amount (almost one-third of the total drainage area use) of water is exported to serve agricultural and municipal needs on the eastern slope of the Continental Divide in Colorado.

The waters of the Colorado River were allocated by the Colorado River Compact of 1922 between the Upper and Lower Basin States and the United States Government. The compact allocated 7,500,000 acre feet of consumptive use per annum to each of the two basins, with the Upper Basin required to deliver 75 million acre feet of water during any ten consecutive year period.

The Rio Grande, Colorado and Tijuana Treaty of 1954 between the United States and Mexico guaranteed delivery of 1,500,000 acre feet of water per year to Mexico from the Colorado River. If there is not adequate surplus water for delivery, the Upper and Lower Basins are to share equally the burden of fulfilling any deficiencies.

The Upper Colorado River Basin Compact of 1948 apportions the water of the Upper Basin allocated in the Compact of 1922. The State of Arizona was allocated 50, 000 acre feet and the other states were allocated the following percentages of the remainder: Colorado 51.75%, New Mexico 11.25%, Utah 23.00% and Wyoming 14.00%.

Orographic Cloud Seeding

The authors of this paper chose winter orographic cloudseeding in lieu of summertime cumulus clouds because augmentation of snowfall from wintertime orographic clouds is considerably more advanced than summertime cumulus precipitation augmentation, and the basic technology for augmenting precipitation in many geographic areas on a determinate basis now exists. Careful research over a 15-year period of winter orographic cloudseeding has provided the basis for defining which clouds are efficient and which ones require treatment to improve their efficiency (Grant and Danielson, 1976).

Clouds are made up of billions of tiny ice crystals or water droplets or a combination of both, which form around microscopic particles — soil, dust, smoke, salt crystals, and other materials that are ever present in the atmosphere enveloping the earth. Scientists classify some of these microscopic particles as condensation nuclei on which condensed water freezes, or ice crystals form directly from water vapor. As a general rule there is an abundance of condensation nuclei, but usually a scarcity of ice nuclei available in the air.

The sizes, types, and concentrations of nuclei present in the atmosphere play an important role in determining the efficiency with which a cloud system precipitates. Tons upon tons of water flow above the United States in these "rivers in the sky," precipitating little or not at all for want of certain required conditions. Of prime importance for both initiation and amount of precipitation from a cloud system are (1) vertical and horizontal dimensions of cloud, (2) lifetime of cloud, and (3) sizes and concentration of cloud droplets and ice particles. Under proper conditions, one or more of these three factors can be favorably modified through seeding the cloud with appropriate nuclei.

Cold-cloud seeding of winter orographic storms (Figure 3) is fairly well established and understood. Clouds form as moist air is lifted and cooled during its west-to-east course across the mountains. Left to nature's devices, many are highly inefficient precipitators, content to keep aloft more than 90 percent of their moisture burden.

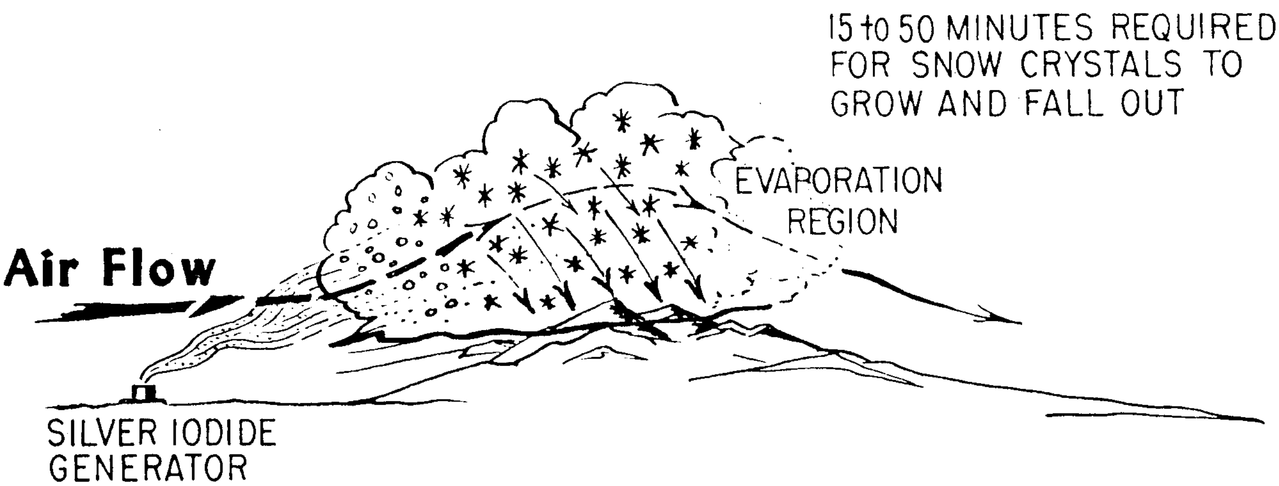
By treating certain of these cold clouds with silver iodide, their precipitation efficiency can be greatly improved. The microscopic crystals of silver iodide act as artificial ice nuclei that form ice crystals which attract moisture from surrounding droplets and grow large enough to fall to the ground as snow.

FIGURE 3

NATURAL MOUNTAIN CLOUD
(Top temperature (14° to -9° F)

Relatively few snow crystals form & fallout. Most cloud water remains aloft in the form of tiny supercooled droplets

SEEDED MOUNTAIN CLOUD
(Top temperature (14° to -9°F)



Many snow crystals form in seeded clouds, thus depositing most of the cloud water on the ground.

Silver iodide (AgI) is the most commonly used nucleating agent for seeding supercooled clouds. Dry ice was used in many early experiments and provided reasonable results. The stability and ease of dispersement of silver iodide have led to its almost extensive use at the present time. The success as a nucleating agent of this type of compound is dependent upon its having a crystal structure similar to that of ice.

A number of delivery systems are available for introducing the nuclei into the clouds. Silver iodide can be combined with combustible solids and used as a projectile which is launched from an aircraft. It can be burned in external attachments on the plane while flying in or upwind from the cloud. The most common means of dispersement is through use of a ground-based propane generator. The silver iodide is dissolved in an acetone solution and then sprayed under pressure into a propane fueled fire, thus producing microscopic nuclei.

A network of these generators is placed upwind from the target area. Although these ground generators lack the precision of aircraft seeding, they are much cheaper to obtain and operate. They can also be operated on a more consistent basis because they are not affected adversely by unsettled weather conditions as are aircraft.

Much knowledge has been amassed relative to seeding under these conditions. A major finding is that success or failure can to a large degree be predicted by a single variable—cloud-top temperature.

Present knowledge indicates that a "seeding window" exists between $14^{o}F$ and $-9^{o}F$; within this range the introduction of seeding nuclei produces a significant increase in snowfall (Kahan, 1972). Professor Lewis Grant observed in his work that the careful recognition of the conditions which produce positive results is essential--seeding outside of the above range can lead to significant decreases in the amount of precipitation which reaches the ground.

SYNOPTIC OBSERVATIONS

In summary of the potential for precipitation augmentation, a few general observations can be made. Kahan (1972)[4] discussed precipitation management with winter orographic seeding and summer cumulus seeding. He summarized some common points as follows:

1. The potential for increasing precipitation is the range of 10 to 30 percent.

2. Not all types of clouds or storms can be beneficially seeded for increases and some clouds cause decreases.

3. Experiments and commercial operations have conducted throughout the nation as well as in several foreign countries.

4. The ratio of expected benefits to cost is high, generally 10:1 or higher.

5. Silver iodide has been the principal seeding material used.

While these general observations on the technology of precipitation augmentation appears to be quite positive, they must be tempered with the experience of the technology since 1972. According to the Weather Modification Advisory Board (WMAB) (1978). "The experimental evidence for cloud seeding has not yet reached the levels of objectivity, repeatability and predictability required to establish new knowledge and techniques."

The first attempts at precipitation augmentation were poorly planned and conducted without an understanding of the physical processes at work. Many overzealous individuals thought that cloudseeding was the panacea for man's water problems and went forward unscientifically and sometimes unscrupulously. Consequently, the scientific development of the technology had for a time been hindered by the "rainmaker" stigma attached to the technology by the general public.

Nevertheless, the gap in the understanding of the physical processes involved in precipitation augmentation can be said to be narrowing rapidly. Research has developed simulation models to determine the probable effect of seeding nucli, more refined instrumentation techniques are in use to monitor cloud systems so that haphazard seeding can be discarded for a more scientific approach of seeding at the proper time. Detailed cloud and environmental measurements by radar, aircraft and satellites are being employed in the prediction of the consequences of seeding. All of this has built lines of evidence suggesting that carefully controlled seeding, using appropriate means, will result in effects of useful dimensions.

The line of evidence for seeding winter orographic clouds is particularly strong. The Weather Modification Advisory Board reports, "Of all the U.S. cloud seeding objectives considered, that of increasing snowpack over the western mountains of the United States rests upon the firmist theoretical and experimental grounds." Moreover, "There is strong evidence that snowfall from winter storms over Colorado mountains can be increased by 10-20 percent provided that seeding can be limited to clouds having certain well defined characteristics."

So, why weren't we seeding on an operational basis? This question frames the purpose of this report. Basically, the answer to this question lies outside of atmospheric sciences community. The questions of proof and effects no longer are in the clouds but now on the ground. A major question is that of runoff. Because of the geographic and time induced variability in precipitation, it is extremely difficult to prove the statistical significance of increased runoff due to artificial augmentation. Studies have shown that increases as great as 30 percent did not provide statistically significant runoff.[5] Similarly, the environmental, social and economic effects of snow enhancement through precipitation augmentation have not been adequately demonstrated, let alone proven. This failure to determine the significance of snowpack enhancement effects has caused the non-scientific public to balk on their endorsement of operational programs.

