WEATHER MODIFICATION FOR PRECIPITATION AUGMENTATION AND ITS POTENTIAL USEFULNESS TO THE COLORADO RIVER BASIN STATES

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Executive Summary

This paper provides a brief background of weather modification, information on existing programs and current issues, and provides recommendations for the Colorado River Basin States (Basin States) involvement or support of precipitation management through weather modification efforts.

The purpose of winter cloud seeding to increase snowfall in mountainous areas is to increase runoff for hydroelectricity and water supplies for downstream areas. Increases in precipitation can improve soil moisture, stream flows, and reservoir levels. More water storage in reservoirs can allow for increased power generation, irrigation, and municipal and industrial use. Recreation, water quality, salinity reduction, fisheries, forest health, sensitive species, ranching, and tourism can all benefit from additional runoff.

Members of weather modification organizations, public agencies, and private sector companies believe that cloud seeding has reached the point that a well managed program including a proper design component can be implemented to produce cost-effective water resources benefits. More research on the specific cause and effect relationship between cloud seeding and additional water on the ground should be conducted as well. Any proposed operational cloud seeding program should include a strong evaluation component.

It is estimated that cloud seeding six major runoff-producing areas within the Colorado River Basin could produce between 1.1 and 1.8 million acre-feet (maf) in the Upper Basin (approximately 10% of the average annual stream flow) and an additional 830,000 acre-feet in the Lower and adjacent basins. Of the total, it has been estimated that approximately 1.7 maf would be available to reduce deficits and meet new demands.

Although there is wide discussion regarding the effectiveness of weather modification since it began in the 1940s, proponents of ongoing projects believe programs in Utah have resulted in precipitation increases between 7 and 20%, at costs of less that $20 per acre-foot, which compares favorably with traditional water resources projects. The programs currently in operation in Colorado and Utah demonstrate the success of weather modification (WxMod) activities there. Ski areas, water authorities, and agricultural users are the most common project sponsors.

There are several good reasons for the Basin States to continue its research on this topic. One of the most important is the 2000-2004 Colorado River drought, which is a normal part of the climate of the arid Western United States and Colorado River Basin. Others are a general trend toward reduction in snowpack, increased water demands, as well as the growing concern about reductions in precipitation due to inadvertent anthropogenic modification to weather (air pollution). Factors to consider in deciding how to proceed are that: new projects take 1-3 years to plan; planning is relatively inexpensive; there is a real need for research and project funding; these projects are very cost-effective, and there are existing programs with data that can be leveraged.

This paper recommends:

- further investigation continue as to the availability of WxMod projects in which the Basin States can participate, particularly those focusing on the Upper Basin States of Colorado and Utah;

- legislation continue to be monitored, and attempts to influence legislators be considered;

- an implementation plan be developed with next steps, including a schedule, costs, and deliverables for a feasibility study to increase winter precipitation that would include both operational and evaluation components;

- the Basin States enlist either the U.S. Bureau of Reclamation (Reclamation) and/or the National Oceanic and Atmospheric Administration as the lead federal agency in the development of a coordinated national research program, and that this program should piggy-back research onto existing and proposed operational programs like Reclamation's Weather Damage Modification Program;

- cost-share with Reclamation in an objective impartial evaluation of existing operational programs, and;

- for an interim period while the feasibility study is being prepared, expand ongoing operational programs by adding generators and by operating the programs for an expanded period of time each year, including those shown in Table 1.

The additional precipitation can help the Basin States potentially increase water supply in the Colorado River basin, and assist in reducing shortages, or reservoir storage recovery. WxMod should be a standard tool, similar to implementing conservation measures or storing and withdrawing water in groundwater basins for water resources managers to meet demands and assure reliability.

I. INTRODUCTION

Background

There is an ongoing debate as to the efficacy of cloud seeding as a means of precipitation enhancement. Although much money has been spent over decades in support of cloud seeding to increase precipitation, science has been able to conclusively demonstrate strong evidence of which seeding techniques produce positive effects in only a limited number of weather situations. In the over half-century since cloud seeding demonstrations began, substantial progress has been made in understanding the natural processes of weather. Some voice concern that the scientific challenges of proving seeding effects have been found to be significantly more formidable and complex than initially perceived and proof is elusive (National Research Council (NRC), 2003). However, many others believe that despite the difficulty in objectively quantifying the absolute values of seeding effects, it has been established that certain aspects of the weather, specifically cloud microphysical and precipitation processes, can be intentionally modified with beneficial effects and without detrimental environmental effects. The large body of positive indications reported by many (Weather Modification Association (WMA), 2004) references in this paper, as well as a multitude of analyses in the literature constitute a collective positive signal. The overarching premise of this paper is that cloud seeding does work, but both sides of the argument are provided here for consideration by decision makers.

There are several reasons why WxMod has been pursued: fog and stratus dissipation; hurricane strength reduction; lightning reduction, hail suppression, and precipitation augmentation. This document focuses on the use of winter orographic WxMod for precipitation enhancement to augment water supply.

History

The first laboratory and field experiments by Vince Shafer, Irving Langmuir, and Bernard Vonnegut began in the mid-1940s and were known as the "Cold Box" experiments. There was much enthusiasm and the positive results from cloud seeding and the potential for producing rain were widely distributed. The combination of excited scientists, an interested media, and a receptive populous resulted in a worldwide commercial industry focused on cloud seeding, and an era of great interest among scientific organizations and government. By 1951, weather modification programs were operating in about 30 countries.

Wild claims of effectiveness led to differences in opinion as to the economic benefits of cloud seeding and Congress held hearings on the matter between 1951 and 1953. It was learned that millions of dollars were being spent annually by farmers, utilities, ranchers and other users on weather modification activities covering approximately 10 percent of the nation's area. As a result, the Advisory Committee on Weather Control was established by an Act of Congress of August 13, 1953.

Users were so interested in results that, for commercial operators there was no room for randomization or scientific method. As a result, rigorous proof of a seeding effect in the commercial cloud-seeding projects was not pursued. Even today, the words "weather modification" and "cloud seeding" are met with some skepticism.

In the late 1950s, some projects were developed with support of governmental agencies and although the experiments (e.g., the Missouri Project, Whitetop) ran for several seasons, the results were mixed. None of the experiments provided incontrovertible evidence that seeding was effective. Even in 1964 after many more projects were completed, the National Research Council (NRC) concluded that precipitation from orographic storms would not be increased significantly by seeding and that eventually relevant processes could be understood and usefully applied. "The timescale required for success may be measured in decades" (NRC, 1964). An NRC report in 1966 presented results with an "indication of positive effect." In general, the authors of the time found that cloud seeding experiments had not yet provided the evidence required to establish scientific validity, though the prospects were promising and worth pursuing.

One of the references for this paper is *Critical Issues in Weather Modification Research* prepared by the National Research Council of the National Academy of Sciences in 2003 (NRC Report). To paraphrase the 2003 report, the Committee on the Status of and Future Directions in U.S. Weather Modification Research and Operations finds little reason to differ from the findings of the 1964 and 1966 studies. This is due in part to the lack of concerted research in weather modification. In the three decades since the last NRC report there have been improvements in the understanding of cloud processes and significant development in tools and techniques, including remote sensing and computing. These improvements, plus new methods for physically evaluating the impacts of cloud seeding, mandate a fresh look at the status and potential of weather modification.

There are, however, others that do not subscribe to this point of view. List (2005) reviews the NRC Report and finds it flawed in several ways. He submits that the level of accuracy of experiments that WxMod researchers face is higher than that of all other meteorology and atmospheric physics disciplines, which he calls a double standard. Other criticisms of the NRC Report include: the use of old, outdated and misleading criteria; lack of specific criticisms of the science; no discussion of the role of statistics; and the lack of identifying the progress and achievements made in recent decades. The Weather Modification Association takes issue with the NRC Report as well, and its perspective is presented in the section below under Policy Statements.

Meanwhile, numerous short and long-term operational seeding programs have been ongoing with program proponents claiming meaningful, measurable results. These operations programs are described in Section II below.

Authority

What follows is a brief description of the major authorities that have been enacted for this subject matter. There are dozens more for the individual states, but this provides an overview of how this subject has been of interest to Congress for decades.

<u>The National Weather Modification Act of 1976</u>. The National Weather Modification Act of 1976 (Public Law 94-490), directed the Secretary of Commerce to develop a comprehensive and coordinated national policy on weather modification and recommended a national weather modification research and development program. The motivation for this legislation was a severe drought in Kansas and annual damage to property and crops caused by severe weather. It was recognized that all the ongoing weather modification activities were not realizing their potential to mitigate such effects. The Secretary of Commerce was directed to prepare a study on the state of scientific knowledge of the atmospheric processes, research needs, economic studies, and funding issues. The study was to be completed in one year and $1 million was appropriated to carry it out. The author could not find a reference to this report being completed.

<u>Colorado River Basin Project Act of 1968</u>. The Colorado River Basin Project Act of 1968 (Public Law 90-537) directed the Secretary of the Interior (Secretary) in Section 102(a) "... to provide a program for the further comprehensive development of the 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 the Lower Colorado River Basin." Under Title II, the Secretary is authorized to prepare an augmentation plan to meet the water requirements of new projects, existing projects, current water allotments, and the 1944 Water Treaty with Mexico.

Section 202 of Public Law 90-537 recognizes a national obligation to annually provide 1.5 million acre-feet of water, together with any associated losses of water from the Colorado River, to meet the requirements of the Mexican Water Treaty. Section 202 also states that "The Congress declares that the satisfaction of the requirements of the Mexican Water Treaty from the Colorado River constitutes a national obligation which shall be the first obligation of any water augmentation project planned pursuant to Section 201 of this Act and authorized by the Congress."

<u>Colorado River Basin Salinity Control Act of 1974</u>. The Colorado River Basin Salinity Control Act of 1974 (Public Law 93-320) authorized and directed the Secretary to proceed with a program of works of improvement for the enhancement and protection of the quality of water in the Colorado River. Section 101(c) states that replacement of the reject stream from the Yuma desalting plant and of bypassed Wellton-Mohawk drainage water is "recognized as a national obligation as provided in Section 202 of the Colorado River Basin Project Act." As stated in Section 202, augmented streamflows resulting from cloud seeding would result in decreased salinity concentrations in the Colorado River Basin, and could provide a source of replacement for the Yuma desalting plant reject stream.

Reclamation States Emergency Drought Relief Act of 1991. The Reclamation States Emergency Drought Relief Act of 1991 (Public Law 102-250) authorized the Secretary "to conduct a Precipitation Management Technology Transfer Program to help alleviate problems caused by precipitation variability and droughts in the West, as part of a balanced long-term water resources development and management program." Section 206(b) states that "in consultation with State, Tribal, and local water, hydropower, water quality and in stream flow interests, areas shall be selected for conducting field studies... to validate and quantify the potential for appropriate precipitation management technology to augment stream flows." Upon successful completion of such a program, validated technologies will be "transferred to nonFederal [sic] interests for operational implementation." The 1991 Act was the authorizing legislation for the Weather Damage Modification Program, described in a subsequent section.

Weather Modification Research and Technology Transfer Authorization Act (S. 517) K.B. Hutchison, (R-Texas). On March 3, 2005, Senator Hutchinson re-introduced a bill that is identical to the weather modification bill she introduced in the last Congress. The Act would develop and implement a comprehensive and coordinated national weather modification policy and a national cooperative Federal and State program of weather modification research and development. The work would be accomplished through the Department of Commerce Weather Modification and Advisory Research Board. The duties include promotion of research and development, providing financial assistance, and biennial reporting. The legislation would authorize $10 million for 10 fiscal years. There has been no movement on the bill since its introduction, and her staff is working to get at least some of the provisions of this bill incorporated into the Senate's version of a NOAA authorization bill, which is again making its way through the legislative process. A copy of the bill may be found in Appendix A.

