TECHNICAL EVALUATION OF OPTIONS FOR LONG-TERM AUGMENTATION OF THE COLORADO RIVER SYSTEM

WEATHER MODIFICATION FOR PRECIPITATION AND RUNOFF AUGMENTATION

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ACRONYMS LIST

AF	acre-feet
AFY	acre-feet per year
AgI	silver iodide
AMS	American Meteorological Society
Basin	Colorado River Basin
CRWC	Colorado River Water Consultants
MWD	Metropolitan Water District of Southern California
NAWC	North American Weather Consultants
Seven States	Seven Colorado River Basin States
U.S.	United States
USBR	U.S. Bureau of Reclamation

1.0 WEATHER MODIFICATION FOR PRECIPITATION AND RUNOFF AUGMENTATION

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1.1 SUMMARY AND PURPOSE

This discussion of Weather Modification for Precipitation and Runoff Augmentation is one of a series of White Papers being prepared for the Seven Colorado River Basin States (Seven States). The purpose of the White Papers is to present evaluations of potential options to provide long-term augmentation of the water supply of the Colorado River system. This White Paper presents background information on the overall evaluation program, followed by a preliminary evaluation of the weather modification option.

1.2 BACKGROUND

The Seven States have authorized Colorado River Water Consultants (CRWC) to provide a technical evaluation of long-term options. The States will supplement the technical evaluations with legal, administrative, and/or institutional considerations.

The White Papers are the first step in an iterative process to develop, screen, and evaluate options. Evaluation criteria will be applied progressively and will be developed in increasing detail as selected options become more promising. In parallel with White Paper development, the CRWC research team will meet with representatives of the Seven States and will refine the White Papers/develop new White Papers based on their input. White Paper results will be reviewed with a Steering Committee comprised of delegates from the Seven States.

Each White Paper will present a brief overview of the option being evaluated, followed by discussions of history and viability of obtaining additional water from the source, quantity of water potentially available, location of supply, water quality, environmental issues, permitting issues, technical issues, general reliability, and project costs. A list of reference documents for each White Paper will also be provided.

1.3 OVERVIEW OF OPTION

The vast majority of the runoff produced in the Colorado River and its drainages is produced from melting snow within Upper Colorado River Basin (Basin) watersheds. Much of this snow accumulates at elevations above 8,000 feet, remains throughout the winter season, and becomes runoff in Colorado River system drainages between mid-May and mid-July. Additional precipitation in the form of snow produced from operation of winter cloud seeding programs would increase the total runoff within the Colorado River Basin. While a debate occurs within science and research communities, significant anecdotal evidence exists that winter cloud seeding can increase the total winter precipitation. The range of increases in winter precipitation

varies widely. Several studies have indicated that an average of 10 percent increase in total precipitation can reasonably be obtained. In addition to increased water supplies for irrigated agriculture and municipalities, the increased runoff benefits various recreational activities and hydro-electric generation.