RESEARCH AND DEVELOPMENT

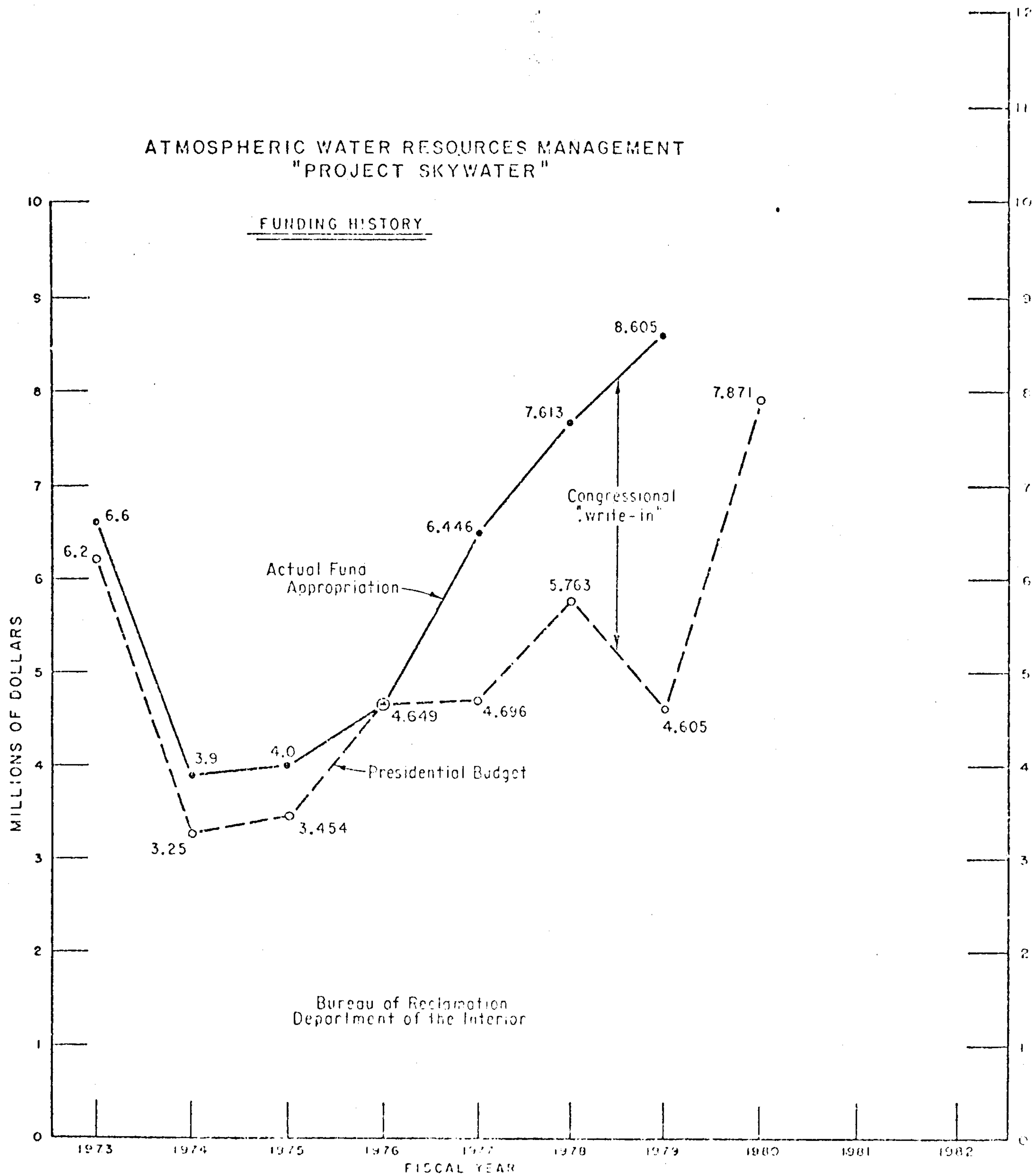
Federal Programs

The Bureau of Reclamation, U. S. Department of the Interior is the major federal agency working within the scope of this paper. The National Oceanographic and Atmospheric Administration with offices in Boulder, Colorado, is primarily involved with hail suppression research and therefore was not contacted. The National Science Foundation provides only research funds to Colorado State University, Department of Atmospheric Sciences and their involvement will be discussed as a part of the CSU program.

Bureau of Reclamation

Weather modification research involving cloud seeding by the Department of the Interior, Bureau of Reclamation, was authorized by Congress within the Public Works Appropriations Act of 1962 (Public Law 87-330). In response to this legislation the Bureau initiated Project Skywater in 1962 with the goal of developing practical cloud seeding techniques to increase rain and snow in the nation's critically water-short areas - the Colorado River, the Sierra Nevada and the High Plains. Most of the research in connection with Project Skywater has been performed in cooperation with universities, state agencies and private firms dealing in cloud seeding. Figure 4, showing the recent funding history

FIGURE 4



ATMOSPHERIC WATER RESOURCES MANAGEMENT
"PROJECT SKYWATER"
FUNDING HISTORY
MILLIONS OF DOLLARS
FISCAL YEAR
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
6.6
6.2
3.9
3.25
4.0
3.454
4.649
4.696
6.446
7.613
5.763
8.605
4.605
7.871
Actual Fund Appropriation
Presidential Budget
Congressional "write-in"
Bureau of Reclamation
Department of the Interior

of the Bureau's Project Skywater, indicates the relative "health" of the Bureau's activities in precipitation augmentation.

According to the Bureau (1979), four main facts about the Colorado River Basin made it an area for consideration under Project Skywater. These were, and still are:

1. It is a dry region and natural precipitation does not yield enough streamflow to meet water demands.

2. Recorded streamflows in recent decades have been less than previous averages.

3. The Colorado River compact and Mexican Water Treaty have apportioned more water than is available.

4. Projects are being planned and built without assurance of future natural water supplies.

In 1968, the Colorado River Basin Project Act of 1968 (Public Law 90-537) was passed by Congress to provide for the further comprehensive development of water resources of the Colorado River Basin and for the provision of additional and adequate water supplies for use in the upper as well as lower Colorado River Basin. Under Title II of this Act, the Secretary of the Interior was authorized to prepare and implement an augmentation plan to meet the water requirements of the new projects created by the Act (Central Arizona Project and Colorado River Storage Project), existing projects and water allotments, and the 1944 water treaty with Mexico.

Augmentation was one of the main issues in the deliberation on the Act. The Act defines augmentation as " 'augment' or 'augmentation' when used herein with reference to water means to increase supply of the Colorado River system or its tributaries by introduction of water into the Colorado River system, which is in addition to the natural supply of the system." The Statement of the Managers on the part of the House with regard to augmentation stated "all possible sources of water must be considered, including water conservation and salvage, weather modification, desalinization and importation from areas of surplus."

The Colorado River Basin Pilot Project (CRBPP) was the Bureau's first major effort on weather modification in Colorado under the auspices of Project Skywater and P.L. 90-537. The purpose of the Colorado River Basin Pilot Project was to provide for scientific and economic evaluation of precipitation augmentation technology and to increase precipitation. The specific objectives to be achieved were (1) to establish and operate a ground-based meteorological network in and near the San Juan Mountains of Colorado to provide data input in the selection of suitable storms for seeding, and (2) to establish and operate a ground-based silver iodide seeding system to increase snowfall in the project target area. The field phase of CRBPP began with the winter of 1970-71 and ran through the 1973-74 operating season.

At about the time of completion of CRBPP in Colorado, the Bureau began funding Project Snowman in Utah. Project Snowman was conducted for the Bureau by Utah State University's Water Research Laboratory. The objective of this four-year project was to develop cold-cloud seeding technology using airborne generators and ground-based generators located in the northern portion of the Wasatch Mountains.

The Bureau's early work on precipitation augmentation in Colorado was based on a fairly extensive background of research activities. Three major research efforts in winter seeding contributed directly to the Bureau's CRBPP project in the Upper Colorado River Basin. These were:

1. The National Science Foundation sponsored research experiments by Colorado State University at Climax, Colorado, during the 1960's.

2. The operational research funded by the State of Colorado during the 1960's at several mountain passes, particularly Wolf Creek Pass in the San Juan Mountains, and

3. The Bureau sponsored experiments in the Park Range near Steamboat Springs, Colorado during the late 1960's.

The results of the Colorado River Pilot Project indicated the need for further verification and improvement in technology before a large augmentation program could be undertaken. Thus, the Bureau's research program continued. Winter experiments were conducted outside of the Colorado River Basin at:

Elk Mountain, Wyoming (University of Wyoming)

Bridger Range, Montana (Montana State University)

Jimenez Mountains, New Mexico (New Mexico State University)

Pyramid Lake Pilot Project (University of Nevada)

In addition, the Bureau continued to provide supplemental funds to Colorado State University's NSF research and to Utah State University's state-sponsored research project. Through the Emergency Drought Act of 1977 the Bureau granted over $2 million to six states for supplemental support of their cloud seeding projects including over $1 million to the States of Colorado and Utah for cloud seeding in the Colorado River Basin.

To complete the development of a cloud seeding technology, the Bureau is currently proposing a program known as the "Colorado River Basin Augmentation Demonstration Project." This program is the direct result of a request in 1975 by the Secretary of the Interior that a program be planned for weather modification in the Colorado River Basin. That same year, the Bureau provided an initial planning paper, "Demonstrating Water Augmentation in the Colorado River Basin and Adjoining Basin by Weather Modification." This paper and the Bureau's report on the comprehensive westwide water supply investigations, containing the Secretary of the Interior recommendation for a demonstration program in the Colorado River Basin, formed the impetus for the proposed program.

The proposed program encompasses four broad phases with reviews and separate decisions between each:

PHASE	ESTIMATED COSTS
1. Planning	\$3.3 million
2. Confirmatory	\$16 million
3. Demonstration	No projection
4. Operational	No projection

The first three phases are essentially research in nature. The Planning Phase was initiated with congressional funding in fiscal years 1978 and 1979. Planning to date has resulted in a conceptual plan (1979). The proposed Confirmatory Phase includes a confirmatory experiment of cloud seeding techniques and associated research of impacts and issues. The Demonstration Phase is a broad-scale water production test and could begin in the late 1980's. Decision on the Operational Phase would depend largely upon results of Demonstration Phase and the future water resources situation. Figure 5 provides a flow chart of the proposed program.