Weather Modification Research and Technology Transfer Authorization Act of 2005 (HR. 2995). On June 20, 2005, Rep. Udall (D-Colorado) introduced this companion bill to S. 517, which also seeks to develop and implement a comprehensive and coordinated national weather modification policy and a national cooperative Federal and State program of weather modification research and development. The House and Senate bills are nearly identical.

The Primary Winter Cloud and Precipitation Process

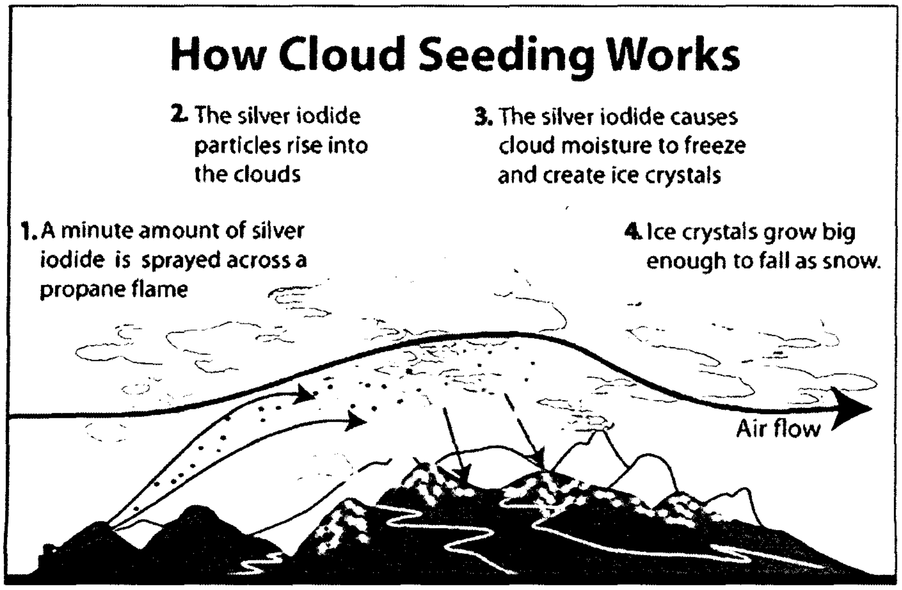
Because there is strong evidence that wintertime seeding for snowpack augmentation works and because the high mountains in the Colorado River Basin provide excellent seeding targets, only winter seeding will be addressed here. In general terms, winter cloud seeding attempts to mimic natural snow production processes in clouds that are inefficient in producing ice crystals and snowfall. During winter storms, moist air is forced to ascend over mountain ranges by prevailing winds (orographic ascent). This upward movement causes the air to cool. The rising and cooling of moist air results in water vapor condensing into droplets to form a cloud. The rate of production of liquid water is determined by the air's temperature, humidity, and upward motion. The tiny cloud water droplets have insignificant fall speeds so they are suspended in the airstream. If not converted to snowflakes while continuing to rise over the mountain, the droplets quickly evaporate because of downward motion on the lee side of the mountain range. Figure 1 is a generalized depiction of the primary process.

Cloud droplets often remain in the liquid state at temperatures lower than 32 degrees Fahrenheit because of a scarcity of effective ice forming nuclei in the atmosphere. These droplets are called supercooled liquid water (SLW). When effective ice forming nuclei are present, ice crystals form. After formation, the crystals grow from available water vapor. As they fall they collide with SLW droplets that freeze onto them, creating larger crystals. The process continues as the larger crystal falls faster and grows larger into a snowflake. This process is most effective in deep clouds and must occur before reaching the crest of the mountain range. In situations where natural ice nuclei are too scarce to efficiently convert the supercooled liquid water into snow, seeding can assist the conversion process.

There is no doubt that the most commonly used agent, silver iodide (AgI), released into sufficiently cold SLW clouds, will produce multitudes of embryonic ice particles. The same result is achieved when liquid propane is expanded into even slightly supercooled liquid clouds. The challenge is to create seeding-induced ice particles at such locations that their subsequent trajectories will be within SLW clouds for a sufficient time (distance) to permit growth to precipitation sizes (WMA, 1999).

Technical advances have increased the capability to augment precipitation in higher temperature and shallower orographic cloud systems. Numerical modeling has improved understanding of atmospheric transport mechanisms. Improvements in computer, radar, satellite, and communications systems have resulted in better assessments of cloud seeding potential and more effective dispersion of seeding agents from properly positioned cloud nuclei generators. Sensors such as radiometers that continuously monitor SLW amounts greatly improve the chances of successful seeding.

Figure 1 – Primary Winter Cloud and Precipitation Seeding Process



Agencies and Programs

This section provides a description of the agencies that have, currently do, or may participate in WxMod activities. For those agencies that do have ongoing programs, the program is briefly described.

Bureau of Reclamation. The need for additional water in the Colorado River Basin has been recognized and studied for many years. As stated above, the Secretary through the Bureau of Reclamation (Reclamation) is specifically charged with the responsibility for development of the water resources of the Colorado River Basin. Reclamation has the longest history of any Federal agency in WxMod research, dating back to the 1960s. A number of options have been considered to provide additional water supplies for the Colorado River Basin. These options include importation, desalination, evaporation suppression, vegetation management, and precipitation management (weather modification by cloud seeding). Of all the options, precipitation management appears to be one of the most cost effective and economical means of providing additional fresh water supplies. Cloud seeding technology, when properly applied, appears to have the potential to increase winter snowpack in the mountainous areas of the Colorado River Basin (U.S. Department of the Interior (DOI), 1993).

Weather Damage Modification Program (WDMP). WxMod research has been in significant decline since the 1980s. This decline was briefly interrupted in fiscal year 2002, when Congress authorized funding of the WDMP and specified that it be administered by Reclamation. The primary goal of the program is to "improve and evaluate the physical mechanisms... and to enhance water supplies through regional weather modification programs..." There was no funding for this program beyond fiscal year 2003. In order to participate, states were expected to match federal funding and piggy-back their research on existing operational weather modification projects. The WDMP received a total of $2 million in federal funds over two years and some significant research has been accomplished by the seven states involved. The program provides an excellent model of federal/state collaboration and funds – leveraging that can apply to the national cooperative federal and state program proposed in the House and Senate (see above).

The individuals managing this program presented a paper at the January 2005, 16th Symposium on Planned and Inadvertent Weather Modification at the 85th American Meteorological Society Annual Meeting in San Diego (Symposium). They expect the WDMP to conclude in early 2006 in the absence of further funding, from either federal sources or non-federal partners. Final reports from three WDMP states have been completed and are available from Reclamation. A copy of the four page paper (Hunter, 2005) given at the Symposium may be found in Appendix A.

Colorado River Enhanced Snowpack Test (CREST). The CREST was planned to operate for eight years but was not implemented because of declining federal support of WxMod research and some wet years in the late 1980s and early 1990s. The program was designed to significantly improve the scientific basis for increasing winter mountain snowpack in the Colorado River Basin. The objective was to obtain scientific proof that properly conducted seeding of winter orographic clouds in the Colorado River Basin will beneficially and cost-effectively enhance snowpack and subsequent runoff without deleterious effects to the environment. The program was designed to produce results in the shortest time, for the least cost, and with the highest probability of success. Its total cost was estimated at $70 million (1993 dollars). See Department of the Interior, 1993[1] for a detailed plan for CREST.

The original CREST envisioned physical and statistical evaluations conducted at two sites in the Basin – the Grand Mesa of west-central Colorado and the Wasatch Plateau of central Utah. The program was designed in two phases – the first emphasized physical process studies and direct snowfall measurement (3 years); the second was seeding with statistical modeling (4 years), preceded by one year of environmental compliance and project planning. The hypothesized result after cloud seeding all suitable storms was an estimated 10 to 15% increase in seasonal snowfall, resulting in a similar increase in streamflow. In 1993 the State of Colorado declined to participate in the test, and it did not move forward as proposed.

Some seeding trials were conducted on winter clouds over the Grand Mesa and there was a repeated indication of precipitation increases in response to seeding. However, the work did not include a statistical component for evaluation of precipitation so the increases are not certain. Reclamation then did some work on the Mogollon Rim in Arizona for two winters. After that some of the federal funds were transferred to the National Oceanic and Atmospheric Administration which did some additional seeding on the Wasatch Plateau. Finally, remaining funds were used for the North Platte River Basin Headwaters Project, which demonstrated promise for recently developed technologies; unfortunately that river is not in the Colorado River Basin. Nevertheless, some of the lessons learned are still applicable and were used in a recent feasibility study. (DOI, 2000).

<u>National Oceanic and Atmospheric Administration (NOAA)</u>. From 1986 through 1995, the NOAA Federal-State Atmospheric Modification Program funded weather modification research in six states, at a level of about $500,000 per year per state. The funding was used for research components, and was split between winter orographic and warm season programs and included cloud seeding experiments using both silver iodide and liquid propane. The breadth of the research was significant and several advances related to winter orographic cloud seeding are worth noting. In Arizona a new polarized radar technique was used to track the dispersion of airborne seeding plumes and the evolution of seeded ice crystals in naturally precipitating clouds. Seeding trials using ground releases of silver iodide and propane on the Wasatch Plateau of Utah produced considerable direct evidence of ice crystal and snowfall enhancement. In Nevada and California a new dual-tracer chemical technique was developed to assess the impact of seeding on winter snowpacks. Several state projects used numerical models, verified by observations, to study the transport and dispersion of seeding material over mountainous

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[1] p. 19

terrain. The results of these studies were published in numerous peer-reviewed journal articles.

Weather Modification Policy Statements

North American Interstate Weather Modification Council (NAIWMC). The NAIWMC is a non-profit, tax-exempt organization of regulatory agencies, sponsoring organizations, and research institutions involved in atmospheric water resource management technology. The NAIWMC is comprised of nine western state representatives and exists to facilitate the free exchange of information regarding cloud seeding research and operations in North America. The group meets twice a year. Members describe the status of their projects and work together to influence policy makers.

With regard to precipitation enhancement, the primary recommendation by the NAIWMC, with which the NRC agrees, is that future efforts should capitalize on existing field facilities and partnership development among research groups and select operational programs. This is a group that focuses on the scientific aspects of cloud seeding, speaks for the public agencies and states which it represents, and believes that cloud seeding works.

Western States Water Council. The Western States Water Council is an organization consisting of representatives appointed by the governors of 18 western states. Since its creation, through adoption of a resolution at the Western Governors' Conference in 1965, the Council has strived to fulfill its chartered purposes. The purposes of the Council are to: (1) accomplish effective cooperation among western states in the conservation, development and management of water resources; (2) maintain vital state prerogatives, while identifying ways to accommodate legitimate federal interests; (3) provide a forum for the exchange of views, perspectives, and experiences among member states; and (4) provide analysis of federal and state developments in order to assist member states in evaluating impacts of federal laws and programs and the effectiveness of state laws and policies. In July, 2005 the Western States Water Council, adopted a resolution supporting enactment of the Weather Modification Transfer Act of 2005, and supporting continued funding for the federal WDMP.

Weather Modification Association (WMA). The WMA is an association of scientists, engineers, economists, water management professionals, government and private business people, and others who have spent their careers working in the field of weather modification. This group is primarily composed of people in the business of weather modification, for example vendors, industry, and private business interests.

The WMA prepared a response (WMA, 2004) to the NRC Report, a summary of which follows. The WMA does strongly support the NRC Report recommendation for randomized, statistical experiments along with the necessary physical measurements and modeling support to reduce the many uncertainties that exist in the science of weather modification. The WMA believes that a coordinated national program should include exploratory and confirmatory field studies, should capitalize on operational programs and use them as a basis for testing models, and develop new statistical methods for evaluating the efficacy of those operations. However, the WMA believes that there is convincing scientific evidence of positive effects[2], and the NRC authors "had very limited experience or knowledge in weather modification operations."[3] Other areas of concern were that the NRC committee had no members from the WxMod operations community, lacked depth in research, lacked expertise in hail suppression, orographic seeding, and the modeling of seeding effects.

