UPDATED PRELIMINARY FEASIBILITY STUDY AND COST ESTIMATES FOR A POSSIBLE WINTER CLOUD SEEDING PROGRAM IN THE HUMBOLDT RIVER BASIN, NEVADA

Prepared for

Humboldt River Basin Water Authority

by

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1.0 INTRODUCTION

Representatives from the Utah Division of Water Resources (UDWR) and North American Weather Consultants (NAWC) were invited attend a meeting of the Humboldt River Basin Water Authority (HRBWA) on May 9, 2014 in Winnemucca, Nevada. Mr. David Cole (UDWR) and Mr. Don Griffith (NAWC) attended this meeting and gave Power Point presentations on Utah cloud seeding regulations, UDWR support of winter operational cloud seeding programs and discussions on four major long-term winter cloud seeding programs being conducted in Utah over selected mountain barriers. These discussions touched on the theory of winter cloud seeding in mountainous areas and the design, conduct, evaluation and cost of these Utah programs. These programs employ manually operated cloud seeding generators that disperse Silver Iodide particles into selected clouds that are considered to be "seedable." Indications of increases in either precipitation or snow water content from these programs average from 5% to 15%. A question was raised during this meeting whether a program might be conducted to benefit the Sonoma Range south of Winnemucca.

Following this meeting Mr. Griffith with NAWC offered to perform a preliminary feasibility assessment of conducting winter cloud seeding programs in mountainous areas of interest in the Humboldt drainage and to provide some preliminary cost estimates for these areas. On June 25, 2014 Dr. Baughman, Executive Director of the HRBWA, provided NAWC with this list of areas of interest:

Independence Mountains

Ruby Mountains

Toiyabe Range

Santa Rosa Range

Sonoma Range

Humboldt Range

Diamond Range (not in Humboldt Basin but of interest to Eureka County, a member of the HRBWA)

Figure 1 provides the locations of these areas.