Colorado Program

Personal interviews with Mr. Harris Sherman, Executive Director, Department of Natural Resources, revealed minimal interest, both from the department and the legislature, with respect to research and development or any operational programs in orographic cloud seeding in Colorado. Mr. Sherman feels that conservation of Colorado's existing water supply

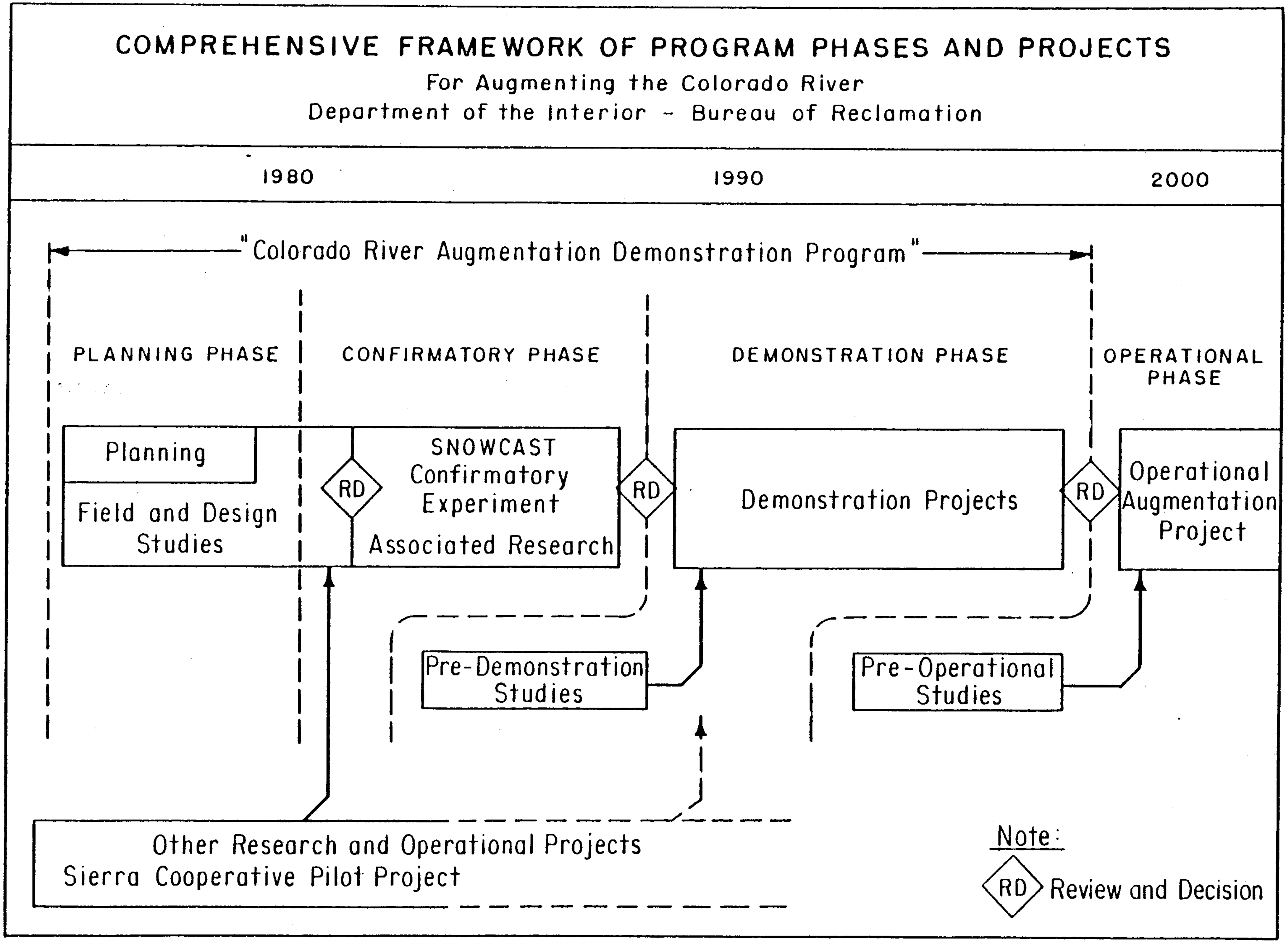

COMPREHENSIVE FRAMEWORK OF PROGRAM PHASES AND PROJECTS
For Augmenting the Colorado River
Department of the Interior - Bureau of Reclamation
1980
1990
2000
"Colorado River Augmentation Demonstration Program"
PLANNING PHASE
CONFIRMATORY PHASE
DEMONSTRATION PHASE
OPERATIONAL PHASE
Planning
Field and Design Studies
RD
SNOWCAST Confirmatory Experiment
Associated Research
RD
Demonstration Projects
RD
Operational Augmentation Project
Pre-Demonstration Studies
Pre-Operational Studies
Other Research and Operational Projects
Sierra Cooperative Pilot Project
Note:
RD Review and Decision

FIGURE 5

should be examined in lieu of new water development such as that produced by orographic cloud seeding. Mr. Sherman gave several reasons for the lack of such interest by the state legislature and the Department of Natural Resources. First, if the cloud seeding actually produces newly developed water supplies, only developed water can, if measurable, be assigned rights according to the corresponding cost and benefits incurred by the producer of such supplies. Otherwise, the augmented water can only be used in existing system to fulfill existing rights[6] or be allowed to flow out of the basin for use by other states. Another problem with cloud seeding in Colorado as well as other states is the down-wind effects. Professor Lewis Grant (Utah's Annual Cloud Seeding Seminar, 1976) gave two important reasons for consideration of down-wind effects: (1) numerous societal and environmental implications exist for areas outside target areas, and (2) application of the technology may provide large area seeding, resulting in lower operating cost and a reduction of complications with traditional seeding techniques. Another problem identified by Mr. Sherman is that of compensation to adversely affected areas. Without some measurement or determination of the direct impact of added snow removal by target area communities or the added inconvenience to miners and cattlemen, payment cannot be made or even determined. Until these questions are answered to the satisfaction of both the state and the affected parties, orographic cloud seeding as a source of new water will remain a low priority tool for water resources planning within the State of Colorado.

Aside from the viewpoints noted above, Colorado, in absence of adequate Federal regulation, operates under the Weather Modification Act of 1972, wherein the Department of Natural Resources acts as a regulatory agency in conjunction with a ten-man advisory committee. The Department's Director is given the discretion to establish such rules and regulations as are necessary to administer the act and is empowered to issue all licenses and permits as specified in that act. It is through this function that the Director monitors projects within the state to further evaluate the research and development of orographic cloud seeding. The Director assured the authors of this paper that every effort is made to regulate cloud seeding contractors and that nothing short of true professionalism is demanded within the State of Colorado. Colorado's regulatory program is discussed later on in this paper.

Funding of weather modification by the state legislature has been relatively small except during drought years, when $300, 000 was provided in both 1976 and 1977.

Utah Program

Utah is somewhat unique in the weather modification field because it emphasizes operational programs. The Utah Division of Water Resources, Department of Natural Resources is the state agency responsible for all cloud seeding activities. Basically, the Division of Water Resources takes the position that cloud seeding is simply a tool to develop more water for Utah residents and has set out to develop a weather modification program that includes operational projects, research evaluation and monitoring studies. Utah's initial willingness to participate in such a program was based on the reported successes of previous out-of-state research and operational programs. The program continues on the basis of "lets do it and utilize the techniques of cloud seeding as research develops them" (Division of Water Resources, 1976).

The Utah law dealing with weather modification was passed in the 1973 Legislature and is entitled Cloudseeding to Increase Precipitation. This law states, "The State of Utah through the Division of Water Resources shall be the only entity, private or public, that shall have authority to authorize, sponsor, and/or develop cloudseeding research, evaluation, or implementation projects to alter precipitation, cloud form, or meteorological parameter within the State of Utah, except cloudseeding for suppression of fog is excluded. The Division of Water Resources shall authorize, sponsor, and/or develop local or statewide cloudseeding projects that conform to over-all state water planning objectives and are determined to be feasible by the Division of Water Resources . . . . A cloudseeding project as used in this Act shall be a planned project to evaluate meteorological conditions, perform cloudseeding, and evaluate results." The law also designates the Division of Water Resources as the regulatory agency for licensing of cloud seeding operators and permitting specific projects.

In terms of water rights the law states, "All water derived as a result of cloud seeding shall be considered as a part of Utah's basic water supply. The same as all natural precipitation water supplies have been heretofore, and all statutory provisions that apply to water from natural precipitation shall also apply to water derived from cloud seeding." According to the Division of Water Resources (1975), this means that in Utah's water right structure, which recognizes priority rights, the extra water goes to fulfill the priority right. When a primary user is fulfilled, the secondary user gets the water, and so on. It does not mean that water derived from cloud seeding can be filed on separately.

In essence, Utah considers the water derived from cloud seeding to be part of the basic water supply of the state and regulated by existing water rights under the jurisdiction of the State Engineer. Further, as a matter of policy, cloud seeding is considered an integral part of the State Water Plan and one way to provide additional water supply to remote areas of the state where expensive physical water conveyance systems would be prohibitive to build.

The first effort at an operational snow enhancement project also began in 1973 and included 12 counties of the southern area of the state--Beaver, Emery, Garfield, Iron, Juab, Kane, Millard, Piute, Sanpete, Sevier, Washington, and Wayne. These counties were members of the Southern Utah Water Resources Development Corporation, a non-profit corporation. In Washington and Sanpete counties, the County Conservancy District was the member agency to this corporation, while the other counties were represented by their respective county commissions. This corporation contracted with North American Weather Consultants of

Santa Barbara, California, for winter orographic cloud seeding in this 12 county area.

In 1975, the counties of San Juan and Tooele joined the Southern Utah group, making a total of 14 counties in the project. San Juan County is represented in this corporation by its conservancy district and Tooele is represented in this corporation by its county commission. Approximately 65% of the total land area of the state is in this one project. The target river basin for this project is the Sevier River Basin and it is noted that the Sevier Basin is a closed river system.

During the 1975-76 winter season, 13 southern and central counties participated in a cloud seeding program. The 1977 drought increased the interest in cloud seeding, and, during the winter of 1976-77, county participation increased to 26 and involved over 90 percent of the land area in Utah. Seventeen southern and central counties participated in the 1977-78 and 1978-79 winter season program. According to Mr. Summers, the cloud seeding program coordinator for the State of Utah (interview 1979), it is feasible that all of the major mountain watersheds in the state will be seeded in the next few years.

In addition to the operational cloud seeding programs, the state is directing a number of research projects. The state through contracts with the U. S. Bureau of Reclamation is conducting an ecological impact study of weather modification, designed to: (1) provide information for use in preparation of an environmental impact statement for weather modification research, (2) formulate and test hypotheses for determining change in regional vegetation with changing snowpack, and (3) recommend monitoring procedures for long-term cloud seeding research in the Upper Colorado River Basin.

A second cooperative project includes field research and design studies within the Colorado River Basin. The objectives of this study are to determine characteristics of natural and seeded clouds in conjunction with the state's winter cloud seeding program, provide design information for planning the Colorado River Augmentation Program, and investigate methods of coordinating research and operational cloud seeding activities.

In addition to the two specific research contracts, the Division of Water Resources has a cooperative agreement with the Utah Water Research Laboratory, Utah State University, for performance of some basic research on cloud seeding. The primary purpose of this agreement is to determine new methods of modifying the clouds and to find techniques for evaluating the results.