The primary topic with which the WMA takes issue relates to the difficulty in quantifying the absolute values of seeding effects. They disagree with the NRC's conclusion regarding lack of scientific proof that cloud seeding produces desired results. They argue that the NRC's standard of proof is so high that research associated with few atmospheric science endeavors could satisfy it, and that there is a logical inconsistency. The WMA points out that arguments for both global climate change and inadvertent weather modification both fail that level of proof, yet the NRC acknowledges that both of those processes are realities. On the other hand, the efficacy of cloud seeding is questioned. The WMA also believes, unlike the NRC panel, that it is not premature to initiate large-scale operational projects.

American Society of Civil Engineers (ASCE). In May 2003, the ASCE adopted Policy Statement No. 275, which supports and encourages the protection and prudent development of atmospheric water (also known as weather modification or cloud seeding) for beneficial uses. Sustained support for atmospheric water data collection, research and operational programs, and the careful evaluations of such efforts including the assessment of extra-area and long-term environmental effects, is essential for prudent development. ASCE recommends that the results and findings of all atmospheric water-management programs and projects be freely disseminated to the professional community, appropriate water managers and the public. The ASCE has published a Cloud Seeding Manual (ASCE, 1995).

American Meteorological Society (AMS). In January 1992, the American Meteorological Society adopted a policy statement with regard to Planned and Inadvertent Weather Modification. The AMS indicated that there is considerable evidence that, under certain conditions, precipitation from supercooled orographic clouds can be increased with existing techniques. Statistical analyses of precipitation records from some long-term projects indicate that seasonal increases on the order of 10% can be realized, however the cause and effect relationships have not been fully documented (AMS, 1992).

World Meteorological Organization (WMO). In their latest WxMod status statement (2004), the WMO states that "Improved observational facilities, computer capabilities, numerical models and understanding now permit more detailed examination of clouds and precipitation processes than ever before, and significant advances are consequently possible." Also, "...it is considered that the glaciogenic seeding of clouds formed by air

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[2] WMA, 2004, p. 8

[3] WMA, 2004, p. 3

flowing over mountains offers the best prospects for increasing precipitation in an economically-viable manner." Among their recommendations:

- Operational cloud-seeding projects should be strengthened by allowing an independent evaluation of the results of seeding. This should include measurements of physical response variables and a randomized statistical component;
- It is essential that basic measurements to support and evaluate the seeding material and seeding hypothesis proposed for any weather modification experiments be conducted before and during the project, and;
- Weather modification programmes are encouraged to utilize new observational tools and numerical modeling capabilities in the design, guidance and evaluations of field projects.

II. CURRENT ISSUES

Purpose and Need

Many believe that WxMod technology has developed into an effective and economic tool for increasing water yields. Cloud seeding is most effective under normal or near-normal weather conditions; but the benefits during dry years cannot be ignored. The technology is best used as a long-term water management tool rather than an activity to be undertaken during drought. During droughts there are few clouds suitable for seeding, and during wet winters there is enough precipitation so seeding operations would not be necessary. Drought is a normal part of the climate in the arid Western U.S. and Colorado Basin, and research using tree ring data has shown that far more severe and lengthy droughts have occurred than the one of the last six years (U.S. Geological Survey (USGS), 2004). In the last century (1925-2000), there have been widespread declines in mountain snowpack of western North America, particularly since midcentury (Mote et al., 2005) The authors of this investigation point to several climate studies suggesting that this trend will continue and even accelerate. Perhaps the foremost concern is that, even outside of drought periods, the consumptive use of water in the West continues to grow rapidly, largely to explosive urban growth. This situation has already caused major water conflicts and is expected to worsen in the coming years unless significant action is taken (DOI, 2003). While snowpack is declining, demand for water is increasing.

The purpose of winter cloud seeding to increase snowfall in mountainous areas is to increase runoff for hydroelectricity and water supplies for downstream areas. Increases in precipitation can improve soil moisture, stream flows, and reservoir levels. More water storage in reservoirs can allow for increased power generation, irrigation, and municipal and industrial use. Recreation, water quality, salinity reduction, fisheries, forest health, sensitive species, ranching, and tourism can all benefit from additional runoff.

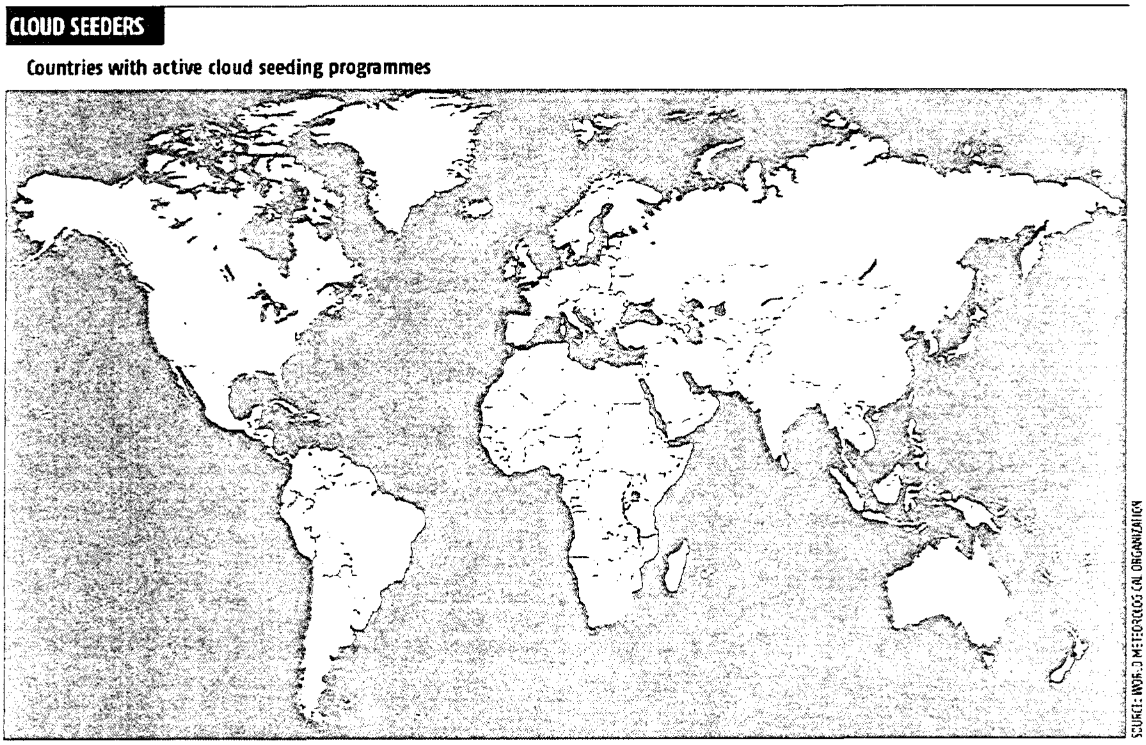
Weather modification is still a comparatively young science and technology. The following is paraphrased from a draft WMA Statement (2004). Although the fundamental principles and the primary cloud treatment strategies involved are reasonably well understood and a substantial body of evidence regarding the effectiveness of cloud seeding exists, the discipline is still evolving. Attainment of desirable WxMod effects depends upon several factors. Challenges include determining and defining the conditions under which predictable and consistent effects may be achieved, and establishing and executing the most effective cloud treatment strategies.

Programs in Operation

International

In the WMO's annual register of National Weather Modification Projects, 24 countries provided information on more than 100 ongoing WxMod activities in 1999. China is the most active country pursuing WxMod with an investment of over $40 million annually. The primary activity in Europe is hail suppression. Figure 2 shows countries with active cloud seeding programs.

Figure 2 – Countries with Active Cloud Seeding Programs



National

In the United States approximately 66 programs for hail suppression and snow and rain enhancement were being conducted in 10 states in 2001 according to activities reported by NOAA. All these projects are located in the semi-arid western states and sponsored by local, state, or private entities. WxMod does not appear as a line item in the fiscal year 2004 budget of any federal agency – although closely related topics such as cloud physics, water management, and climate change are being pursued – and no work is being done on the complex social and economic implications of attempts to modify weather (NRC, 2003). The next phase in a comprehensive WxMod science and technology development program could be based on a model suggested by DeFelice (2005) where he proposes a comprehensive agenda of fundamental and applied research and development efforts directed toward optimizing existing technologies used to manage "treatable" atmospheric processes and conditions, and to allow the development of relevant innovative technologies under an umbrella of permanent national administration.

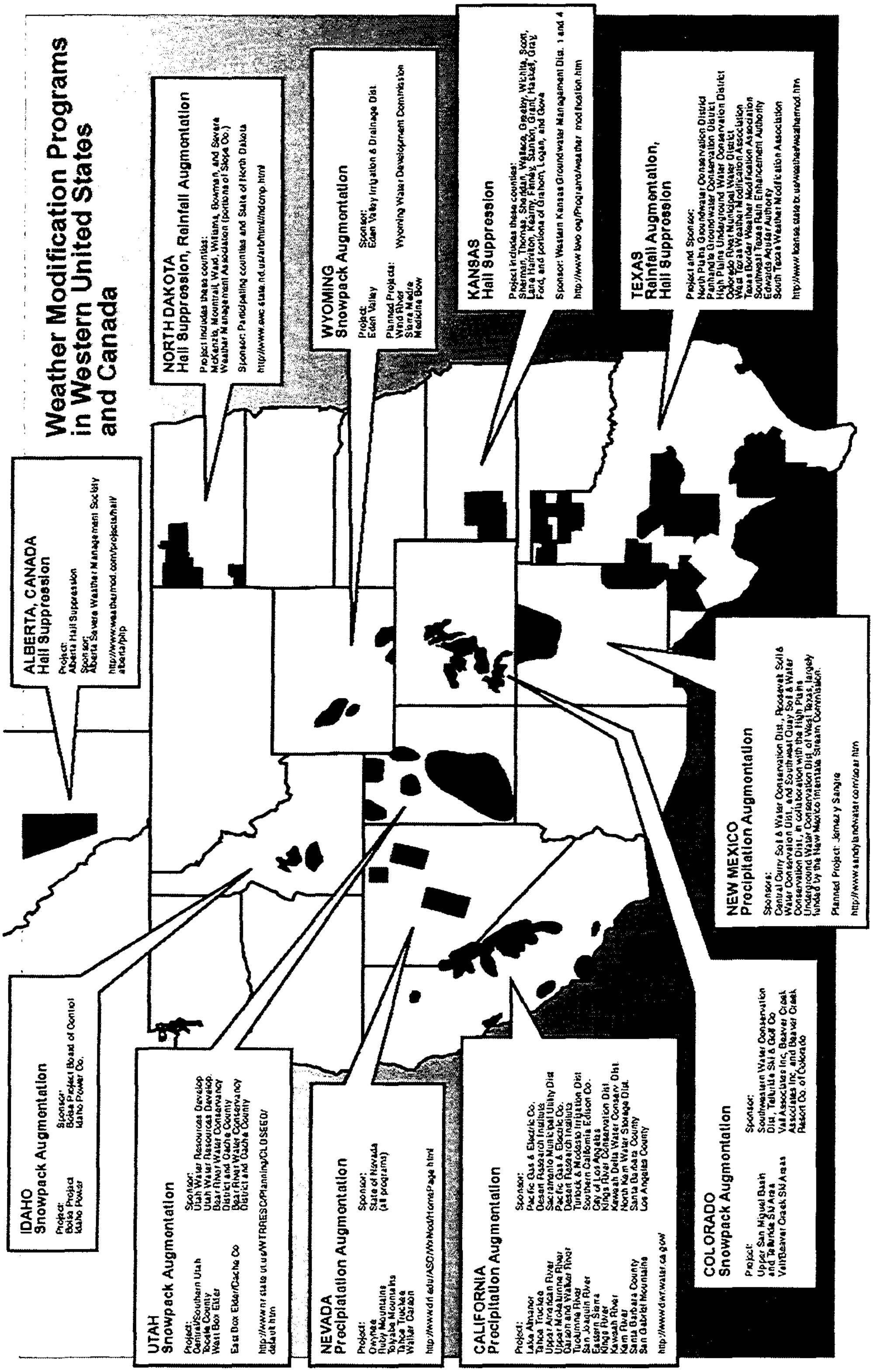
Although there are numerous cloud seeding programs in twelve states and provinces that serve various purposes, this paper will only focus on the larger winter orographic snowfall augmentation projects in a few states as this is the process most relevant to the issue being addressed by the Basin States. Figure 3 shows operational cloud seeding programs in North America.