1.4 HISTORY AND VIABILITY OF OBTAINING ADDITIONAL WATER FROM THIS SOURCE

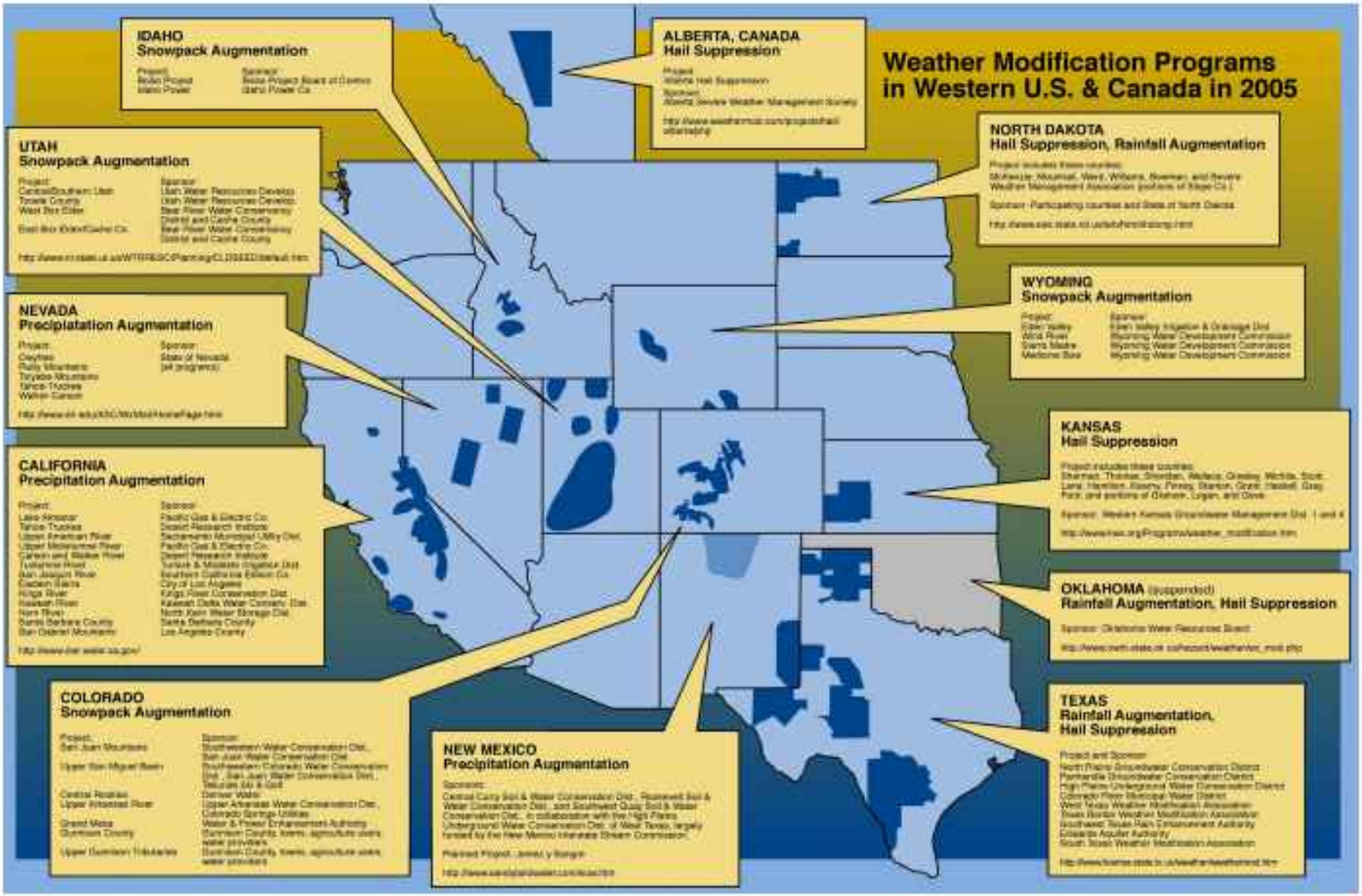
Winter weather modification programs have been in effect since the late 1940s. The potential for producing additional snowpack and rain interested many entities, and by 1951 modification programs were operating in about 30 countries for either precipitation augmentation or research purposes. In 1999, there were approximately 100 ongoing weather modification programs in 24 countries and 10 states. As recently as 2001, it is estimated that 66 programs for hail suppression and snow and rain enhancement were being conducted in 10 states. All of these projects are located in the western states and sponsored exclusively by local, state or private entities. Figure 1 shows the weather modification programs in operation in the western United States (U.S.) and Canada in 2005 (Weather Modification Association). Currently, five states within the Seven States (Wyoming, California, Colorado, Nevada, and Utah) have operating winter snow pack augmentation programs. A recent paper produced by Tom Ryan, Metropolitan Water District of Southern California (MWD) provides details on these programs (Ryan, 2005).

The process of wintertime cloud seeding is quite simple in theory. The seeding operation releases multitudes of embryonic ice nuclei that can convert supercooled (below freezing) liquid water cloud droplets to ice crystals in cloud formations that are conducive to the growth of these ice crystals, which, upon reaching an adequate size, fall to the ground as snow flakes. Under the right conditions, these snow flakes will fall to the ground in the intended target area. While ice forming nuclei exist in nature, frequently cloud formations do not contain an adequate amount of these nuclei to maximize the precipitation. The seeding essentially improves the efficiency of the natural storm system in producing precipitation that reaches the ground when the cloud system passes over mountain barriers. The snow flakes produced by seeding are formed from water droplets which otherwise would be lost to evaporation on the downwind side of the barrier.

The typical agents used for the seeding process are silver iodide (AgI), liquid propane, and dry ice. Silver iodide is most commonly used in ongoing operational programs in the intermountain west.