The Division of Water Resources does not employ a large staff to administer Utah's weather modification program. Mr. Paul Summer is the coordinator on a 3/4 time basis. A technical advisory committee, however, has been established to guide the state in its decisions. The committee is comprised of representatives from the Forest Service, Bureaus of Land Management and Reclamation, National Park Service, and Soil Conservation Service, and representatives from the state agencies of Agriculture, Extension Service, Water Rights (State Engineer's Office), State Lands, the Director of the Utah Water User's Association, and a statistician from the University of Utah. There are three meteorologists involved, one from the National Weather Service, University of Utah, and one private consultant.

Funding for the Utah program comes from state funds to be cost shared with counties and/or other political subdivisions of the state.

The Legislature appropriated $200, 000 in 1975 and $231, 000 in 1976. The 1975 appropriation was used as follows:

$120, 000	for operational projects, cost sharing	60%
47, 000	for research	24%
25, 000	for evaluation	13%
8, 000	for travel and miscellaneous	3%
$200, 000		

The 1977 Legislature appropriated $390, 000 for cloud seeding and set aside $406, 000 to finance the program in 1978.

In addition, during the 1976-77 drought, interest in cloud seeding technology quickened. Governments ranging from the federal to the country level mobilized cloud seeding projects, not only in Utah, but throughout the Western United States. Congress responded to pleas from the states. It appropriated several million dollars for grants and loans to states for cloud seeding as well as other water supply development programs. Utah received a $500, 000 grant from the Bureau of Reclamation for operational cloud seeding over the state.

Colorado State University Program

Colorado State University has a well known and respected history of research and development of weather modification. Professor Lewis O. Grant and his staff at the Atmospheric and Science Center, Colorado State University, have demonstrated that winter orographic cloudseeding actually increases precipitation 10 to 20 percent. This has been verified many times by carefully designed field and laboratory experiments covering a period of 15 years.

Currently, Professor Grant (interview, 1979) is conducting field experiments in Roosevelt National Forest (winter season only) to confirm previous research results of orographic cloudseeding and to monitor or trace the direction and distance of seeding agents used in cloudseeding experiments. Colorado State University is also a National Testing Laboratory for cloudseeding agents and devices for testing those agents. Unrelated directly to orographic cloudseeding, but interesting from a research standpoint, is the work being conducted for NASA and the Navy. Colorado State University is studying the impacts from burning solid fueled rocket engines such as those currently used on NASA's Space Shuttle. According to Professor Grant, the burning of the aluminum oxide combined with other fuel components has the potential to act as unplanned cloudseeding nuclei similar to the now used silver iodide cloudseeding agent.

Colorado State University's budget for weather modification is attributed to the excellent research ability of the center. According to Professor Grant, the state of Colorado will fund $50, 000 from a total of $70, 000 obligated toward weather modification. Although this amount was seen as good for state funding, it falls far short of the $2, 000, 000 needed annually to conduct and monitor impacts of a reliable research and development program for orographic cloud seeding. Adequate and reliable programs are being taxed more and more because of added monitoring and data collection for societal issues. The issues include social impacts, economic impacts, environmental impacts, legal questions and political aspects from not only Federal and state levels, but from an international context. The bulk of CSU funds for 1979-80 hopefully will come from the National Science Foundation. CSU plans to utilize about one-third of the Foundation's total $900, 000 this year in its research and development of weather modification related work.

When asked about the position Colorado State University takes on the rights to augmented water supplies from orographic cloudseeding, Professor Grant stated that the state of Colorado should start laying claims now to any new water in order to set precedence for future debates.

Utah State University Program

Utah State University has worked with the research and development aspects of orographic cloudseeding for many years. The research being done currently appears small when compared to the research work at CSU. However, when the reader takes into consideration the magnitude of the state's operational program and the potential for data collection and analysis of such a program, the need for large-scale research and development programs is reduced.

In 1976, the Division of Water Resources entered into an agreement with the Utah State Water Research Laboratory, Utah State University, under the direction of Dr. Geoffrey Hill, to conduct cloudseeding research aimed at increasing knowledge of seeding techniques and seedability recognition. This research was funded by the Division of Water Resources, State of Utah, for the amount of $75, 000. In the 1977-1978 winter, the Bureau of Reclamation contracted with the Division of Water Resources to carry out a climatological study over the Uinta Mountains. Part of this contract is development of methods of evaluating winter snowpack augmentation projects. The Utah State Water Research Laboratory was research subcontractor for this project. Funding under this contract was approximately $100, 000.

Other Interest

The Upper Colorado River Commission is an interstate administrative agency created under the terms of the Upper Colorado River Basin Compact of 1948. The Commission represents the states of Colorado, New Mexico, Utah and Wyoming, and the Federal Government. The Commission's purpose is to: (1) assure equitable division of water use according to the Compact of 1948 among the Upper Basin States; (2) to establish obligations of each state with respect to the delivery of water to the Lower Basin; (3) to promote interstate harmony; (4) to remove causes of controversies; (5) to secure the expeditious agriculture and industrial development of the Upper Basin States, the storage of water and the protection of life and property from floods.

Mr. Paul Billhymer, legal counsel for the Upper Colorado River Commission, Salt Lake City, Utah (Interview, 1979), expressed the desire of the Commission for development within the Upper Colorado River Basin. Development of augmented water supplies and economic development are given high priorities within the Commission according to Mr. Billhymer. There is, however, a reluctance to strongly support policies on orographic cloudseeding by the Commission which eminates from two facts. One holdback is the old controversy of "is it water" and if so, how much is augmented stream flow? The second question is, do the states really want the augmented water identified? To carry the second question a little further, as long as no water is identified, then other states and the Federal government have no claims to these augmented supplies and hence it can be utilized by the state augmenting the water so long as they provide their original share to the Lower Basin according to the 1968 compact agreement.

Mr. Billhymer expressed that the Commission lobbies in Congress on behalf of the Upper Basin States in all aspects of increased water supplies and participates in all weather modification meetings concerning the Upper Basin States. From a political viewpoint, the Commission's policy and desires on weather modification are actually those of the various state legislatures since most powers of the Commission flow from the states to the Commission and not vice-versa.

REGULATION

The fact that weather modification can have important external effects suggests that a framework of laws, policies and agency regulations are required to insure that it is employed in those cases where it is in the public interest. At present, the Federal policy on weather modification is essentially one of laissez-faire. The options for weather modification policy are left with various mission-oriented Federal agencies and regulation is left to state government.

Federal involvement in the future, however, may be much more substantial, possibly becoming regulatory. Evidence of this movement by the Federal Government is seen in the enactment of 1976 of Public Law 94-490, the National Weather Modification Policy Act of 1976, and the introduction of two more weather modification bills in the 1977 Congress, which are still pending. The first, H. R. 4069, was introduced by Congressman Evans of Colorado and referred to the House Committee on Science and Technology. This bill provided for the establishment of a comprehensive system for regulation of weather modification activities. The second bill, H. R. 4461, was introduced by Congressmen Sisk and Krebs and referred to the House Committee on Interior and Insular Affairs. It provides for conducting weather modification activities and collecting hydrometeorological information in wilderness areas and other federal land.

On October 13, 1976, President Ford signed Public Law 94-490, the National Weather Modification Policy Act of 1976. It declared as the purpose of the Congress "to develop a comprehensive and coordinated national weather modification policy and a national program of weather modification research and development" and mandated the Secretary of Commerce to "conduct a comprehensive investigation and study of scientific knowledge concerning weather modification technology, the problems impeding effective implementation of weather modification technology, and other related matters." This resulted in the forming of a Weather Modification Advisory Board which on June 30, 1978 delivered its final report, The Management of Weather Resources ("Cleveland Committee Report") to the Secretary of Commerce (1978). The centerpiece of the Advisory Board's recommendation is a 20-year research and development effort aimed at learning more about the atmosphere and adopting a policy stance on weather modification.

Federal Requirements

At present, there are no federal regulatory controls over weather modification activities, although there are rather detailed reporting requirements to coordinate all weather modification activities in the United States. The federal statute requiring reporting of all weather modification activities in the United States or its possessions if found at 15 U.S.C. 330. It deals only with reporting on activities, and does not touch on licensing or permit policies. The Secretary of Commerce is directed to make regulations. These regulations became effective in 1972, and are found at 15 C.F.R. 908. The statute, Public Law 92-205, was enacted in 1971, and amended in 1974 to extend the appropriation for record keeping.

The Secretary of Commerce, through NOAA, is to keep the reports as a record of weather modification activities in the United States and its possessions, and is to publish summaries of this activity at intervals of his choosing. The reports are to be open to the public to the "fullest practicable extent," but the availability of such information is subject to prohibitions of the public release of trade secrets contained in required documents. Confidential information, however, can be made available under certain circumstances. These are public health and safety emergencies, in response to court orders drafted to insure limited access to materials needed for a trial, and transfer of the information between government agencies.

The statute also gives the Secretary the authority to require other records and logs to be kept by weather modifiers or persons having a relation to weather modification activity such as sellers or manufacturers of equipment. Any person who knowingly violates any provision of the reporting requirement, can be fined not more than $10,000 under Section 330d.

An initial report must be filed with the Administrator of NOAA at least ten days before the project is scheduled to begin, must include:

the name of the project if it has one, the date of the first weather modification activity to be undertaken, the expected date of the last activity, the name and address of the hiring party, the intended purpose of the project, maps showing the location of the operation sites and the target areas, the location and nature of monitoring devices, a description of the equipment and techniques used, and the name and address of the person responsible for keeping the logs and additional records of the project. Any environmental impact statement, information regarding long-range forecasts from the National Weather Bureau, and descriptions of precautions taken to protect the operators and the public should be submitted if they are available. Any additional information the reporter wishes to submit may be included.

An interim report is filed as a statement of progress and a description of the work done to date. The information required by the regulations is the total number of days when weather modification took place, and the number of days such activity took place segregated according to the prevailing weather conditions. The interim report must also include the total number of air missions attempted, the total hours of operation for each type of apparatus, the total quantity of each agent of material used, and a general summary of the project for each month it has been in operation.

A final report is submitted to bring the information up-to-date since the last report, and then provides a total for all of the information required in the interim reports.

While there appears to be no specific Federal legislation for regulating weather modification, other Federal environmental legislation may be viewed as picking up the slack in terms of Federal regulation. Weiss and Lambright (1974) as well as Davis (1974) have reported that the National Environmental Policy Act has emerged as a new policy instrument regulating Federal projects in weather modification. In addition, Davis goes on to cite the Wilderness Act of 1964 and the Technology Assessment Act of 1972 as additional regulatory legislation for weather modification.