Colorado

Colorado has had a weather modification permitting program since 1972 and the Colorado Water Conservation Board (CWCB) has served as the regulatory and permitting agency since 1987. The CWCB's primary mission is to protect, conserve, and develop the waters in Colorado, and the Board manages several programs. One program is the Enhanced Snowpack Assessment Project which collects data on 44 sub basins in eight major watersheds in Colorado. The project provides snow water equivalent, snowmelt, snow temperature, and depth at 1 kilometer resolution or by basin average. These data might furnish a quantitative method for evaluating seeding effect, given sufficient time to establish a long data set.

There is currently no annual appropriation for weather modification in Colorado. The firm Western Water Consultants has had an active permit for the Vail/Beaver Creek Ski area since 1972 and operates to assist snow augmentation for early skier days. The Colorado Water Conservation Board has made grant funding available for 2004 and 2005 and will continue to apply for funding to offset costs incurred by water users that sponsor projects. The CWCB mostly provides support to seven commercial projects (two are ski areas) in the Central Colorado Rockies, the South Platte and Arkansas Basins, the San Juan Mountains, the Grand Mesa, the Gunnison Basin, and the Upper San Miguel Basin. In related news that might have a bearing on WxMod, there have been climate studies suggesting that Colorado's $2 billion ski industry could be significantly reduced or could completely disappear due to warming by 2050 (Rocky Mountain News, 2005).

Figure 3 – Operational Cloud Seeding Programs in North America



Source: Weather Modification Association

Recently Colorado utilized a WDMP grant to evaluate the Denver Water Cloud Seeding Program using a numerical model for the 2003-04 season.

The CWCB, with assistance from Reclamation and consultants, has recently started a Colorado Winter Storm Climatology Study. This study builds on previous work in several mountain ranges by Dr. Edmond W. Holroyd of Reclamation. The project uses NOAA's National Centers for Environmental Prediction reanalysis climate and weather data to characterize SLW, temperature, and terrain in various mountain ranges for seeding potential throughout Colorado. The study will also examine climatological snowstorm variability and past relevant literature on SLW, and should be completed in early 2006.

Approximately 70% of Colorado's water is supplied by snowmelt runoff (Sherretz and Loehr, 1983), and mountain snow is extremely valuable because winter sports have surpassed agriculture as the state's leading industry. Six major runoff-producing areas within the Colorado River Basin have a total high-water yield area (areas of concentrated and abundant snowfall accumulation) of 58,500 square kilometers. If cloud seeding could produce 1.43 million acre-feet (maf) in the Upper Basin (approximately 10% of the average annual stream flow) and an additional 830,000 acre-feet in the Lower and adjacent basins, it has been estimated that approximately 1.7 maf of the total would be available to reduce deficits and meet new demands. Valuing this water at $30 per acre-foot (af), the total benefit from additional water would be $48.5 million per year (Lease, 1985). This does not include hydropower or recreation benefits.

Utah

Utah is the nation's second driest state. In 1973 the Utah legislature passed the Utah Cloud Seeding Act, which allows for cost-sharing. The state has six large-scale projects at a total cost of $404,300, of which the state paid approximately 38%. There are also six inactive project areas.

A detailed study by the Utah Department of Natural Resources in 2000 showed an average increase in April 1 snowpack water content ranging from 7 to 20% from a group of projects that had been operating from nine to 22 years. The overall estimated annual runoff increase from WxMod was about 250,000 acre-feet or 13% for the study area (UDNR, 2000).

As in other states, early season snowfall is highly valued by the ski industry. According to the Utah Division of Water Resources, the agricultural need for late-season irrigation water is valued near $40 per acre-foot whereas the estimated direct cost of water from an 8 to 12% increase in snowpack from cloud seeding in key mountain watersheds is $10 per acre-foot. Benefit-to-cost ratios of 3:1 to 10:1 were estimated for 10% mountain snowfall increases in the Sevier River basin in Utah (Super and Reynolds, 1991). The basis for these figures was the amount of additional water potentially produced, the estimated value of the additional stream flow, and the direct cost of conducting an effective operational program. The 3:1 and 10:1 ratios are dependent on spacing of the seeding material generators.

During the 2003-2004 winter on the Wasatch Plateau, the Utah component of the WDMP was conducted (Super and Heimbach, 2005). New chemical compositions, such as silver chloride-iodide complexes, may act more efficiently to produce ice particles at temperatures warmer than -5 degrees C, where AgI is ineffective. Similar warm temperature results may be achieved by cost-effective liquid propane generators (Medina 2000). The Utah WDMP experiment operated such generators. AgI is thought to be effective between -6 to -8 degrees C. Propane releases however can produce abundant ice crystals as warm as -2 degrees C. This was one of the first attempts to test liquid propane (LP) as a seeding agent in a fully randomized experiment. Targeting of the seeded plume was assured from previous experiments. LP dispensers were remotely and automatically operated, based on the presence of SLW measured at the dispenser site in real time. A short-duration experimental unit (EU) elicited a robust population for statistical analyses, of which there were three types. Seeded units produced over 20% more snowfall than unseeded units. It was estimated that if all hours containing the EUs had been operationally seeded, the seasonal (entire winter) precipitation increase would have been 8%. The Utah WDMP experiment needs replication in other areas.

Nevada

Although Nevada is one of the seven Basin States, its snowpack enhancement activities have been focused in northern Nevada in basins outside the Colorado River system. Its research and operational programs are still applicable to the overall endeavors in wintertime cloud seeding. Research in WxMod has been conducted through the Desert Research Institute since the mid-1960s through both Bureau of Reclamation and NOAA sponsored programs. Nevada actively participated in Project Skywater and the Sierra Cooperative Pilot Project (Reclamation in 1970s and 1980s), the NOAA Atmospheric Modification Project (1980s and 1990s) and the Reclamation Weather Damage Modification Program (2003 to present). Two of the key areas of research have been use of remote sensing to document seeding potential through the measurement of supercooled liquid water, and the use of trace chemistry techniques to evaluate seeding effectiveness (Warburton et al, 1995). In addition, a 3-year randomized cloud seeding experiment was conducted in the 1970s (Pyramid Lake Project) to evaluate the effects of seeding in the Lake Tahoe Basin. A statistical evaluation showed positive effects of seeding (~+17%) in some storm partitions (stratifications), but the results were not significant at the 5 to 10% level.

Nevada has conducted a state-funded operational program since the 1970s, with continuous operation over the past 21 years. The current program seeds five separate drainage basins in northern Nevada and California (California basins drain into Nevada). The project uses a combination of remotely-controlled ground generators and a single seeding aircraft. Estimates of snowfall augmentation are based on periods of operation and nominal precipitation increases during periods when all seeding criteria are satisfied. The augmentation estimates have ranged from 50,000 to 80,000 acre-feet annually, which corresponds to costs of $6 to 12 per acre-foot. Chemical analysis of partitioned snow profiles are used routinely to determine the effectiveness of targeting. Results have shown a significant increase in the percent of time (over the past decade) that seeding material is detected in the snowpack. Recent research through the federal cooperative programs has focused on refining these techniques to allow for quantifying augmentation estimates over a basin-wide area.

Wyoming

In 2005, the Wyoming legislature approved nearly $9 million for a five-year WxMod pilot program. The program is administered by the state Water Development Commission and is intended to increase snowpack and runoff through winter cloud seeding within the Green River, Wind River/Bighorn, and Platte River Basins. The program includes a thorough independent evaluation of effects. The expenditures are significantly greater than any other existing WxMod program in the United States. Aircraft and ground-based seeding will be conducted, along with numerical cloud modeling physical sampling, in accordance with recommendations of the NRC report. The first field studies will likely begin in the winter of 2006-2007.

New Mexico

Responsibility for Cloud Seeding was transferred to the New Mexico Interstate Stream Commission in 2003 and licensing rules were adopted in 2004. The New Mexico Weather Modification Association, Inc was founded in 2004 to promote precipitation augmentation projects, research, and education. It works very closely with the Interstate Stream Commission to advance economically justified cloud seeding projects. Cloud seeding activity currently consists of summer seeding in Roosevelt and Lea Counties. This seeding is an extension of a Texas project, the Southern Ogallala Aquifer Rain (SOAR) Program.

An appropriation request is planned to be submitted to the New Mexico Legislature to fund a three-year winter seeding demonstration project in the Jemez and Sangre de Cristo Mountains. This will benefit water rights holders in parts of Santa Fe, Rio Arriba, and Taos counties and some water flowing off the Jemez south of the Otowi Gauge will benefit the entire Middle Rio Grande Valley. The recently prepared Regional Water Plans indicate that there will substantial growth in water demand by municipalities along the Rio Grande. Consideration is also being given by the New Mexico Weather Modification Association to summer seeding in the Guadalupe mountains and perhaps winter or summer seeding in the Sacramento Mountains. There is a summer seeding project in the Texas Guadalupe Mountains. New Mexico is very interested in cooperating with projects in neighboring states and in developing project planning and assessment capabilities within the New Mexico University System.

Issues

The Need for Funding

There is little or no research associated with any of these operational programs, which highlights the need for intensive studies to further develop a scientific basis for WxMod technology. Many current precipitation enhancement projects, particularly in developing countries, use old technology and lack the latest instruments and other operational tools. The use of modern observational tools, models, experimental design techniques, and statistical evaluation techniques are prerequisites for shedding light on cause-and-effect relationships.

As discussed earlier, when WxMod was actively pursued up until the late 1970s, funding in the United States was around $20 million per year for both operational and research projects. This amount dwindled to about $3 million per year from the mid-1980s to mid-1990s, for the Atmospheric Modification Program, then declined markedly after that. Several projects continue in the United States, but most work occurs in South Africa, Australia, Israel, China, the United Arab Emirates, and other countries.

Program Costs

Cost per acre-foot and benefit-to-cost rations for Utah and Nevada were provided above, and the cost to expand ongoing projects in Colorado (described in Section III below) is approximately $10 per acre-foot.

Generally, existing programs cost one-third that of new programs, and costs for cloud seeding generally would be less than $20 per acre-foot. This is because much of the background work has been completed and the instrumentation array is in place. However, this would not be true for a relatively large program in the Colorado River Basin. It is estimated that $3 million are being spent on current operations in the United States. The California Department of Water Resources has estimated that seeding to produce 300,000-400,000 acre-feet of potential new supply could require around $7 million, which would be about $19 per acre-foot which includes an initial investment of an estimated $1.5 to 2 million in planning and environmental studies (DWR, 2004)[4]. This is favorable compared to developing traditional water resources projects.

Evidence Versus Proof and Uncertainties

The effectiveness of WxMod is probably best presented as a "level of proof" needed to meet project objectives. There is a growing body of evidence that cloud seeding does work and can produce beneficial effects, yet it is also stated that conclusive proof does not exist. The WMA submits that ranges of effects can be developed using statistically significant results of carefully controlled, randomized experiments, physical evidence obtained through laboratory and atmospheric experimentation and observation, and the

[4] p. 10

results of less robust evaluations of large numbers of non-randomized cloud seeding events over decades. See Garstang et al. (2005) for an analysis of the differences of opinion between the WMA and NRC regarding level of proof. It is the responsibility of individual decision makers to determine which level of proof is appropriate for their project.