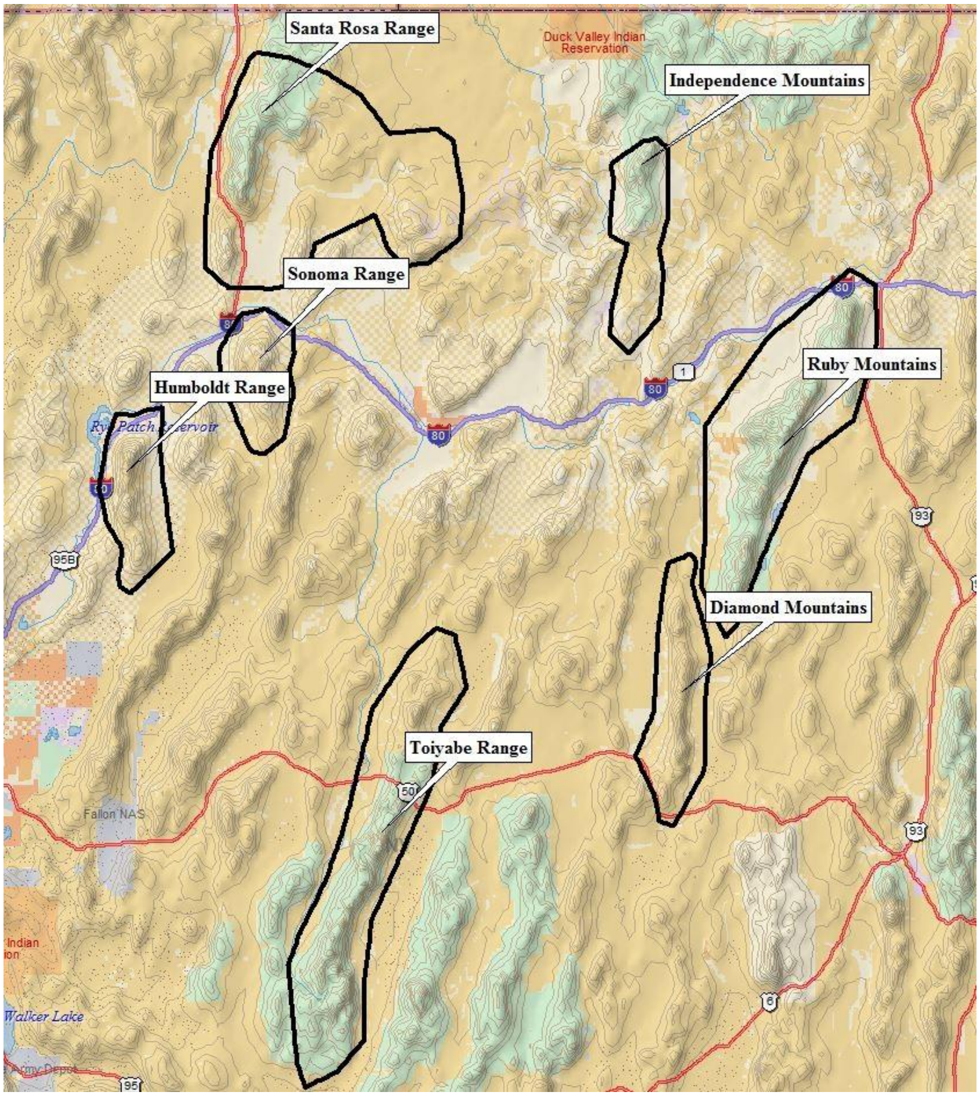

Figure 1 **Possible Target Areas for Winter Cloud Seeding Programs in the Humboldt River Drainage**

Table 1 provides some statistics on each of these potential target areas.

NAWC has performed a preliminary cloud seeding feasibility assessment for the areas identified in Figure 1 and has also prepared some preliminary cost estimates for the conduct of programs in these areas. This information has recently been updated and will be discussed in the following sections.

Table 1   Characteristics of the Seven Potential Target Areas

Independence Mountains - Basin 44
Wheeler Mountain (9,057 ft (2,761 m),
Jack's Peak (10,198 ft (3,108 m),
McAfee Peak (10,439 ft (3,182 m), highest point
Center lat/lon: 41° 14' N; 116° 2' W
Extent: ~ 73 miles N-S, 22 miles E-W

Ruby Mountains - Basins 43,45,46,47
Ruby Dome 11,387 feet (3,471 m), highest peak
Center lat/lon: 40° 12' N; 115° 32' W
Extent: 103 miles N-S, 39 miles E-W

Toiyabe Range - Basin 56
Arc Dome 11,773 feet (3,588 m), highest peak
Center lat/lon: 39° 7' N; 117° 7' W
Extent: 117 miles N-S, 50 miles E-W

Santa Rosa Range - Basins 67,68,69
Granite peak (9732 feet, 2966 m), highest peak
Santa Rosa Peak (9701 feet, 2957 m).
Lat /lon : 41° 27’ N; 117° 41’ W
75 miles north of Winnemucca

Sonoma Range - Basin 71
Sonoma Peak (9,396 feet, 2864 m), highest peak
Center lat/lon: 40° 47' N; 117° 37' W
Extent: 35 miles N-S, 23 miles E- W

Humboldt Range - Basin 72
Star Peak (9,836 feet, 2,998 m), highest point
Center lat/lon: 40° 25' N; 118° 8' W
Extent: 45 miles N-S, 19 miles E-W

Diamond Range - Basin 153
Diamond Peak (10,614 feet, 3,235 m), highest point
Center lat/lon: 39° 48' N; 115° 49' W
Extent: 63 miles N-S, 19 miles E-W

2.0 Preliminary Analysis of the Feasibility of Winter Cloud Seeding in the Humboldt River Basin

An initial analysis was conducted of weather conditions during storm days for the November – April seasonal period, and resulting estimates of cloud seeding potential. Precipitation data from the Lamoille #3 SNOTEL site in the Ruby Range southeast of Elko, Nevada was used to identify periods of significant storm activity during the past 4 winter seasons (2010-11 through 2013-14). This site was selected to identify storm occurrences that impacted the possible target areas as identified in Figure 1. Storm events were broken down into periods of approximately 4-6 hours duration in order to collect/estimate relevant data for analysis. A total of 145 of these periods (on 68 different calendar days) were identified over the 4-season period, roughly representing storm events during which 0.5" or more of total storm precipitation occurred at the Lamoille #3 SNOTEL site. Data used in the analysis includes 700-mb (approximately 10,000 feet MSL) temperatures and winds, cloud top temperature, and estimates of lower-level thermodynamic stability of the atmosphere (an important consideration in the likely transport of ground based seeding material releases rising to altitudes where silver iodide begins acting as an ice nucleant) for each of the time periods identified. Data were collected from archived RAOB (weather balloon) sounding profiles from the twice daily observations taken at Elko, Nevada, as well as archived maps of weather parameters available for a variety of atmospheric levels (with particular focus on the 700-mb level). Interpolation/estimation of these parameters was necessary for some of these time periods.