Of particular interest is the effect of the Wilderness Act. According to the Act, "(a) wilderness in contrast with those areas where man and his works dominate the landscape, is . . . an area where the earth and its community of life are untrampled . . ." . According to Davis, the National Park Service and the U. S. Forest Service have taken a purist approach to the administration of wilderness areas and, in the case of weather modification, assert that it would result in unnatural conditions incompatible with the intent of the Congress.

State Regulation

Both Colorado and Utah have enacted weather modification statutes. In Colorado the statute is the Colorado Weather Modification Act of 1972. The statute was first enacted in 1963, but was repealed, rearranged and re-enacted in 1972. In Utah it is the Utah Weather Modification Act. The first Utah Act on weather modification was passed in 1953. This original Act was repealed and replaced by the present law in 1973,

According to Dewsnup and Jensen (1977) there are some very basic differences between the Utah and Colorado Acts in terms of administration and regulation procedures. Basically, these differences are the result of a difference in philosophy between the two states. Colorado's philosophy is that weather modification is a commercial activity which the law should encourage. Utah's philosophy is that weather modification is a state activity. Dewsnup and Jensen have compared the weather modification law of eight western states by essential categories. The following is a comparison of just the Colorado and Utah statutes from their work.

1. Administrative Agency over Weather Modification

The Colorado statute sets forth the administrative structure in C.R.S. SS36-20-105 through 108. All licenses must be issued by the Executive Director of the State Department of Natural Resources. The Director is empowered to prepare such rules and regulations as he feels necessary to implement the Act. The Governor is directed to appoint an Advisory Committee to assist the Director in the preparation of forms, rules and regulations, and to provide technical information. The Committee is also empowered to hear damage claims and rule on liability when the claims arise from weather modification activities carried out with a valid permit. The Director is empowered to conduct a full range of management chores, including hiring of personnel, contracting for research, holding hearings and so on, and, or course, issuing the licenses and permits.

The Utah statute places all weather modification activity in the State or state agencies. Under U.C.A. S-75-15-3, the supervisory agency is the Division of Water Resources.

2. Licenses and Permits Required

Under the Utah statute, a literal reading would suggest that all weather modification is to be done either by the State itself, or through contract with the State. The only express statutory exception is a provision allowing for fog suppression. Other exceptions have been provided by regulation. Private contractors wishing to take part in state-sponsored projects must register with the administrative agency and meet its requirements.

The procedure for obtaining approval for weather modification operations in Colorado is more involved, since both a license and a permit is required for each operation. The license and permit are required for each weather modification organization and each operation unless there is an exception made by the statute or administrator for research activities by government, universities, or non-profit private organizations, or for emergency situations such as fog, frost, or fire. The exceptions are discretionary, not mandatory, under the statute.

The licenses are valid for a period of one year, and a fee of $100.00 must be paid before the license will be issued. Licenses must have appropriate scientific backgrounds, and must comply with all regulations issued by the administrative agency. The statute requires either eight years of practical experience in weather modification, or a degree in meteorology plus a minimum of two year's experience. If the bachelor's degree is not in meteorology, three year's experience is required.

In addition to the license, which allows persons or organizations to attempt weather modification, a permit must be issued for each operation undertaken by a licensee. Like the license, the permit is valid for only one year and can be renewed. The statutes require that each applicant for a permit have a valid license, pay the permit fee, furnish proof of financial responsibility, demonstrate scientific and economic feasibility, submit plans for the proposed operation, and publish a notice of intent.

3. Financial Responsibility and Limitation on Liability

In general, both states require the applicant to show his ability to respond in damages for injuries resulting from his activities. Colorado allows insurance or bonding to be used to demonstrate financial responsibility. Utah only requires the applicant to be financially able to answer in damages for negligence. Each statute provides that neither the State nor its employees will be liable for the acts of private parties act under a property issued permit. In addition, both statutes place limitations on liabilities by providing that the dissemination of material or the precipitation resulting therefrom is not presumed to be either a trespass or nuisance.

4. Hearings

Colorado requires a hearing on the issuance or revocation of a permit or license.

There is no statutory requirement for hearings in Utah, probably because the statute does not expressly provide for "private" permits, or permits issued to private parties. The State, or state agencies sponsoring a weather modification project, must give notice of intention to the State Division of Water Rights before a project begins. The statute does not require hearings in the area affected by a project.

5. Requirements for Recording and Reporting

Colorado requires records of each operation, and at the minimum it must contain descriptions of the method employed, the equipment used, kinds and amounts of materials used, times and places of operation, and the name and addresses of all participants in the operation. This report is required of all weather modification organizations--even those research groups exempt from the permit and license requirements. All records are to be open to the public, and failure to submit the reports is grounds for immediate termination of the license, permit, or both. Biweekly reports are required during the operation, a preliminary report within thirty days after completion, and a final scientific evaluation within 100 days of completion.

The Utah statute declares that cloud seeding project, by definition, include evaluations of the meteorological conditions before the operation, and an evaluation of the results achieved. The administrative agency is directed to keep records and evaluation of all cloud seeding projects in the State. There is no express provision for public access to this collection of information.

6. Promotion of Research

Both statutes recognize the need for continued research into the processes of cloud formation and weather modification. Little is known about the field now, and the States are trying to generate more reliable knowledge. The required reports of projects aid in the gathering of practical information. Provisions which exempt research organizations from the permit and/or license fees make research projects less costly.

The Utah's statutes, however, directs the administrative agency to sponsor and develop project. The agency is to keep reports on the projects and also on any research which it conducts or sponsors.

7. Penalties for Attempting Weather Modification Without Permit or License

Under the Colorado statute, operating without a permit or license is a misdemeanor, carrying a penalty of $5,000 or six months in jail. The Utah statute makes no penalty provision for persons who violate this most basic element of the statute.

PUBLIC CONCERNS

In their paper, Weise and Lambright (1974) quote Myron Tribus, former Assistant Secretary of Commerce for Science and Technology, "NASA was fortunate in Apollo - there were no people between here and the moon. A scientist can bombard a nucleus with neutrons without asking the permission of the nucleus. But man cannot engineer the environment without consulting the people who will be affected." A major problem for artificial precipitation projects both in terms of scientific interpretation of effects and interaction with user and the public, concerns the modification of processes over the target areas and the effects of the project in off-target areas.

With the advent of the "environmental age" there has developed an upsurge in concern about cloud seeding. Whereas in the past there was skepticism as to whether the weather modifiers could do to the weather what he claimed he could do; now the tendency is to question whether he is not doing much more than he claims. Thus, the impacts of weather modification are being questioned from ecological social and economic viewpoints.

Environmental Impacts

From an ecological viewpoint, clearly if man alters the precipitation regime he can expect certain ecological changes in the associated life community. The problem is determining exactly what the changes are. To date, only modest attempts have been made to collect and organize data on ecological changes that could result from weather or climate changes. One problem revolves around deciding what data are most important. Weather changes can affect everything from wildlife and plants to soil erosion. Each variable is profoundly affected by variables other than manmade weather changes. Another problem is the natural variability in precipitation, which occurs from year to year, making detection of change due to modification activities difficult. A final problem is separating the effects of other of man's activities, such as air pollution, unintentional weather modification and pesticides, which by themselves or in combination with weather modification may be affecting the ecosystem.

In light of these problems and an almost nonexistent data base, the best that can be presented in terms of the general ecological effects of weather modification are the thinking of the few scientists that have worked with the problem. Cooper and Jolly (1969)[7] and Weisbecker (1974) have expressed a number of generalizations concerning the ecological effects of increased precipitation. These will be summarized below (and annotated with the results of some of the current research where possible) to provide some insight into the substance of the problems.

First, it must be noted that in view of the fact that increased snowpack due to weather modification is highly variable and that plant and animal communities change slowly to such environmental alternations. Therefore, the ecological impact will not be sudden or catastrophic. Rather, the changes will be reflected in cumulative year-to-year subtle shifts in rates of reproduction, growth and production of affected species.

The effects of increased snowpack on the aquatic environment range from the direct effects of more runoff to the indirect effects of say, longer and deeper snow cover over mountains, lakes and streams. Weisbecker reports that increased snowpack and its subsequent runoff would tend to shorten low-flow periods, exaggerate peak flows and extend the period of melt-water runoff into late spring or early summer. The ecological implications of these changes in the physical environment could be many, ranging from the actual scouring of aquatic plants and animals from streambeds to affecting the production of the primary producer (algae) or removing detritus from the food chain in upper stream areas. The effect of deeper and longer snowpack on mountain lakes and streams would be to extend the possibility of winter kills of aquatic life. Although this phenomenon has already been documented as an effect of natural snowpack, it is not known if the length of the snowpack is a variable of snow depth or spring temperatures. (Pat Hurly USBR personal interview). These are just a few of the impacts thought to occur in the aquatic environment as a result of increased snowpack. The literature poses many more, all of which are the subject of current research.

Increased precipitation can also have effects on the terrestrial environment. Changes in moisture and temperature regimes as a consequence of increased snowpack, have a direct bearing on vegetation distribution, and in turn on associated wildlife communities. For example, Sternhoff and Ives (1979) report that the initiation of shoot elongation was delayed for plants in tundra and forests as a result of lower temperatures associated with deeper snowpack. The reported effect on the associated wildlife community was a delay in breeding of rodents and a restriction in movement of big game animals. Weisbecker states that one of the effects of increased snowpack resulting from the winter orographic snowpack augmentation project would be a retreat down-mountain of the forest boundary, causing changes in existing wildlife habitat. The train of secondary and tertiary impacts from this primary event reaches from the distribution of pocket gophers to big game survival. Virtually every class of animal in the ecosystem was considered to be affected. The effect on big game was considered of primary importance, since hunting is an important activity in the Upper Colorado River Basin.

In addition to the ecological effects of increased snowpack, the use of silver iodide is also a question of environmental concern. The highly publicized adverse effects of mercury and other heavy metals in the environment have caused concern that similar problems will arise from widespread dispersal of silver due to using silver iodide as a seeding agent. Although additional research is needed, at this time, it appears that this concern is unfounded.

Under normal seeding application rates, silver will be dispersed in very small quantities, on the order of 1×10^{-5} to 2×10^{-4} pounds per acre per year over the target area. In comparison, mercury used as a seed dressing was commonly distributed at four to five times a higher rate (Cooper 1973).