The NAIWMC has prepared a position paper discussing this topic. It posits that although weather modification may not stand up to the kind of rigorous, even allegedly unreasonable standards of scientific proof advocated by the NRC, it is seen by many (for example the ASCE; see above) as a viable tool. The NAIWMC also opines that weather forecasting cannot meet the statistical and reproducible standards imposed on weather modification, yet attempts to forecast weather continue. The logic continues with the point that: "It seems reasonable that if we can affect negative changes to weather by inadvertent means, we also have the potential to produce positive changes by intentional means" (NAIWMC, 2004).[5]

Although limited to small scale experiments, scientists have been able to trace the physical effects of seeding from the point of seeding to the end product of precipitation on the ground. Examples of documented cases appear in Deshler et al (1990) in the Sierra Nevada, Super and Boe (1988) over the Grand Mesa of Colorado and Holroyd et al (1995) for the Wasatch Plateau in Utah. Although the ability to measure the amount of precipitation reaching the surface is often inexact because of gauge limitations, recent work in Utah (Super and Heimbach, 2005) shows that seeding experiments can be evaluated with well-sited high resolution gauges. Recent advances in radar technology have led to better areal precipitation measurement, but conventional radars still have significant limitations, particularly for snowfall measurement. Polarized radars show much more promise in providing better estimates of precipitation, in differentiating between precipitation particle types and in tracking seeding plumes embedded in mixed phase clouds.

Atmospheric dynamics and the physical processes in clouds are complex and difficult to diagnose, let alone predict. If one looks at a radar depiction of precipitation and compares it to large-scale dynamics, one sees patterns that have little resemblance to model predictions of large-scale lifting. There is an internal complexity that cannot be predicted by current models. Some believe that the state of the art is unable to assess in real time where a WxMod intervention could provide predictable results on a meaningful scale.[6] In wintertime cloud seeding situations numerous remote sensing and in situ measurement platforms have been used to document seeding opportunities, which have been found to be quite lengthy in many winter storm situations. While we cannot predict or model all the internal complexities of a storm, the real time recognition of opportunity is within the capability of modern observing systems and this has led to the design of experiments which have produced predictable results when all criteria for seeding

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[5] p. 2
[6] Personal communication. Dr. Charles L. Hosler, Department of Meteorology, College of Earth and Mineral Sciences, The Pennsylvania State University.

opportunity have been met. As mentioned earlier however, continuous SLW and temperature monitoring can provide useful guidance to WxMod decisions.

Other issues that have been identified are: 1) many current operational programs have serious problems with targeting sufficient concentrations of seeding agent into desired cloud regions, calling into question the increases claimed by some WxMod proponents,[7] and 2) lack of a statistical randomization component. By having approximately 10% of the seeding events randomized, a project can achieve statistically significant results on the effectiveness of the seeding, depending on the time scale.[8] The failure to fund these relatively inexpensive items is often due to budget constraints, the desire for good public relations, or the ability to claim success without having to fuss with rigorous and defensible scientific methods.

Refer to Appendix B for a discussion of technical uncertainties regarding weather modification for precipitation enhancement. In general they are summarized here. There are scientific and methodological issues regarding microphysics, verification, nucleation, seeding dispersion, and separation of seeding effects from natural ones. Other issues include: cloud properties and dynamics; cloud modeling; the accuracy of instrumentation, and; the need for accurate numerical simulation and multi-parameter, three-dimensional observations. It should also be noted that a percentage increase in snowpack does not translate to a corresponding percentage increase in runoff. This is because of differing basin characteristics, one primary factor being soil type. The development of a new cloud seeding program should consider addressing some of the technical uncertainties in Appendix B.

Societal Attitudes

The perceived value of cloud seeding must incorporate more than just economics and the effectiveness of the technology. There is concern about human intervention in weather processes, from both an environmental and spiritual perspective. Given the extremely high level of complexity of this science there is much ignorance or misunderstanding about cloud seeding and some people think of it as interfering with nature. Many do not realize that almost all human activities modify nature, particularly since the time of the industrial revolution. Attitudes may be shaped by fear of the potential effects of cloud seeding such as floods or avalanches that may cause property loss (ASCE, 1995). There are those that are convinced that weather modification is possible and also those that believe that it is a fraud, irrespective of the scientific basis. It should be noted that the recent funding of a five-year pilot project by the State of Wyoming was in part the result of a successful scoping and public outreach program by the Wyoming Water Development Commission. A public education and outreach component should be considered in any new cloud seeding program.

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[7] Personal communication. Arlin Super, U.S. Bureau of Reclamation, retired.
[8] Personal communication. Jon Medina and Steven Hunter, U.S. Bureau of Reclamation.

Environmental

There has been a concern about the toxicity of the most common cloud seeding material, silver iodide (AgI) on the environment. The typical concentration of silver in rainwater or snow from a seeded cloud is less than 0.1 micrograms per liter. The Environmental Protection Agency recommends that the concentration of silver in drinking water not exceed 0.10 milligrams per liter of water. Many regions have much higher concentrations of silver in the soil than are found in seeded clouds. Industry emits 100 times as much silver into the atmosphere in many parts of the country, and silver from seeding is far exceeded by individual exposure from tooth fillings. The concentration of iodine in iodized salt used on food is far above the concentration found in rainwater from a seeded storm. No significant environmental effects have been noted around operational projects, many of which have been in operation for 30 to 40 years (WMA, 1996).

Although several NEPA documents have been prepared for WxMod programs, the only three that have been located are:

> "Sierra Cooperative Pilot Project, Environmental Assessment and Finding of No Significant Impact", Edward R. Harris, Office of Atmospheric Resources Research, US Bureau of Reclamation, August 1981.
>
> "Final Supplement to the Environmental Impact Statement Environmental Impact Report, Prototype Project to Augment Snowpack by Cloudseeding using Ground Based Dispensers in Plumas and Sierra Counties", Forest Service, U.S. Department of Agriculture and California Department of Water Resources, October 1991 and Joint Environmental Impact Statement Environmental Impact Report, Prototype Project to Augment Snowpack by Cloudseeding using Ground Based Dispensers in Plumas and Sierra Counties, September 1990.
>
> "Environmental Assessment for the Pacific Gas and Electric Company Mokelumne Weather Modification Program", Parsons Engineering Science, Inc., October 1995. (prepared for Pacific Gas and Electric Company and the U.S. Forest Service, Stanislaus National Forest)

The Wyoming Water Development Commission has begun planning a process for compliance with the National Environmental Policy Act for their proposed Weather Modification Five-Year Pilot Program. Wyoming and its partners are currently deciding on the lead federal agency and what type of environmental document would be appropriate.

Anthropogenic Effects

There have been recent articles describing studies at the Desert Research Institute in Nevada (Borys et al. 2003), and Hebrew University of Jerusalem (Rosenfeld 2000) about the role of air pollution in reducing precipitation. In sum, researchers are demonstrating that human-induced air pollution is reducing precipitation from clouds. Long-term studies have also linked polluted air from increased urbanization to drought conditions (Rotstayn and Lohmann, 2002). Air pollution generated in urban areas generates very small (less than 1 micron in size) particles. The microphysical cloud process involves more numerous smaller moisture-attracting particles, which results in fewer cloud droplets that grow heavy enough to fall as rain; i.e., there are fewer large particles of an optimal nucleating size. It has been estimated that pollution-contaminated clouds can produce half as much snow as pristine clouds. A recent study by Hindman et al. (2005)

in the Colorado mountains failed to confirm the inverse relationship between aerosol concentration and precipitation rate reported by Borys et al. (2003).

A recent study compared historic (1950-2002) daily precipitation and wind data in the "polluted" Denver metro area and "pristine" sites along the Colorado Front Range north of Denver, to identify the possibility of precipitation suppression by air pollution. Decreasing trends of upslope precipitation for elevated sites relative to upwind polluted sites were found, without a statistically significant trend for a more pristine area. As this trend has occurred during a period of industrialization and urbanization, it suggests that anthropogenic air pollution has led to the suppression of orographic precipitation west of the Front Range over the last half century (Jirak, Cotton, and Woodley, 2005). A similar long-term study showed precipitation losses over topographical barriers downwind of major coastal urban areas in California and in Israel that amount to 15% to 25% of the annual precipitation (Givati and Rosenfeld 2004).

Legal Issues

To address potential flooding liability, all ongoing projects have suspension criteria designed to stop seeding any time there is a flood threat. Also, the type of storms that produce large floods are naturally efficient in processing moisture into rain so there is little benefit to be gained from seeding.

Colorado and Utah have statutes addressing the issue of water augmented by weather modification. Under Colorado law, a permit can be obtained to appropriate the right to use surface water made available by seeding (Colorado Legislative Council, 1971). Utah would allocate its use to the most senior water appropriator whose allocation was not already filled by water naturally in the stream (Dewsnup and Jensen, 1977). California law says that water gained from cloud seeding is treated the same as natural supply with regard to water rights (DWR, 2004).

Conclusions on Effectiveness

With regard to uncertainties, the NRC (2003) concludes that future work should emphasize the understanding of processes rather than on modification. Further, they assert that the initiation of large scale operational WxMod programs would be premature because many fundamental problems need to be answered first. The NRC indicates that expanding existing programs, which are essentially uncontrolled experiments, will not answer critical questions and that long-term (possibly decades) of patient investigations is the optimum route to success. Their recommendation is a coordinated national program to conduct sustained research.

The NRC further states that although there have been some randomized experiments, most could not provide evidence sufficient to reject the null hypothesis of no seeding effect. A common conclusion is that there were indications of seeding effects based on physical measurements, but the data were insufficient to reach statistical conclusions. The NRC report concludes that there is "...no conclusive scientific proof of the efficacy of intentional weather modification, although the probabilities for seeding-induced alterations are high in some instances." So even though those that have reviewed the report may view weather modification with some skepticism, the report still contains much optimism which is welcome in the operational WxMod community.

Perhaps the most up-to-date and balanced assessment of the state of WxMod comes from Garstang et al. (2005). This article presents the report of a workshop addressing the NRC report from both operational and research perspectives. Major findings were:

- Substantial advances in understanding, observing technology, data acquisition and processing, and numerical modeling have occurred in the last three decades;

- There is now considerable evidence, but not definitive scientific proof, that treatment can cause changes in clouds and the physical processes leading to the formation of rain, hail, and snow;

- The ability to focus on remaining uncertainties and to remove or reduce obstructions to progress is now very real, and;

- Conducting controlled WxMod experiments and capitalizing upon operational programs will advance understanding in both deliberate and inadvertent WxMod. The need for a coordinated national research program is supported in this context.

WxMod operations can be effective in drought preparedness and as a drought recovery tool if there are sufficient storms with which to work. Developed programs should be sustainable and operate year-in and year-out to achieve maximum efficiency. Seeding can be effective on naturally efficient storms and can improve marginally efficient storms. There must be some storms with which to work, however, and these are infrequent during a drought. Therefore waiting until a drought to initiate WxMod is likely too late.

III. USEFULNESS TO THE BASIN STATES

Drought Management

Weather modification/precipitation management is a potential cooperative interstate activity for consideration in Colorado River drought/shortage management strategies which could lessen the impact of drought, prevent water shortages, and enhance reservoir system recovery. Depending on the measures that are pursued, it may be desirable to develop a federal/state drought management and storage recovery initiative, especially if there is a need for timely congressional action, federal appropriations and rules and regulations.