1.5 LOCATION OF SUPPLY

The conduct of winter precipitation augmentation programs contain a number of variables which are difficult to accurately evaluate. These variables certainly limit the ability to predict an exact location of additional supply. The most recent study referenced above assumes a 10 percent increase in winter precipitation in the Upper Basin and, using stream flow model predictions performed by the National Weather Service, estimates a total additional runoff into


Weather Modification Programs in Western U.S. & Canada in 2005
IDAHO
Snowpack Augmentation
ALBERTA, CANADA
Hail Suppression
NORTH DAKOTA
Hail Suppression, Rainfall Augmentation
UTAH
Snowpack Augmentation
WYOMING
Snowpack Augmentation
NEVADA
Precipitation Augmentation
KANSAS
Hail Suppression
CALIFORNIA
Precipitation Augmentation
OKLAHOMA (suspended)
Rainfall Augmentation, Hail Suppression
COLORADO
Snowpack Augmentation
NEW MEXICO
Precipitation Augmentation
TEXAS
Rainfall Augmentation,
Hail Suppression

Lake Powell of 1,227,000 acre feet (AF) (Griffith and Solack, 2006). The best current estimate of additional runoff that could be generated from a seeding program in Arizona is 154,000 acre feet per year (AFY) (Griffith and Solack, 2006).

A report prepared by the U.S. Bureau of Reclamation (USBR) (Hunter, 2005) provided existing and potential target areas in four states within the Colorado River Basin. Table 1 provides these areas as potential locations of additional precipitation. Other potential target areas likely exist as well.

Table 1
Potential Locations of Additional Precipitation

Existing Target Areas			
Colorado		**Utah**	
Upper Arkansas		Fishlake Mountains	
Gunnison North		Boulder Mountain	
Gunnison South		Uinta Mountains South	
Vail		Dixie National Forest	
Beaver Creek			
Grand Mesa North			
Grand Mesa South			
San Miguel Mountains			
Western San Juans			
Eastern San Juans			
Potential Target Areas			
Colorado	**Utah**	**Wyoming**	**Arizona**
Park Range	Uinta Mountains North Slopes	Wyoming Range	Kaibab National Forest
Elkhead Mountains	La Sal Mountains	Wind River Mountains West	Chuska Mountains (AZ/NM)
White River Plateau	Mount Ellen		White Mountains
Uncompahgre Plateau	Abajo Peak		San Francisco Peaks
Central Rockies			

As stated earlier, the nature of precipitation augmentation creates many questions which have not adequately been studied to provide definitive answers, certainly not answers considered acceptable by the scientific and research community. Generally, policymakers and the public believe that other atmospheric science phenomena such as global climate change or inadvertent weather modification are occurring. What is interesting is that there appears to be a higher standard for the presentation of "proof" that weather modification works. The statistical and physical tests that some have asked for to "prove" the effectiveness of weather modification could, in fact, not be met for either of the two phenomena mentioned, but yet there is support for work in those disciplines. These questions include variability of yield due to different winter weather conditions, a scientifically accurate prediction of the amount of additional precipitation that would result in runoff within the Basin, effect of priority diverters within the seeded areas on the amount of additional runoff occurring in various regions, etc.

1.6 AMOUNT OF WATER POTENTIALLY AVAILABLE

Table 2 below provides information on water yield estimates from winter snow pack augmentation from several past reports.

Table 2
Previous Water Yield Estimates from Cloud Seeding
In the Colorado River Basin

Source	Dates	Water Yield Estimates (Acre-ft)
USBR	1967 – 1968	1,870,000
Stanford Research Institute	1971 – 1972	1,150,000
North American Weather Consultants, Twelve Basin Investigation	1972 – 1973	1,315,000
USBR (Hunter, 2005)	2005	867,170

A recent paper prepared by North American Weather Consultants, Inc. (NAWC) (Griffith and Solak 2006) assumes a 10 percent increase in October through March precipitation resulting in an expected average increase in April through December runoff from new and existing winter augmentation programs of 1,227,000 AF into Lake Powell. The estimated average contributions to this total from areas where seeding is currently ongoing is 576,504 AF. The estimated contribution from seeding in new areas is 650,500 AF. In addition, it is estimated that an additional 154,000 AF of annual runoff could be generated from a new seeding program in Arizona, providing a total estimated potential runoff from winter seeding augmentation programs of 1,381,000 AF. Larger volumes of runoff are predicted in above normal water years, and smaller volumes in drier than normal water years. It should be noted that the 576,504 AF contribution from currently seeded areas is significantly more than has been historically produced from these areas since seeding operations have not been conducted on an ongoing,

systematic basis for the entire winter season. The NAWC paper predicts less than half of the potential increase in runoff has historically occurred from the existing seeding programs. It should be pointed out that all estimates of additional runoff are rough estimates and would require additional study for refinement. However, the 1,381,000 AF value given earlier is in the middle of all previous studies and is felt to be reasonably accurate based on current knowledge of this practice. The paper discussed earlier prepared by NAWC provides significantly more discussion concerning potential extra runoff and should be reviewed by all interested participants.