In addition, although the silver will accumulate in the soil, it apparently is not transported to harvestable parts of the plants as other heavy metals are. The biochemical behavior of silver differs significantly from that of other heavy metals. With mercury, for example, the principal ecological problem in not the direct toxicity of the mercury ion, but the ease with which mercury compounds are biologically converted to its toxic form methylmercury. The analogous silver compound, methylsilver, is very unstable to $-60^{\circ}C$ and therefore is not present in the normal environment. Steinhoff and Ives concluded that no deleterious effects (ecological) of silver iodide have been found at concentrations which would be expected due to cloud seeding.

Social Impacts

Of all the impacts of precipitation augmentation, the social impacts are the least understood. This is because an understanding of other impacts and the required social and political adjustments seem to lag the technical progress. While at present the technology has advanced past the "can we do it" stage, it has not reached the "should we do it" stage of social assessment in development. There is no doubt that modification in the atmosphere can have broad sociological effects, both in an intended seeding area, in immediately adjacent areas and potentially inter-active effects on even much broader politically defined areas. From a sociological standpoint, many problems with precipitation augmentation need resolution and at present the technology can only provide guidelines as to the expected effects.

Sewell (1974) for example, states that the social desirability of weather modification would appear to rest on at least four conditions.

1. that the benefits of the technology outweigh the costs;
2. that those who gain from it compensate those who suffer loss as a result of its use;
3. that it provides these benefits more efficiently than other ways of attaining the same objectives;
4. that undesirable alternatives in the environment do not result from it.

In addition, Sewell lists several unresolved important social questions relating to the development of the technology.

1. control of the activity;
2. compensation of those who believe they have suffered losses; and
3. the resolution of international disputes which may arise from weather modification activities.

Other sociological questions may also be seen in the work of Farhar (1974) in assessing the public acceptance of cloud seeding in South Dakota under the South Dakota Weather Modification Program (SDWMP). This study lists the following as key dependent variables in the public evaluation of SDWMP:

1. Attitudes toward weather modification, including favorability of the technology, religio-natural orientation, and importance of weather modification;
2. Belief in the effectiveness of weather modification;
3. Sources of information about weather modification; and
4. Knowledge about the SDWMF.

Finally, some sociological effects can be seen in weather modification attempts which have already created controversies and have generally been unresolved by the legal process. Fischer (1976) identifies several more or less social questions which have come before the courts:

1. Who is liable for floods caused by the modification?
2. What are the relative rights between users and non-users?
3. Are we stealing water from the appropriators in another water basin?
4. Does induced precipitation in one area wrongfully deprive residents in another area of their water?

5. May the one who develops water through weather modification lay claim to those waters?

As can be seen from the above, the social impacts of precipitation augmentation are complex including effects on society itself, effects on its economic structure, effects on the environment and effects on the legal system. Additionally, consideration of extra area or broadscale weather effects particularly complicate the social effects.

Economic Impacts

Economics also addresses the "should we do it" question. A major effort was attempted by the Stanford Research Institute to answer this and other related questions in a Technology Assessment of Winter Orographic Cloud Seeding in Colorado (Weisbecker). The significance of this study is that it was the first real attempt to evaluate economic, social and environmental impacts of winter cloud seeding. Specification of the exact economic value of weather modification to agriculture or any economic sector has been difficult for two reasons: we do not yet know the exact capabilities of weather modification, and few authoritative "what if" socio-economic studies have been made. However, general values, benefits, and costs can be estimated and all point to the fact that the potential economic returns are potentially attractive.

Precipitation augmentation is not designed nor expected to eliminate droughts. However, the value of even relatively small increments of moisture in agriculture and for water supplies may be quite large during most years. Water for agriculture and other purposes can be augmented by increased snowfall in mountainous western areas that subsequently becomes water used in irrigation, power production, and mining. Snowpack enhancement is a relatively inexpensive way to augment water supplies in mountain regions and areas downstream from them. An extensive assessment of the potential enhancement of winter snowpack in the Colorado River Basin considered three water management alternatives (Weisbecker). If no new water resource management facilities were built, the benefits (from a predicted 2 million acre feet of added water) would be $12.8 million. Two other alternatives involving different assumptions about the construction of new water facilities would result in a benefit of $30 million in one case, and in the other, no economic benefits. Additional water from snow augmentation in the western mountains is expected to cost a fraction of 3 cents per cubic meter (about $4.50 per acre feet). Compare this to costs of providing additional water of about 12 cents per cubic meter (about $150 per acre foot) for interbasin transfers of water (Weisbecker).

The essence of basic research is the inability to define precisely all future paths that it may open up; yet the history of science demonstrates conclusively the important economic contribution of the fundamental search for knowledge. Research in weather modification will undoubtedly complement and reinforce other ongoing work to improve weather forecasting.

Both good economics and good politics require the identification of adverse impacts and the development of appropriate policies to minimize them. A number of external economic effects must be considered. One has to do with effects in areas other than the area intended for modification. An example would be a snowpack augmentation program that results in considerably greater snowfall in the cities downwind of the target region. The costs of additional snow removal and disruption of transportation in an urban area may be significant enough to be considered in an overall evaluation of that augmentation effort. A side issue also involves those in the target and downwind areas who benefit but do not pay. One common source of local arguments about cloud-seeding projects is the scientific uncertainty that is bound, in the present state of the science, to surround them. If the experts cannot agree on the probable consequence of a proposal to seed clouds in an area, and if the seeders cannot even prove afterward whether whatever happened would have happened without their assistance, some people are likely to attribute local floods and drought conditions to local cloud-seeding efforts. Many people will opt for a policy of prudence: to leave nature alone.

Of course, as the state of the science approaches reasonable certainty, a new set of problems will emerge in that scientific proof of damage caused by weather events affected by seeding will then be possible. The ensuing conflict will be unavoidable. Rules will then need to be developed to handle the controversies in a socially acceptable manner. Nonetheless, public awareness of, and support for, a strong weather modification program are unlikely without some reason to believe that the payoff is positive and without some understanding of how, where, and for whom the benefits are to be realized.

One attribute of all the types of weather modification is its reversibility, in a technical sense. Once a particular storm is modified, it is not possible to undo the effects on that storm, but there does not appear to be any evidence that storms the next day will be affected. The seemingly independent nature of weather modification is attractive when considered as an alternative for major projects with long-lasting effects (e.g., construction of canals for interbasin water transfers). In addition, present and foreseeable weather modification systems are quite mobile and can be installed or removed quickly and do not require sizable in-place facilities. It is worth emphasizing that the maximum economic benefit which can be realized from technically successful weather modification is bounded by the cost of achieving the same objectives with the "next best" alternative.

Since the full impact of weather modification on society will be felt only after a period long enough for people to adjust to it, continuous economic evaluation must be considered a small but necessary long-term cost of the operation.

Public Participation

A major concern that underlies most others in weather modification is whether the public will have a voice in any of the decisions that determine the extent to which their lives are affected by cloud seeding projects. The approach so far has been to deal with these concerns so that the impacts are felt indirectly or are balanced by offsetting benefits so that a confrontation of the national and regional interest with the local interest can hopefully be avoided. The basis of such an approach is information exchange. The first priority of such an approach is to learn the concerns of the people; the second priority is to inform the public of the facts concerning all cloud seeding projects. An effective information exchange program will lead to normalization of social concerns in which the social attitude is founded on a detailed, sophisticated, and objective understanding of the facts.

According to Paul Summers, Cloud Seeding Coordinator, Utah Division of Water Resources,[8] one of the major challenges of a weather modification program is to convey information to the public about what is happening in each program, particularly in operational projects. The challenge is not only to give them the information, but in a manner which means something to them. The Division of Water Resources uses two tools to convey such information. One tool is Utah's annual cloud seeding seminar; the other main tool is the newsletter. In the Newsletter, Utah prints articles that not only inform the reader, but teach them about the technology of weather modification.

In interviews with the Bureau of Reclamation, the authors of this paper found that most public involvement concerning weather modification activities of that agency was left to the individual states in which the Bureau's projects operate. Such is the case with the Bureau of Reclamation and its Demonstration Project[9] currently planned for the San Juan Mountains of Colorado.

Colorado, in contrast to Utah, uses mainly a public hearing process in conjunction with its permits program for cloud seeding, giving all interested and affected parties a chance to express their concerns and objections at formal hearings.

From all indications, it appears that adequate attention is being given to public participation and the related information dissemination about cloud seeding projects in Colorado and Utah. However, the authors of this paper concede that skepticism still prevails in weather modification both nationally and regionally and earnest attempts must be maintained to win the trust and support of the public in general.

Legal Aspects (from Dewsnup and Jensen)

In a world as crowded and complex as ours, everything we do affects others in some way. Often the impact is harmful or damaging to a person's business, property, relations with others, or even emotionally or physically injurious to him. Most of these negative impacts are minor, and we tend to regard them as the price we pay for living in society. The basic assumption is that the benefits offered by modern life more than outweigh the irritations. However, when negative impacts go beyond the level of common irritation and are the product of conduct that society regards as unreasonable, the legal system ordinarily provides remedies to protect against, or redress, such damage. The law will thus come to the aid of the person who is unreasonably wronged and force the wrongdoing party to compensate the injured party.

Before the injured party can invoke the power of the courts to obtain compensation for his injuries, he must prove to the jury, or the judge in non-jury trials, that the injury he has suffered is one for which the law provides a remedy.

The easiest way for an injured plaintiff to get compensation (damages) from a weather modifier is perhaps on the theory of "strict liability." The availability of this theory for weather modification claims will be determined as a matter of state law. Strict liability is generally applied in cases involving activities that the court regards as ultrahazardous. The test for determining if an activity is ultrahazardous is measured by the risks involved. If the risks of causing substantial harm to others cannot be reduced or eliminated by using even the utmost care, the activity is regarded as ultrahazardous. For example, the use of explosives is generally regarded as an ultrahazardous activity.

As already noted, the classification of an activity as ultrahazardous is a question of state law, and will vary from state to state. It is usually a product of court decisions rather than legislative enactments. How the courts will regard weather modification activities is not yet clear. The first case to come before the courts of each state on this issue will provide the initial precedent. If the damage is minor, the courts probably will not be as willing to declare weather modification ultrahazardous as they would if the damage is extensive.

Sometimes state legislatures have included provisions in statutes dealing with liability or the theories of liability for claims arising from weather modification activities. Most states have not legislated on this specific question, so it will be left to the courts.

Another theory a plaintiff might use is that of "trespass." Traditionally, trespass was the act of interfering with the possessory interest in the land of another. It required some tangible, physical intrusion onto the land without permission. Trespass actually deprives the rightful owner of his possession of the land. There are at least three ways that trespass could be applied to weather modification activities. The first is really the most basic trespassory action, that of entering on the land—in this case, to operate a cloud seeding generator without the permission of the landowner.