In the early 1980s, the Basin States and Reclamation were preparing legislation to authorize a cost-shared WxMod demonstration program for the Colorado River Basin that focused on augmenting winter orographic storms. The high runoff years of 1983-1986 and nearly full reservoirs thereafter prevented the program from proceeding. The Basin-wide seeding program ideas was revived in the form of CREST (see above) during the early 1990s, but was again not pursued. Reclamation could make an updated evaluation of the status of the technology and its potential for augmenting the Colorado River water supply. Such an endeavor could mitigate the adverse effects of climate change, an inadvertent form of WxMod.

Approaches

Funding of Research Institutes. The roadblocks impeding progress in weather modification are part of the wider research problems facing atmospheric sciences as a whole – lack of coordinated research. Since the 1980s the need for a large national laboratory facility to study different simulation experiments has been identified. Such a facility has not yet been created, nor is there even a mechanism for long-term planning and funding of a laboratory for cloud physics research. There is no coordinated effort to address the overall process of precipitation formation or ice interactions, only limited studies by individuals. The California seeding group is proposing strong interactions with research agencies, and possibly formation of a WxMod research facility.

Monitoring and Legislative Activities. The Basin States should monitor legislative initiatives made in this field, such as the Congressional legislation or WDMP continuance. This activity requires little effort or cost, but does not necessarily lead to a new water supply because of the vagaries of federal interest and funding. Nevertheless, participation of this type by state and private entities lends credibility to proposed legislation. This activity could be one component of a larger set of activities that the Basin States could undertake.

Program Development. The sponsorship decision to support an operational cloud seeding program can be viewed as a risk management assessment. What is the risk of making the wrong decision weighed against the potential benefit/cost ratio? Numerous studies have demonstrated that a 10 to 15% increase in precipitation can provide sizable benefits to a variety of stakeholders (irrigated agriculture, hydroelectric production, municipal water supplies) at very favorable benefit ratios of 5 to 10:1 or higher (DOI, 1993). For example, if a potential sponsor of a cloud seeding program, following careful deliberation, decided they had an 80% likelihood of obtaining a 10% increase in precipitation and that increase would yield a benefit/cost ratio of 10:1, they would probably choose to support the program. However, as stated above, the initial costs of developing a program are high, the permitting may be onerous, and the timeframe for the production of additional water may be several to many years. Yet the benefit-to-cost ratios are significantly greater than investment in other water development projects, such as desalination or the construction of new reservoirs.

Watershed Experiment. The Board of Atmospheric Sciences Workshop Report (BASC, 2001) included a strong recommendation that a "Watershed Experiment" be conducted in the mountainous West, using all available technology and equipment. The NRC report has a similar recommendation with many suggestions for evaluation and requirements for protection of the environment and local water users. There are several western states' watersheds worthy for consideration of such a program. This experiment has not yet been funded. The Basin States could work cooperatively and cost share with other agencies in developing this experiment, or suggest one in Colorado or Utah and work with other agencies to design the experiment. This might be a cost-effective way to gain experience.

Participate in Ongoing Program. As stated earlier, the cost of participating in an ongoing program is significantly lower than developing a new one. Other advantages include: use of the data generated during the operating period; an understanding of the costs, and; some indication of the effectiveness of the program. Even if the program is not operational as in the case of the CREST, much of the planning work has been completed, which can be leveraged. That stated, even though some of the needed infrastructure for the cloud seeding part of the program may be present in a basin, it could be argued that in order to optimize operations, one would like to start fresh by evaluating generator positions and likely add new ones to ensure complete coverage of the intended target. All the research equipment needed for a comprehensive physical evaluation would certainly not be in place. A high cost item is manpower to collect and analyze the data from a wide variety of platforms.

Combination of Operations and Research. An operational program could be developed or an existing one expanded. Part of any program should include a research or evaluation component. Recently, the state of Wyoming (see above) has taken it upon itself to initiate WxMod evaluation experiments, without assistance from federal or other agencies. The Wyoming evaluation component includes statistical evaluation of snowpack data in seeded versus non-seeded areas, or a historical versus seeded approach, modeling studies, and real-time SLW verification, among other things. Another option would be to piggy-back additional research onto an existing project since even the relatively large Wyoming budget may not be adequate to perform detailed physical studies.

Identification of Target Areas

In the Colorado River Basin, two areas to consider would be those that the CREST originally targeted with high priority (Grand Mesa in Colorado and Wasatch Plateau in Utah). A good reason to choose these sites is that much of the work in assessing their usefulness has already been defined. The CREST planning document (DOI, 1993) also identified 23 secondary experimental areas in the states of Colorado, Utah, Wyoming and Arizona. However, since the project was not completed, there are no statistically significant results that can be used for the purposes of this paper. However, the physical studies done in these areas are more valuable than statistical ones, and since none of the areas have statistical results, these original project areas have a big advantage.

A recent proposal for target areas, circulated at the 2005 Western Governors Association meeting, is shown in Figure 4.

In a June, 1992 Precipitation Management Demonstration Program progress report prepared by Reclamation and provided to the Colorado River Board of California, the results of work in fourteen watersheds in both Colorado and Utah are mentioned. More research would be required to determine the specific watersheds. If a project is identified in Colorado, transfers and permitting issues would need to be addressed, which could take one year.

Regardless of the location of a potential weather modification program there are several issues that must be resolved in order for the Basin States to realize the benefits of enhanced precipitation and runoff. These issues include: how to allocate changes in precipitation if they can be identified; the role that priorities play; the potential exchanges and transfers of the water that may be necessary depending on the "plumbing" between the target and water service areas, and the potential permitting and approvals that may be necessary.

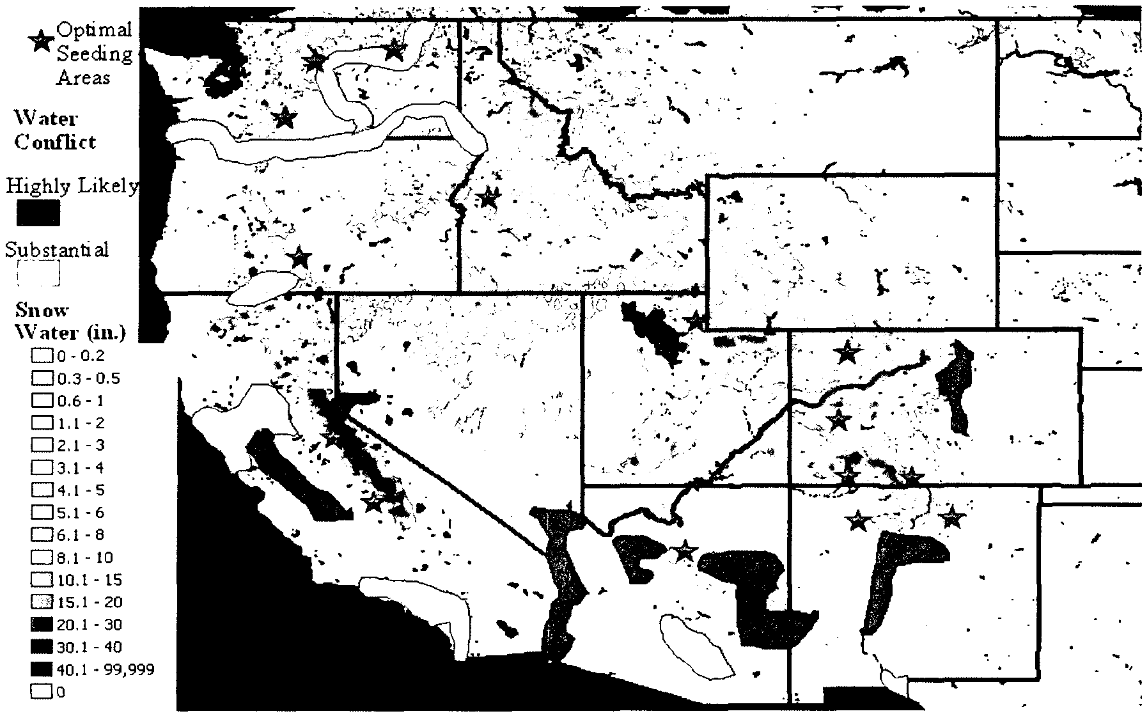

Figure 4 - Map of expected water conflict areas from Water 2025 (Dept. of the Interior), along with areas having substantial snow (water) on March 15, 2005. Snow water increases according to key at left, with dark blue areas having the most water. Based on the water conflict areas and their sources of water (mountain snowmelt), optimal cloud seeding areas to augment snowpack and alleviate water conflicts are designated by purple stars. The Colorado River, which provides the major water supply for several water-stressed areas in the southwest U.S., is shown by the thick green line.

Potential Projects

This section provides a brief description of ongoing programs that could be extended in time or expanded in space, and identifies watersheds for potential new programs. It then provides a general list of next steps for further analysis.

The amount of water that could potentially be made available by precipitation augmentation in the Colorado River Basin has been estimated in three studies:

Bureau of Reclamation	1967-68 Study	1,870,000 acre-feet
Stanford Research Institute	1971-72 Study	2,300,000 acre-feet
North American Weather Consultants (Twelve Basin Study)	1972-73 Study	1,315,000 acre-feet

It should be noted that the studies above are old, and the Stanford results should be multiplied by 0.5 as it assumed a 20% increase in snowpack. Even with these caveats, the range of between 1.1 and 1.8 million acre-feet is a consistent estimate of the amount of water the cloud seeding could develop in the Colorado River Basin (DOI, 1980).

Expand Ongoing Operations

One way to increase runoff would be to expand current operations. Table 1 provides a list of ongoing projects in Colorado whose operation time could be expanded. The estimates for cost and potential yield are preliminary and subject to change.

Table 1 – Operations that Could Potentially be Extended

Location	Extension of Operations	Estimated Cost	Potential Runoff (af)
Southwestern Water Conservation (SWCD) District	2.5 months	$11,000	16,000
SWCD/FloridaWater Con. & Farmers/City of Durango (FFFDC)	2 months	$13,000	4,000
SWCD/Durango Ski Area/Dolores & Animas La Plata (DMDALP)	2 months	$41,000	38,000
SWCD/Upper San Miguel & Telluride Ski Area (SMTWMP)	2 months	$30,000	8,000
SWCD/Upper Piedra/Upper San Juan (in standby mode)	3 months 5 months	$74,000 $105,000	30,000 50,000
Vail/Beaver Creek Ski Areas	2 months	$86,000	20,000
Denver Water Department WxMod Program (in standby mode)	3 months 5 months	$289,000 $423,000	60,000 100,000
TOTALS Low High		$544,000 $709,000	176,000 236,000

Adding factors for adminstration, contingencies, and maintenance, the cost for the extension of the projects in Table 1 average $10 per acre-foot of water. These costs reflect estimates of additional seeding hours, final costs would reflect actual seeding hours and seeding rate. These costs do not include randomization or evaluation components, which are recommended to be added to these ongoing programs. Expanding the programs by adding generators would be an additional cost.

Potential New Project Areas

The suggested criteria for selecting new sites is that used by CREST (DOI, 1993). In summary, the mountain ranges examined should have: significant areas above 9,000 feet; a location at least partially within the Colorado River Basin; a limited area with a wilderness land use designation; at least a 20 kilometer west-to-east dimension, and some mountains with parallel north-south ridges separated by a valley. Although there are sites that met these criteria in Wyoming and Arizona, this paper focuses on mountains in Colorado and Utah.