1.7 WATER QUALITY

The quality of water produced from winter weather augmentation should be considered the same as the current water quality in all reaches of the Basin. Although some improvement in the water quality (i.e., reduced salinity) in downstream Colorado River areas should be contemplated from additional flow in all reaches, this improvement in quality cannot be quantified without additional study.

1.8 TECHNICAL ISSUES

A significant advantage of winter weather modification programs is the lack of technical issues and problems with utilization of the additional water supply. Essentially, once the water augmentation program is permitted, designed, and operated, the project develops high quality water. The water will require no additional treatment beyond the existing supplies and can generally be collected, stored, and distributed through existing facilities. Identification of the water supplied through the weather augmentation project will be difficult. Increases in water supply resulting from weather modification projects would become system water and would not create any additional supply for a Contractor or State that engages in weather modification.

1.9 GENERAL RELIABILITY OF SUPPLY

The issue of reliability of supply related to winter weather modification programs must revolve around the debate as to the effectiveness of weather modification. The Weather Modification Association, World Meteorological Organization, American Meteorological Society (AMS), and National Academy of Sciences all state that there is strong evidence for seasonal precipitation increases over natural precipitation. The AMS further states that increases of about 10 percent from winter programs is feasible. To obtain such increases, well designed and conducted projects must be operated on a long-term and continuing basis, not just during drought periods. The NAWC paper presents the position that, although weather modification may not stand up to the kind of rigorous, even allegedly unreasonable standards of the scientific proof advocated by National Research Council, it is seen by many as a viable tool. Most sponsors of operational winter cloud seeding programs are willing to accept a lower level of proof than demanded by most scientists due to the typically very favorable benefit/cost ratios potentially available from the conduct of these programs.

The uncertainty about the effectiveness of cloud seeding can best be summarized by stating that a growing body of evidence exists that cloud seeding is effective in increasing winter precipitation and the subsequent runoff within seeded areas. Many studies conducted for agencies operating cloud seeding programs have demonstrated increases in precipitation ranging from 5 to 20 percent, and a figure of 10 percent is widely used as feasible in well run and carefully operated programs. The increase in precipitation obtained in a given year may vary greatly due to the frequency and type of weather systems which occur during the winter seeding period.

However, many in the scientific and research community remain unconvinced and suggest that additional funds for research into the effectiveness of weather modification should be provided. The dilemma is that, given the very limited funds for research and the large number of research needs indicated by scientists, it would likely be decades before the level of proof required by scientific and research organizations will be available. A partial solution to this dilemma, should some federal funds become available for weather modification research, is to "piggyback" focused research programs on existing operational programs.

1.10 ENVIRONMENTAL ISSUES

A number of studies have been conducted to evaluate the potential for creation of negative environmental impacts from winter cloud seeding programs. Some of the studies were conducted by the USBR for the "Project Skywater" program. In general, the conclusion of these studies was that significant environmental impacts due to possible conduct of cloud seeding programs in the studied areas were not expected to occur.

A concern is occasionally raised about the toxicity of the most common cloud seeding material (AgI) on the environment. Typical concentration of silver in rainwater or snow from a seeded cloud is significantly less than 0.1 micrograms per liter. The U.S. Environmental Protection Agency recommends that the concentration of silver in drinking water not exceed 0.10 milligrams per liter of water, or 1000 times the typical concentration from seeding with AgI. Many regions have much higher concentrations of silver in the soil than are found in precipitation from 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. Accumulations in soil, vegetation, and surface runoff have not been found to be large enough to measure above the natural background. Previous studies in California and Australia have confirmed these findings.

Regarding iodine, the concentration of iodine in iodized salt used in food is far above the concentration found in rainwater from seeded storms. It is noteworthy that no significant environmental effects have been noted around operational projects, many of which have been in operation for 30 to 40 years.