The second form of trespass would require more imagination on the part of a judge and jury. The actual precipitation in the form of rain, snow or hail, or the seeding materials themselves, could be held as trespasses if they fall on lands owned by others. In normal operations, the quantity of seeding material is relatively insignificant, but in the case of negligence or an equipment malfunction, some damage might result.

A more difficult problem of trespass is the intrusion into the airspace above land. There is not a definite line drawn at any level of altitude which separates private from public air. The law is still grappling with the problem of airspace ownership, but the line will be drawn somewhere between the lower levels of aircraft flight zones and the height now being used by tall buildings. The significance of airspace trespass in weather modification is in the broadcasting of seeding materials which cross over other people's land on their way into the clouds.

A theory closely related to trespass, yet different, is that of "nuisance." Traditional nuisance law deals with activities which unreasonably interfere with a landowner's right to use and enjoy his property. Nuisance does not deprive the owner of possession, only of use and enjoyment. The policy behind nuisance law is different from that of trespass. Trespass is to recover damages for injury to the land. Nuisance is intended to abate the nuisance, or, in other words, to prevent the interference with the other party's property rights. Because the law is expected to abate nuisances, the courts are careful about what they declare to be nuisances. Given a set of parties who are equally balanced —for example, a group of cloud seeding farmers versus members of a golf club and resort in the same valley—there is a possibility that the seeding could be adjudged a nuisance.[10]

The theory of "negligence" conceivably could be used against weather modifiers, but it is not without problems. Negligence is a form of wrongful conduct. One is said to be negligent if he fails to abide by the standard of care that the "reasonable man" would have observed in the same situation. This works out fairly well for activities the average person is familiar with. The members of a jury use their judgment as to what is reasonable conduct. They would be able to do this in traffic accident cases, but where the activity is of a highly technical nature, they have no way of knowing what reasonable conduct is. In the medical malpractice cases, which are nothing more than negligence cases of a technical nature, the standard of reasonable conduct is set by other doctors who testify as to what they would have done, or would have expected another doctor to have done, in similar circumstances. These other doctors are called "expert witnesses."

The courts have generally used expert testimony in the weather modification cases to determine what the standard of reasonable conduct is. At the present stage in the technology, any attempt to determine what is reasonable is rather difficult. The newness of the science makes it difficult to say whether the conduct of the defendant weather modifier was negligent or not. This is especially true of experimental programs using new technology. Negligence might be easier to prove in other instances, such as seeding clouds during high water periods, or seeding when unusually heavy natural precipitation is expected.

Although there are many types of injuries that could occur, the most common will probably be claims for damages because of precipitation changes. Direct damage from flood or drought are the most likely.

Other injuries, less direct, might be claims such as damage from loss of business because of stormy weather. Other claims could come from such things as avalanche damage, floods, and the increased costs of snow removal from public and private roadways.

To succeed in getting the defendant to compensate him for his losses, the plaintiff must prove to the court that (1) he was injured in a way that the law will recognize and protect, (2) that the injury was the result of some act or omission of the defendant, and (3) that the injury would not have happened if the defendant had not acted as he did.

Proof in injury is not usually a problem. That the plaintiff has suffered some harm is sometimes taken for granted, the only issue is determining how much compensation is due. The other two elements of proof pose serious problems for weather modification suits. Given the disparity of various statistical analyses of weather projects, the plaintiff faces a difficult task in convincing a jury of skeptics that the defendant is really able to make it snow or rain when he endeavors to do so. And then there is the problem of proving that the damage would not have happened anyway. The plaintiff must convince the court that the weather modification project increased (or decreased) precipitation, and if it had not been for that, the flood (or drought) would not have occurred.

Perhaps this is an advantage of the common law system. When a particular technology is new and trying to gain acceptance, the law almost inadvertently gives it a boost by giving the plaintiff a nearly impossible job of proof. As the technology improves, and makes new and better information available, the plaintiffs will be able to use this same information to prove that the weather modification project did play a hand in the damage.

There is another important aspect of liability in dealing with weather modification—the possibility of insurance. So far, because there have been no major damage suits won against weather modifiers, liability insurance rates should not be particularly high. The problem is finding someone to write it. Unfamiliarity with the technology, the small numbers of potential customers, and the lack of data on which to base rates are reasons for the hesitancy. With most states now requiring some showing of financial responsibility on the part of weather modifiers for payment of damages, insurance should be readily available in the near future.

When a plaintiff wins a suit against a weather modifier, he will receive either an injunction or money damages, or some combination of the two. Money damages attempt to restore the injured party to the position he was in prior to the injury, to the extent money can do that. An injunction is designed to prevent the injury from being repeated or continued. It can be so narrow as to prevent the use of certain seeding materials in specific ways, or so broad as to prevent the defendant from engaging in any weather modification activity which will affect the plaintiff's land.

Another remedy now being used in nuisance cases is the payment of "permanent damages" which amounts to the purchase of an easement to pollute the air, or in this case, to broadcast materials, over the land of the plaintiff.[11] This remedy has been used primarily when the balancing of the interests is in favor of continuing the "nuisance," yet the damage to the plaintiff is substantial.

OPERATIONAL CONSIDERATIONS IN THE UPPER COLORADO RIVER BASIN

Weisbecker has suggested that the choice of operating authority appears to be a critical question in the transition of snowpack augmentation from a research to an operational status. Further, he lists a number of legal, institutional and practical considerations which come to bear in making the choice. The authors of this paper have selected three considerations which appear to us to be the major hinges swinging the choice and will attempt to examine them in relation to the Upper Colorado River Basin. Basically, the choice is between the Federal Government and the states. The three considerations are proof of runoff from snowpack augmentation, water demand, and regulatory powers.

Proof of Runoff

Proof of runoff has a bearing on the choice of an operating authority, because the potential for intra- and intergovernmental conflicts and for a direct conflict of interest in determining the amount of augmented water is extremely high. This is particularly true in the Upper Colorado River Basin where institutional arrangements play key roles in the appropriation of the water supply.

Most of the flow of the Colorado River originates from seasonal snowpack in the alpine and subalpine watersheds where winter precipitation amounts are high and evapotranspiration losses low due to colder temperatures. These important runoff-producing snowpack watersheds cover only a small part of the Colorado River Basin. Since these high-elevation watersheds are also on mountain barriers where winter orographic clouds occur, applying weather modification over these small areas to significantly augment the Colorado River becomes a reasonable possibility. The major producing runoff areas are generally above the 9000- to 9500-foot elevation level and have an average winter precipitation of about 22 inches during the October through April period (Table 2). These eight areas and adjoining lower water yield areas are the primary locations for cloud seeding.

TABLE II

Runoff Areas

High Yield Runoff Areas	Area Size (square miles)	Average winter (October-April) Precipitation (inches)	States
Upper Green	1,050	23.0	Wyoming
Uinta	2,250	20.5	Utah-Wyoming
Yampa	1,450	23.5	Colorado-Wyoming
White	1,100	23.4	Colorado
Upper Colorado	3,000	20.7	Colorado
Grand Mesa	450	24.2	Colorado
Gunnison	1,600	21.4	Colorado
San Juan	3,300	24.1	Colorado-New Mex.
Upper Basin	14,200 Total	22.3 Avg.	

Numerous research experiments and evaluations of cloud seeding operations show that important seasonal increases in winter snowfall over mountainous areas can be caused by cloud seeding. In assessing all these studies, the Weather Modification Advisory Board concluded:[12]

> We know that: -- Snowpack, and thus the spring runoff, can be increased by seeding wintertime clouds rising over some mountain barriers -- There is no evidence that increases in rain or snow in one area decreases them in nearby areas.

The combined analysis of several research projects by Vardiman and Moore[13] defined the major characteristics and developed generalized criteria for winter cloud seeding. These criteria provided much of the technical basis for the large operational seeding program in Utah and added to the scientific basis for increased confidence in weather modification.

The estimated seeding effect of 10 to 20 percent should cause an average of 2 to 4 inches more winter precipitation in the Colorado Basin mountains which relates to about 20 to 48 inches more snowfall and generally 6 to 15 inches more snowpack.

The latest and best documented study (as determined by the Bureau of Reclamation) estimating the average annual water augmentation potential for seeding in the Upper Colorado River Basin was conducted by North American Weather Consultants in 1973. The NAWC study estimated the Upper Basin would yield 1, 315, 000 acre-feet with an additional potential of 467, 000 acre-feet outside the Basin and about 298, 000 acre-feet in the Lower Colorado River Basin.

The NAWC study estimate is based on application of watershed models, which include evaporation and other losses, and cloud models to individual storm and rawinsonde data for a 20-year (1952-1971) period. The Bureau of Reclamation reported that this more recent estimate appears most consistent with current physical analyses and evaluations of seeding experiments and can be considered the best and most conservative runoff augmentation potential estimate at this time.

In actual cloud seeding practice, however, the entire augmentationpotential will not be realized due to various suspensions to reduce avalanche and flood risks and lessen possible social and environmental dangers. An average 10- to 20-percent reduction in the augmentation potential should be expected in a responsibly conducted operational application program. Reductions will usually be greater in the heavy snowfall years and less in dry years. Thus, a reasonable average augmentation of about 1, 000, 000 to 1, 200, 000 acre-feet per year in the Upper Basin can be considered, based on current estimates, for determining benefits and use of additional water from cloud seeding.

Professor Lewis Grant[14] reports that streamflow from snowpack increases should be at least comparable to corresponding natural increases in snowfall in various watersheds. The Colorado State University Wolf Creek Pass experiment provided strong, statistically significant evidence of a streamflow increase of about 23 percent during the continuously seeded winter seasons. This amounted to a total of 276, 000 acre-feet of water, of which half was produced in the headwaters of the San Juan River Basin and the other half in the Rio Grande. Based on the changes in precipitation determined to be feasible and the results of this Wolf Creek Pass streamflow analysis, the potential for water augmentation from Colorado watersheds should be of the order of 1.5 to 2.0 million acre-feet per year.

The State of Utah has pretty well put their "money where their mouth is" so to speak, because of the emphasis placed on operational programs. Mr. Paul Summers, Utah Division of Water Resources, Annual Cloud Seeding Seminar, 1976, presented a quote from a document titled "State of the Art in Weather Modification For The Pacific Southwest" which states, "Atmospheric scientists involved in weather modification agree almost unanimously that snowfall can be increased in mountainous regions up to 300 square miles. Estimates vary from 5-30%, but 10% is about the average prediction based on current technology."