• Areas identified in the CREST for further consideration for WxMod evaluation and recommended to be considered for operations here:

Colorado:

Elkhead Mountains north of Hayden
Park Range east of Steamboat Springs
Park Range (south end) northwest of Kremmling
Elk Mountains/Parkview Mountains north of Parshall
Front Range east of Dillon
Red Table Mountain south of Eagle
White River Plateau (south end) north of Glenwood Springs
Grand Mesa east of Grand Junction
Sawatch Range east of Crested Butte
Monarch Pass area east of Gunnison
Cochetopa Hills southeast of Gunnison
Cimarron Ridge area southeast of Montrose
Uncompahgre Plateau west of Montrose
Central San Juans around Silverton
Southwestern San Juans northwest of Durango

Utah:

Boulder Mountain north of Escalante
Wasatch Plateau east of Mt. Pleasant
Uinta Mountains (east end) northwest of Vernal
Fishlake Mountains southeast of Richfield
La Sal Mountains east of Moab

- Other areas in Colorado:

  Flat Tops Mountains area near Glenwood Springs
  White River Basin
  Yampa River Basin

Next Steps

The items listed below are not in order of importance, but should be used in developing a feasibility study to increase winter precipitation. Items to consider and address include:

- Estimate the volume of water that could be made available
- Identify permitting issues
- Develop project planning documents
- Outline feasibility study
- Identify Lead Agency(ies) contracting
- Develop request for proposals
- Characterize the target areas
- Model airflow patterns
- Conduct environmental assessment
- Develop seeding programs
- Organize and manage project
- Develop suspension criteria
- Develop cost estimates
- Develop implementation schedule
- Rank the target areas
- Develop list of consultants for operations and evaluation components
- Review of data sets, SNODAS, SNOTEL
- Determine distance to Colorado River mainstem and identify intervening watersheds
- Develop snow water equivalent and runoff amounts
- Consider developing an education and public outreach component

IV. CONCLUSIONS AND RECOMMENDATIONS

Summary of Major Findings

This paper has introduced the history of WxMod with its authorities, agencies involved, ongoing programs, and policy statements from organizations involved in the discipline. A description of programs in operation, issues facing the science, and questions about its effectiveness have been given. Finally, different approaches were identified and their applicability to the Basin States examined.

Although there is no clear cause-and-effect relationship between seeding a specific cloud and resultant precipitation in a specific location as proven by scientific method, there is a sufficiently large body of evidence to indicate that WxMod is an effective tool for precipitation augmentation. There is ample information on the uncertainties, risks, and benefit-to-cost ratios of WxMod, which must be weighed in the development of a program.

The success of the WxMod programs currently in operation in Colorado and Utah are demonstrated by the continuing support of the most common project sponsors - ski areas, water authorities, and agricultural users.

The ongoing as well as previously proposed projects in these states and the authority and expertise of Reclamation, provide knowledge that can be leveraged in the future development of a WxMod program. This paper identifies several different approaches for further consideration.

Although more research should be conducted on the specific cause-and-effect relationships between cloud seeding and additional water on the ground, it is believed that cloud seeding has reached the point that a well designed and managed program with a proper evaluation component can be implemented to produce cost-effective water resources benefits. The additional water can help to satisfy increasing demands and potentially reduced precipitation due to inadvertent weather modification, increased water demands, and natural drought cycles in the West.

Recommendations

There are several good reasons for the Basin States to continue research on this topic, besides the endorsements of the NRC and WMA. One of the most important is the 2000-2004 Colorado River Basin drought. Others are a general trend toward reduction in snowpack and increased water demands, and the growing concern about reductions in precipitation due to inadvertent anthropogenic modification to weather (especially air pollution and global warming). Factors to consider in deciding how to proceed are that: new projects take 1-3 years to plan; planning is relatively inexpensive; there is a real need for research and project funding; these projects are very cost-effective, and there are existing programs with data that can be leveraged.

It is recommended that:

- further investigation continue as to the availability of WxMod projects in which the Basin States can participate, particularly those focusing on the Upper Basin States of Colorado and Utah;

- legislation continue to be monitored, and attempts to influence legislators be considered;

- an implementation plan be developed with next steps, including a schedule, costs, and deliverables for a feasibility study to increase winter precipitation that would include both operational and evaluation components;

- the Basin States enlist either Reclamation and/or NOAA as the lead federal agency in the development of a coordinated national research program and that this program, should piggy-back research onto existing and proposed operational programs like Reclamation's WDMP;

- cost-share with Reclamation in an objective impartial evaluation of existing operational programs, and;

- for an interim period when the feasibility study is being prepared, expand ongoing operational programs by adding generators and by operating the programs for a extended period of time each year, including those shown in Table 1.

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APPENDICES

Appendix A

Weather Damage Modification Program Paper

THE WEATHER DAMAGE MODIFICATION PROGRAM

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U.S. Bureau of Reclamation, Denver, CO

16th Conference Planned and Inadvertent
Weather Modification, San Diego, California
American Meteorological Society, January 2005

1. INTRODUCTION

The U.S. Bureau of Reclamation (Reclamation) has been engaged in weather modification research since the 1960s, although this research declined significantly in the late 1980s through 1990s. In Federal Fiscal Year (FY) 2002, however, Congress authorized funding of the Weather Damage Modification Program (WDMP) and specified that it be administered by Reclamation. The primary goal of the program is to improve and evaluate physical mechanisms to limit damage from weather phenomena such as drought and hail, and to enhance water supplies through regional weather modification research programs and transfer validated technologies for implementation within operational programs. The WDMP program received $1.2M for field research in FY 2002 and 0.8M in FY 2003, but was not funded in FY 2004 and beyond. These monies have supported research in seven states: Colorado, Texas (in cooperation with New Mexico and Oklahoma), Nevada, Utah, and North Dakota.

The WDMP focused on three intermediate targets associated with the overall goal: rainfall augmentation, snowfall augmentation, and hail suppression. Participating states were expected to match federal funding and "piggyback" their research on existing operational weather modification projects. This paper summarizes the science questions pursued, research approaches, and current status of each state project.

A recent report on weather modification research (NAS 2003) cites advances in observational, computational, and statistical technologies over the last few decades that could be applied to weather modification. Based partly on these advances, the report recommends initiation of a sustained national research program. Although the WDMP is not presently funded, the program may serve as a foundation for such a research program with Federal government support. Also, according to the NAS report, such research should be pursued because weather modification has the potential for relieving water resource stresses. Reclamation is the major wholesale supplier of water in the U.S. and operates in 17 western states, where such stresses are the most severe, owing in part to a multi-year drought and rapid population growth. As a result, Reclamation is being forced to make increasingly difficult choices regarding water allocation.

The WDMP represents the first federally supported attempt in the 21st century to investigate some of the major lingering scientific questions about the efficacy of weather modification. Answers to these questions are crucial prerequisites to widespread use of weather modification to alleviate the burgeoning water supply crisis in the West.

2. RESEARCH BACKGROUND AND DESCRIPTION OF PROJECTS

2.1 Winter Orographic Seeding

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Melt and runoff from snowpack contributes most of the reservoir storage in large portions of the Western U.S., so snowpack augmentation is an attractive target in the region. Accordingly, operational cloud seeding to augment snowpack in the mountains has a long history in several western states. Prior studies suggest that seeding of supercooled orographic clouds has worked, yielding seasonal precipitation increases on the order of 10% (AMS, 1998). More research and documentation is needed to buttress these findings, however.

Winter orographic seeding has been dominated by the use of silver iodide (AgI), delivered from ground-based generators or aircraft. The last federally-assisted cloud seeding project was a winter experiment in Utah during the 1990s (Super 1999). There are a number of other seeding technologies that have been put forward but not tested extensively. New chemical compositions, such as silver chloride-iodide complexes, may act more efficiently to produce ice particles at temperatures warmer than -5°C, where AgI is ineffective. Similar warm temperature results may be achieved by cost-effective liquid propane generators (Medina 2000). The Utah WDMP experiment operated such generators.

The use of tracer chemicals with the seeding materials affords a method to verify the targeting of those materials. Such chemicals were employed in the Nevada WDMP experiment, which even attempted to distinguish ground-based and aircraft seeding signatures. This experiment also included a Lagrangian particle dispersion model and windflow from the MM5 cloud model to further characterize seeding plume trajectories (Koracin et al. 1998). The Colorado experiment also used a Lagrangian transport model (Uliasz 1994) coupled with the RAMS cloud model (Cotton et al. 1994) to evaluate targeting of seeding material.

2.2 Convective Seeding

Research into warm-season seeding of convective clouds in the Western U.S. was conducted mostly in the late 1960s through early 1980s, notably through projects such as the National Hail Research Experiment (NHRE) and the High Plains Experiment (HIPLEX; Cooper and Lawson 1984). These experiments had mixed results for hail suppression and rainfall augmentation, respectively. Rosenfeld and Woodley (1989; 1993) reported increases in radar-estimated rainfall with AgI seeding in West Texas during the 1980s. Tracer studies were conducted in North Dakota in 1989 (Boe et al. 1992).

More recently, positive findings regarding hygroscopic seeding have been reported in several experiments, e.g., in South Africa (Mather et al. 1997), Thailand (Silverman and Sukarnjanaset 2000), Mexico (Bruintjes et al. 2001; Fowler et al. 2001), and India (Murty et al. 2000). Yin et al. (2000; 2001) have conducted modeling studies of hygroscopic seeding that offer plausible arguments for why such seeding may lead to rain increases.

2.3 Individual Project Goals

The states conducting WDMP research are shown in Fig. 1. Three projects, in Nevada, Utah and Colorado, are involved in cool-season, orographic seeding. The other two projects, one in North Dakota and the other in Oklahoma, Texas and New Mexico, seed convective clouds during the warm season. Specifically, individual project principal goals are as follows:

- *Nevada* – (1) Remotely sense supercooled cloud water to quantify cloud seeding potential in a selected watershed; (2) Apply mesoscale atmospheric and dispersion modeling to evaluate seeding effectiveness under a variety of storm conditions; (3) Evaluate seeding effectiveness through physical and chemical analyses of snow packs; (4) Use hydrologic modeling to estimate impacts of seeding-induced increases in snow packs on streamflow; (5) Characterize natural and seeded cloud regions with *in situ* aircraft microphysical measurements.
- *Utah* – (1) Conduct randomized cloud seeding on the Wasatch Plateau using propane dispensers to develop embryonic ice particles; (2) Explore impacts on precipitation by the cloud seeding.
- *Colorado* – (1) Configure the Colorado State University cloud model (RAMS) and conduct modeling over operational cloud seeding areas; (2) Implement algorithms simulating cloud seeding generators as sources of ice nuclei, (3) Simulate Lagrangian transport

of seeding materials under different weather conditions; (4) Use RAMS to develop forecasts for seeded and nonseeded days; (5) Evaluate model predictions of precipitation.

- North Dakota – (1) Radar analysis of first echo detection; (2) Analysis of long-term cooperative observer network rainfall data; (3) Explore climatic rain gauge data for evidence of North Dakota Cloud Modification Project seeding effects on rainfall in western North Dakota; (4) Investigate CCN characteristics in western North Dakota; (5) Three-dimensional modeling of North Dakota clouds using a new microphysical parameterization scheme, with explicit treatment of atmospheric aerosols and hygroscopic seeding effects
- Texas/Oklahoma/New Mexico – (1) Statistical analysis of historical precipitation events in the Oklahoma Mesonet; (2) Profile CCN by instrumented aircraft; (3) Study seeding influences on cloud evolution with radar data; (4) Conduct airborne experimental seeding with hygroscopic materials (milled salts) and AgI; (5) Track seeding plumes with a tracer gas.

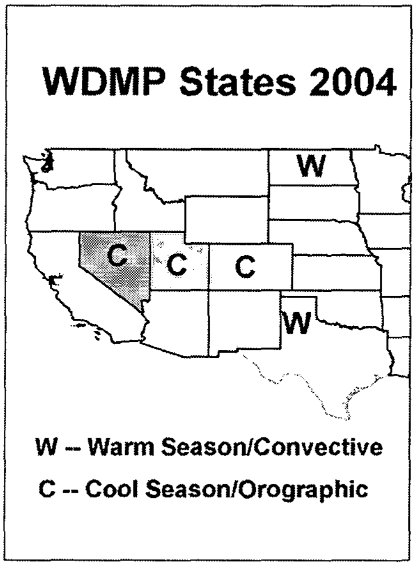

Figure 1. States conducting WDMP research, with indication of season and cloud type seeded. A single project sponsored activities in Texas, Oklahoma and New Mexico.