Another question occasionally asked regarding cloud seeding programs is whether seeding reduces the amount of precipitation received in areas downwind of the seeded location. Most

studies conducted to date do not validate this suggestion, in fact several studies suggest increases in downwind areas. The amount of atmospheric moisture passing over a mountain barrier that is converted to precipitation is usually 10 percent or less. Therefore, if cloud seeding increases natural precipitation by 10 percent, only 1 percent of the original atmospheric moisture is depleted. Winter seeding is performed on clouds on the upwind side of mountain ranges. The atmospheric moisture supply on the leeward side of the mountain range will naturally be less due to warming of the atmosphere and evaporation of cloud droplets resulting in a natural reduction in precipitation (commonly referred to as the rain shadow effect).

1.11 PERMITTING ISSUES

Arizona, Colorado, Utah, Nevada, and Wyoming have licensing and permitting requirements pertaining to the operation of weather modification programs. To date, these permits have been issued without significant concern or controversy. Cloud seeding activities are required to be reported to the National Oceanic and Atmospheric Administration, and there may be a limitation of the installation of ground based equipment on Federal lands. Each State would need to be consulted regarding cloud seeding programs which would benefit drainage areas within and outside of the state border. There is no indication to date that these permitting and licensing functions would be problematic. Suspension criteria exist in all ongoing projects to limit liability due to adverse weather conditions being exacerbated by weather modification.

1.12 COST

Current estimates of the cost of additional water from new operational winter weather modification programs and upgrades to existing operational weather modification programs are very preliminary and will require additional effort to refine the accuracy. The NAWC paper estimates that the additional 1,380,000 AF could be developed at a cost of $6,965,000, or a cost of $5.04 per AF of additional supply. A large number of assumptions were incorporated into this estimate, which necessitates additional study to provide greater certainty in the cost. The Ryan paper provided estimates for expansion of several ongoing programs and the cost for development of new programs. The California Department of Water Resources has estimated that seeding to produce 300,000 to 400,000 AF of potential new supply could require about $7,000,000, which would amount to $19.00 per AF. This estimate includes the required initial investment in planning and environmental studies. The cost for the Denver Water program which was designed, permitted and began operation in 2002/2003 was in the range of $15.00 per AF in the first year.

Based on evaluations done to date, a reasonable yet conservative estimate of the range of costs for design, permitting and operation of a program in the magnitude discussed herein would be between $20 and $30 per-acre foot.

1.13 REFERENCES

This White Paper liberally used information presented in the referenced papers.

Griffith Don A. and Mark E. Solak (March 2006). The Potential Use of Winter Cloud Seeding Programs to Augment the Flow of the Colorado River.

Hunter, S.M., S. Meyer and R. Aman (2005). Water Augmentation from Cloud Seeding in the Colorado River Basin. Bureau of Reclamation Technical Service Center, 9p.

Ryan, Tom (October 2005). Weather Modification for Precipitation Augmentation and Its Potential Usefulness to the Colorado River Basin States.

These papers were written quite recently and thoroughly discuss the best information available related to winter weather modification programs. It is recommended that interested parties read these papers in their entirety if additional information is desired.

1.14 CONCLUSION

White Paper findings are summarized in Table 3.

Table 3
Summary of Findings Related to Option

Parameter	Findings
Location of Supply	The majority of additional runoff will flow into Lake Powell and a smaller amount of additional runoff can be obtained in the Lower Basin states of Arizona and outside the Basin in California (see Figure 1 of report).
Quantity of Water Potentially Available	An estimated 1.23 million AF of runoff into Lake Powell (of which 576,504 acre-feet is from areas where seeding is ongoing when seeding operations are conducted on an ongoing systematic basis for the entire winter season) and an additional 154,000 AF of runoff in Arizona.
Water Quality	Quality the same as existing water within the Basin. Some unquantifiable improvement in quality would be anticipated.
Technical Issues	Additional collection, treatment, and delivery systems will not be required for utilization of additional water supply. Difficulty in quantifying additional water obtained and determination of location of additional supply.
General Reliability of Supply	Significant anecdotal evidence suggests that operating programs create a 10 percent increase in precipitation and snow melt runoff. Proof of additional supply is difficult.
Environmental Issues	No environmental issues identified.
Permitting Issues	No problems in permitting are anticipated.
Cost	Variable. An estimate of $20 to $30 per acre foot is reasonable.