One who does not agree unanimously that cloud seeding produces significant amounts of new water is Hubert J. Morel-Seytoux, Professor of Civil Engineering, Colorado State University. Professor Morel-Seytoux, in two papers (1977) has made an independent evaluation of the Bureau's Colorado River Basin Pilot Project using runoff data as recorded by the U. S. Geological Survey and applying techniques of evaluation with "greater power of detection." The assumptions used in the evaluation were (1) runoff is the only integrated and sufficiently accurate measurement of the net beneficial effect of cloud seeding, and (2) runoff from precipitation augmentation in the field would not be very large and would be very difficult to detect in a statistically significant way over short periods of time. The evaluation revealed that for the Colorado River Basin Project (1971-1975) seeding had no effect of statistical significance of appreciable magnitude on runoff in the Colorado River Basin, the intended target area, or in the Rio Grande Basin, an inadvertant target area.

The difficulty of measuring the increases is compounded by the natural variations from season to season, and general changes in the earth's climate. Other factors such as air pollution and heat build-up around cities have an effect on the weather that is as yet unquantified. All of this makes the accumulation of "base data" or the "before" picture very hard to gather for use as a comparison with the "after" picture. Perhaps, in time, a statistical model can be developed which accurately reflects the effects of weather modification.[15]

This problem of "proving the increase" was mentioned earlier with respect to liability, and the same measure of proof must be used to demonstrate that new water is available for appropriation. Eventually, the technology may be developed to a point that definitive and accurate measurement of such increases is possible. But it is not now possible, and a great deal more knowledge must be available before anyone can prove the amount of water that is developed from cloud seeding.

Water Demand

The subject of water demand is relevant to the Federal Government as an operator of a snowpack augmentation program primarily on the basis of long term comprehensive water resources planning and development. In contrast, the state's primary reason for assuming operational authority would probably be from an economic viewpoint. Basically, both interests are based on the question of whether or not there is or will be a shortage of water supply in the river system. In the Upper Colorado River Basin, the question of water supply was addressed in the Upper Colorado River Region Framework Study (1971).

The Framework Study used a 1965-based condition from which to project future development levels in the Basin. In this base condition the total virgin water supply, which assumed no depletions by man's activities was 14.87 million acre-feet annually, based on a hydrographic record period of 1914-1965. Five levels of development defined by on-site depletions of 3.45, 6.55(2), 8.16 and 9.44 million acre-feet were developed by the study. The 3.45 million acre-feet plan represented the present, at that time 1965. The two 6.55 million acre-feet plans represented the year 2020, regionally interpreted OBERS plan,[16] and a state plan where increased agricultural production was the primary on-site depletion. The 8.16 and 9.44 million acre-feet 2020 plans represented two adjustments by the states of on-site depletions primarily to reflect oil shale development.

From these projections, it can be seen that the question of water shortage in the Upper Colorado River Basin is not dependent on the physical availability of water in the Upper Basin, in an average year, but on the question of downstream commitments. Sufficient water is physically available for on-site regional use to 2020 under all plans but, augmentation would definitely be required in the higher development plans if downstream commitment to the Lower Colorado River Basin and Mexico are to be met. It should be noted, however, that the projections are based on the assumption of a continued average annual supply of 14.87 million acre-feet of water. Local shortages in the Upper Basin may occur at any level of development because of variations in precipitation and other climatic influences which have in the past reduced the average annual discharge of the Colorado River at Lee Ferry, Arizona to as little as 4, 396, 000 acre-feet. It also should be noted that the projections do not include the Indian water rights issue which the Bureau of Reclamation (1979) now feels could place additional demands on the Basin's water supply.

Regulatory Powers

Whenever a governmental agency creates administrative machinery to regulate the activities of its citizens, questions concerning the legal and constitutional authority for such regulation are sure to arise. Regulation of snowpack augmentation is no exception.

Finding a basis for power by a state to regulate various weather modification activities is not particularly difficult. Of the powers reserved to the states or the people in the Tenth Amendment of the Constitution, the most significant and sweeping is the police power. This broad power is generally defined as the power to make and enforce laws to protect the public peace and order, safety, welfare, morals, and the general security of the people. While this inclusive power contemplates authority to draft criminal laws, with a little imagination most other laws can be justified as an exercise of the police power, so long as they do not deprive individuals of the constitutional rights or completely deny the use of property without just compensation.

With this background, it is not difficult to understand source of state authority over weather modification activities. When anyone desires to alter or modify the weather, there is the question of risk to health, safety and security. Certainly, it is an appropriate exercise of the police power for State Governments to intervene on behalf of the public at large by regulating such activities. Therefore, the power to regulate clearly exists, and the form of the regulation will depend on how the legislature of the particular state balances the risks and benefits involved in weather modification activities.

Federal authority for regulating weather modification is not as apparent as state authority. The Constitution does not create an express federal power to regulate cloud seeding operations in the same way that it creates a federal power to coin money, for example. Federal authority to regulate weather modification activities must be read into the Constitution as a part of one of the few delegated powers.

Article I, Section 8 of the Constitution provides that Congress shall have the power "to regulate Commerce with foreign nations, and among the several states, and with the Indian Tribes." One's first impression might be that weather modification activities hardly fall within this seemingly narrow power. According to Dewsnup and Jensen, however, broad definitions of commerce have been supplied by the Supreme Court, so as to justify a measure of federal regulation of weather modification as commerce.

In Wickard v. Filburn, 317 U.S. 111 (1942), the Supreme Court held that wheat grown and consumed on the Filburn farm was in interstate commerce despite the admitted fact that it has never left the farm. This apparently illogical result was justified by including indirect and ultimate impacts on interstate relations as being within the definition of commerce.

Finding an aspect of weather modification which has a substantial economic effect on what is normally regarded as commerce is relatively easy. The effects of a drought in the West are felt in higher food prices in New York and California - a significant effect on interstate commerce. Thus, snowpack augmentation in the Upper Colorado Basin which may affect downstream economics, seems to be within the scope of activities that Congress could regulate.

Other, though more limited, sources of federal regulatory power might be noted. The Constitution grants the Federal Government the power to control its own property as it sees fit. Within this federal management power is the authority to regulate the uses of federal land. Such regulations are seen in the national park system, grazing and timber rights on forest lands, etc. Certainly, the ramifications of snowpack augmentation, including erosion and alterations in the vegetation or growing season, are sufficient to enable the Federal Government to regulate or control weather modification activities on or over Federal lands. In the Upper Colorado River Basin this potential for regulatory power may be particularly significant, since nearly two-thirds of the Basin is in public ownership.

The problem of coordinating and accommodating state and federal powers is one of the difficulties inherent in our system of government. It has been the source of almost constant friction between the States and the Federal Government. When there is concurrent state and federal regulatory power, as there is in the area of regulating commerce, and the Congress fails to adopt regulatory controls for certain activities, the states are free to meet the problem as they see fit. This has been the case with weather modification. If, however, Congress were to pass a comprehensive regulatory scheme, it would pre-empt the field and leave the states no room to act (Dewsnup and Jensen).

CONCLUSIONS AND COMMENTS

--The technology of snowpack augmentation is not fully developed.

While scientific research is narrowing the atmospheric aspects of snowpack augmentation, it has only begun to address the larger question of on-the-ground effects.

--The Bureau of Reclamation is consistent with Federal Policy.

The Weather Modification Advisory Board recommends research and development of weather modification over the next 20 years. The Bureau of Reclamation's Conceptual Plan provides for a continuation of Project Skywater and ultimately to an operational program in the year 2000.

--The Colorado and Utah research and development programs in snowpack augmentation are considerably different.

In Colorado, snowpack augmentation is generally considered to be a low priority item in water resources planning except during drought years. In Utah, on the other hand, snowpack augmentation appears to have a high priority status as evidenced by annual funding, a statewide operational program and an executive position within the staff of the Division of Water Resources.

--The reversibility of short term impacts adds acceptability to operational programs.

While long term impacts remain under study and public reaction remains fickle, the short term impacts are protected by an "on-off" technology with a relatively low fixed cost and state monitoring and regulation mechanisms.

--The effect of state regulation of weather modification in Colorado and Utah is to make weather modification a state activity.

While Colorado's rules and regulations are designed to encourage private development of weather modification, the extensive requirements of the rules and regulations has reduced the number of private operators in the state to only those with previous state endorsements. Utah's rules and regulations simply state that weather modification is a state activity.

--The choice between Federal or State control of an operational snowpack augmentation in the Upper Colorado River Basin will probably not be made until there is a perennial shortage of water in the Basin.

Without a water shortage to stimulate discussion of the vested interest of each water manager in the Basin, the issues of "developed water" and regulatory powers will remain, for the most part, academic. However, experimental snowpack augmentation programs in the Basin may drive the day of reckoning between the states and Federal interests to a nearer future.

--Snowpack augmentation has a definite future in Colorado and Utah.

The Bureau of Reclamation states in its conceptual plan that the water supply of the Colorado River should be augmented within the next two decades or shortages and increased salinity will likely occur. Colorado, however, has taken a somewhat wait-and-see approach while Utah plows ahead, reaping operational present and future benefits.

FOOTNOTES

[1] Taubenfield, Howard, Weather Modification and the Law.

[2] Framework commonly used in Technology Assessment Literature.

[3] Rasmussen, 1968.

[4] Jones and Leaf, Generalized Criteria for Verification of Water Developed Through Weather Modification.

[5] From Operational Modification Prospects by Wayne C. Decker, Weather Modification Technology and Law.

[6] This is the stance Utah has taken with its operational program, no new water is identified for development, it becomes part of the existing supply and is used to fulfill existing rights.

[7] Selle, 1974.

[8] Utah Division of Water Resources, Annual Cloud Seeding Seminar, 1976.

[9] "Conceptual Plan to Develop Water Augmentation by Weather Modification in The Colorado River," Bureau of Reclamation, 1979.

[10] There seems to be some question about the court's rejection of expert testimony when the experts could not agree among themselves. The interest here is that the court issued an injunction against the modifiers, ruling that their activities were a nuisance.

[11] This is similar to "flood" or "flowage" easements now used by government agencies along waterways, in reality it becomes a nuisance payment to land owners for flooding their lands.

[12] Cleveland Committee Report, 1978.

[13] Vardiman and Moore, Generalized Criteria for Seeding Winter Orographic Clouds, 1977.

[14] Grant and Danielson, Augmentation and Conservation of Water Resources, 1976.

[15] A greatly improved statistical model is currently under development by Professor Lewis Grant, C.S.U.

[16] Office of Business Economic Research Service.

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