3. CONCLUSIONS AND FUTURE RESEARCH

Much of the Western U.S. has been experiencing a multi-year drought, creating water shortages that foment conflict between competing water users. This drought was particularly severe in 2002, when rainfall in the Colorado River basin was the lowest in recorded history. The drought has had far-reaching effects, including some of the worst forest fire seasons ever recorded. In response, bills were introduced in Congress to establish a National Drought Preparedness Act of 2003 and a National Drought Council within the Department of Agriculture (Western Governors Association 2004). The U.S. Department of the Interior recently started a "Water 2025" initiative (DOI, 2003). This initiative is intended to focus attention on increasing pressures on already-stressed water supplies by the West's explosive population growth, droughts, agriculture, recreation, and environmental concerns.

WDMP research will continue in 2005 to conclusion. No new funding has been received, however. The WDMP is the first federally-funded weather modification research field program in the 21st century. The program has demonstrated that the U.S. government can partner effectively with states and leverage scarce funds to carry out needed research, using resources already in place for operational weather modification projects. The program can serve as a model for future governmental cooperation and national initiatives such as the one proposed in the recent NAS report (section 1).

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Senate Bill S. 517 Weather Modification Research and Technology Transfer Act
House of Representatives Bill HR. 2995

109th CONGRESS
1st Session

S. 517

To establish the Weather Modification Operations and Research Board, and for other purposes.

IN THE SENATE OF THE UNITED STATES
March 3, 2005

Mrs. HUTCHISON introduced the following bill; which was read twice and referred to the Committee on Commerce, Science, and Transportation

---

A BILL

To establish the Weather Modification Operations and Research Board, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the `Weather Modification Research and Technology Transfer Authorization Act of 2005'.

SEC. 2. PURPOSE.

It is the purpose of this Act to develop and implement a comprehensive and coordinated national weather modification policy and a national cooperative Federal and State program of weather modification research and development.

SEC. 3. DEFINITIONS.

In this Act:

(1) BOARD- The term `Board' means the Weather Modification Advisory and Research Board.

(2) EXECUTIVE DIRECTOR- The term `Executive Director' means the Executive Director of the Weather Modification Advisory and Research Board.

(3) RESEARCH AND DEVELOPMENT- The term `research and development' means theoretical analysis, exploration, experimentation, and the extension of investigative findings and

theories of scientific or technical nature into practical application for experimental and demonstration purposes, including the experimental production and testing of models, devices, equipment, materials, and processes.

(4) WEATHER MODIFICATION- The term `weather modification' means changing or controlling, or attempting to change or control, by artificial methods the natural development of atmospheric cloud forms or precipitation forms which occur in the troposphere.

SEC. 4. WEATHER MODIFICATION ADVISORY AND RESEARCH BOARD ESTABLISHED.

(a) IN GENERAL- There is established in the Department of Commerce the Weather Modification Advisory and Research Board.

(b) MEMBERSHIP-

(1) IN GENERAL- The Board shall consist of 11 members appointed by the Secretary of Commerce, of whom--

(A) at least 1 shall be a representative of the American Meteorological Society;

(B) at least 1 shall be a representative of the American Society of Civil Engineers;

(C) at least 1 shall be a representative of the National Academy of Sciences;

(D) at least 1 shall be a representative of the National Center for Atmospheric Research of the National Science Foundation;

(E) at least 2 shall be representatives of the National Oceanic and Atmospheric Administration of the Department of Commerce;

(F) at least 1 shall be a representative of institutions of higher education or research institutes; and

(G) at least 1 shall be a representative of a State that is currently supporting operational weather modification projects.

(2) TENURE- A member of the Board serves at the pleasure of the Secretary of Commerce.

(3) VACANCIES- Any vacancy on the Board shall be filled in the same manner as the original appointment.

(b) ADVISORY COMMITTEES- The Board may establish advisory committees to advise the Board and to make recommendations to the Board concerning legislation, policies, administration, research, and other matters.

(c) INITIAL MEETING- Not later than 30 days after the date on which all members of the Board have been appointed, the Board shall hold its first meeting.

(d) MEETINGS- The Board shall meet at the call of the Chair.

(e) QUORUM- A majority of the members of the Board shall constitute a quorum, but a lesser number of members may hold hearings.

(f) CHAIR AND VICE CHAIR- The Board shall select a Chair and Vice Chair from among its members.

SEC. 5. DUTIES OF THE BOARD.

(a) PROMOTION OF RESEARCH AND DEVELOPMENT- In order to assist in expanding the theoretical and practical knowledge of weather modification, the Board shall promote and fund research and development, studies, and investigations with respect to--

(1) improved forecast and decision-making technologies for weather modification operations, including tailored computer workstations and software and new observation systems with remote sensors; and

(2) assessments and evaluations of the efficacy of weather modification, both purposeful (including cloud-seeding operations) and inadvertent (including downwind effects and anthropogenic effects).

(b) FINANCIAL ASSISTANCE- Unless the use of the money is restricted or subject to any limitations provided by law, the Board shall use amounts in the Weather Modification Research and Development Fund--

(1) to pay its expenses in the administration of this Act, and

(2) to provide for research and development with respect to weather modifications by grants to, or contracts or cooperative arrangements, with public or private agencies.

(c) REPORT- The Board shall submit to the Secretary biennially a report on its findings and research results.

SEC. 6. POWERS OF THE BOARD.

(a) STUDIES, INVESTIGATIONS, AND HEARINGS- The Board may make any studies or investigations, obtain any information, and hold any hearings necessary or proper to administer or enforce this Act or any rules or orders issued under this Act.

(b) PERSONNEL- The Board may employ, as provided for in appropriations Acts, an Executive Director and other support staff necessary to perform duties and functions under this Act.

(c) COOPERATION WITH OTHER AGENCIES- The Board may cooperate with public or private agencies to promote the purposes of this Act.

(d) COOPERATIVE AGREEMENTS- The Board may enter into cooperative agreements with the head of any department or agency of the United States, an appropriate official of any State or political subdivision of a State, or an appropriate official of any private or public agency or organization for conducting weather modification activities or cloud-seeding operations.

(e) CONDUCT AND CONTRACTS FOR RESEARCH AND DEVELOPMENT- The Executive Director, with the approval of the Board, may conduct and may contract for research and development activities relating to the purposes of this section.

SEC. 7. COOPERATION WITH THE WEATHER MODIFICATION OPERATIONS AND RESEARCH BOARD.

The heads of the departments and agencies of the United States and the heads of any other public or private agencies and institutions that receive research funds from the United States shall, to the extent possible, give full support and cooperation to the Board and to initiate independent research and development programs that address weather modifications.

SEC. 8. FUNDING.

(a) IN GENERAL- There is established within the Treasury of the United States the Weather Modification Research and Development Fund, which shall consist of amounts appropriated pursuant to subsection (b) or received by the Board under subsection (c).

(b) AUTHORIZATION OF APPROPRIATIONS- There is authorized to be appropriated to the Board for the purposes of carrying out the provisions of this Act $10,000,000 for each of fiscal years 2005 through 2014. Any sums appropriated under this subsection shall remain available, without fiscal year limitation, until expended.

(c) GIFTS- The Board may accept, use, and dispose of gifts or donations of services or property.

SEC. 9. EFFECTIVE DATE.

This Act shall take effect on October 1, 2005.

END

Appendix B

Uncertainties of Weather Modification for Precipitation Enhancement
(Excerpts from the NRC Report)

Although WxMod research has declined significantly since the 1970s, much progress has been made in other associated fields such as remote sensing, more accurate and higher resolution precipitation measurement, three dimensional depictions of the structure, airflow, the hydrometeor composition of clouds before and after seeding, computer modeling, Doppler radars such as Next Generation Radar or NEXRAD. There are still, however, many areas of uncertainty.

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

The basic properties of clouds make it difficult to keep track of seeded units and to replicate the treatment of successive trials. No two clouds are identical, and clouds are not independent of one another.

Operational Precision. It is difficult to target seeding materials to the right place in the clouds at the right time. There is an incomplete understanding of how effective operators are in their targeting practices, since they depend on transport by complex wind patterns and atmospheric mixing to dilute the seeding material (see below). Chemical tracer experiments provided support for current targeting practices. There is also the serious challenge of measurement uncertainties, which complicate separation of the effects of cloud seeding from natural variability.

Concern over Potential Impacts. Questions about potential unintended impacts from precipitation enhancement have been raised and studied over the years by Reclamation and others. Concerns relate to downwind effects (enhancing precipitation in one area at the expense of a downwind area, or "robbing Peter to pay Paul"), long-term toxic effects of silver iodide, and added snow removal costs. In the Project Skywater Programmatic Environmental Statement (1977) and the Sierra Cooperative Pilot Project Environmental Impact Statement (1981), available evidence did not show that seeding clouds caused a decrease in downwind precipitation; in fact there were increases for up to 100 miles downwind. The potential effects of silver have not been shown to be a problem, as silver and silver compounds have a low order of both acute and chronic toxicity. Industry emits

100 times as much silver into the atmosphere in many parts of the country, and silver from seeding is far exceeded by individual exposure from tooth fillings. Accumulation in the soil, vegetation and surface runoff have not been large enough to measure above natural background. A common societal attitude toward WxMod is that one is "tampering with nature" and some mistrust has resulted over the decades. Many such opponents are unaware that mankind has been inadvertently modifying the weather to great extent, especially since the industrial revolution.

Statistical Evaluation. Assessments of seeding effects most often consist of comparisons of the amount of precipitation measured in a target area with that from a control area. The issue is how to determine if a change occurred, using measurements taken in a watershed in a period before and during seeding. Similarly, one may take measurements in adjacent "control" watersheds to account for spatial differences arising from seeding. Either method has to deal with biases. A more statistically robust design, known as a cross-over uses two similar fixed areas. During each test case, one area is selected for treatment through a random process while the other serves as the control.

Replication. Since there is so much variability in the natural world, predictability and consistency of the application and effectiveness of techniques is difficult to determine. There are additional difficulties owing to variability in wind, temperature, and other factors. There is also seasonal variation; for example, summer is more spatially and temporally variable in precipitation than winter.

Transport and Dispersion. One of the most significant uncertainties is the transport and dispersion of the seeding aerosols across project areas. Results from studies have revealed that most of the precipitation falling in the targets during seeding periods has not been impacted by the seeding process. New fully automated ground-based generators can be located in often poorly accessible locations in high mountain terrain.

Cloud and precipitation microphysics issues. The following are outstanding cloud and precipitation microphysical issues:

- Background concentration, sizes, and chemical composition of aerosols that participated in the cloud physics process

- Cloud water nucleation processes as they relate to chemical composition, sizes, and concentrations of hygroscopic aerosol particles

- Ice nucleation (primary and secondary)

- Evolution of the droplet spectra in clouds and processes that contribute to spectra broadening and the onset of coalescence

- Relative importance of drizzle in precipitation processes

Cloud dynamics issues. The following are outstanding cloud dynamics issues:

- Cloud-to-cloud and mesoscale interactions, as they relate to updraft and downdraft structures and cloud evolution and lifetimes

- Cloud and sub-cloud dynamical interactions as they relate to precipitation amounts and the size spectrum of hydrometeors

- Microphysical, thermodynamical, and dynamical interactions within clouds

Cloud modeling issues. The following are outstanding cloud modeling issues:

- Combination of the best cloud models with advanced observing systems in carefully designed field tests and experiments

- Extension of existing and development of new cloud-resolving models explicitly applied to weather modification

- Application of short-term predictive models including precipitation forecasts and data assimilation and adjoint methodology in treated and untreated situations

- Evaluation of predictive models for severe weather events and establishment of current predictive capabilities including probabilistic forecasts