The analysis considered three potential seeding modes: Ground-based seeding from lower-elevation sites, remote ground-based seeding from elevations slightly below the crest height, and aircraft seeding. The analysis first identified the likely potential increase (as a percentage of the total November – April precipitation) for ground-based seeding only; then the additional potential increase from remote, high-elevation seeding sites; and finally, the additional potential increase from aircraft seeding beyond what could be achieved from the first two seeding modes. If aircraft seeding is considered secondary to ground-based seeding without consideration of remote sites, the remote seeding category and the aircraft seeding category could be summed. These potential seeding increases assume that a suitable array of seeding sites could be attained in both ground based seeding modes.

The methodology from this analysis is based on results from Climax I and II in Colorado, which was intended to relate seedability to cloud top temperature during storm events. The underlying (and obviously very simplified) assumption, based on the results of this study, is a 25% potential seeding increase for cases with cloud top temperatures of -20 C or warmer; a 10% increase for cloud top temperatures between -20 and -25 C; and no increase in cases of cloud tops colder than -25 C. Realistically, cloud tops would be defined as the top of the cloud deck involved in the active precipitation process, so that higher (clearly separate) cloud layers not involved in the precipitation process are ideally not considered. Once the overall seedability was categorized in this manner, “seedable” cases for each period were partitioned into one of the three seeding modes. If conditions appeared favorable for ground-based seeding (the most economical seeding mode), the potential seedability was placed in that category. If conditions appeared favorable for remote, high-elevation seeding but not ground-based seeding, potential seeding effects were included in that mode. If conditions appeared seedable from aircraft only, potential seeding effects were placed in that category.

Two basic criteria were used to select the potential seeding mode: 700-mb (or approximate crest-height) temperature, and lower-level thermodynamic stability based on sounding data. The 700-mb temperature criterion is used to determine if the crest-height temperature is within the favorable seeding window (-5 to -15 C). If the 700-mb temperature is colder than -15 C, the overall seedability is assumed to be 0 (as it was for periods with cloud tops colder than -25 C). If the 700-mb temperature is warmer than -5 C, it is assumed that only aircraft seeding would be effective. An exception was made for spring (March/April) cases where the atmosphere appeared well-mixed, which often allows ground based seeding to be effective in somewhat warmer conditions as the seeding material may quickly be carried much higher than the crest height. In this limited number of applicable March/April cases, a 700-mb temperature threshold of -3 C was used. The second criterion (lower – level atmospheric stability) is used to differentiate between cases seedable from lower-elevation ground sites versus those likely seedable from only higher elevation sites and/or aircraft. Stability was rated as either well-mixed, slightly stable, moderately stable, or very stable. Well-mixed or slightly stable cases were considered to be seedable via lower elevations ground-based sites, while the remainder were generally not. Well-mixed or slightly stable cases are analagous to situations where surface warming (or crest height cooling) of less than 2 degrees C would be necessary for complete, free mixing of the atmosphere. Although ground-based seedability may be marginally inhibited in some of the “slightly stable” cases, modeling dispersion studies have suggested that a significant amount of seeding material would likely reach the crest height within an hour or two in these cases.

After the data were partitioned in this manner, the potential seedability (defined in terms of percentage increase of precipitation) was averaged for all the time periods in the analysis, which of course includes 0% values for those periods assumed to have no seedability. This is intended to provide a reasonable approximation of the likely seasonal (November – April) precipitation percentage increase that could be obtained based on the seeding mode. Results suggest that an approximate 4.5% increase could be obtained from ground-based seeding alone; an additional 0.7% increase with the addition of remote, high-elevation sites;

and a further 2.0% increase with the addition of aircraft seeding. Figure 2 provides a graphic portrayal of this information. This implies a potential 7.2% increase with all three seeding modes, or possibly with aircraft alone (since any of these situations may be **theoretically** seedable with aircraft, although more than one seeding aircraft might be required to do so). Applying these percentages to the long-term average precipitation for the Lamoille SNOTEL (a total of 21.5" for the November – April period) yields a potential increase of just under an inch; 0.97" for ground-based seeding only; 0.15" additional for remote seeding sites; and 0.44" additional seeding potential beyond this if using aircraft. Figure 3 provides a graphic portrayal of this information. This would suggest a total potential increase of about 1.56" if all three seeding modes are considered.   Of course, seeding target areas with higher or lower seasonal precipitation than the Lamoille SNOTEL site would have proportionally higher or lower total potential average increases of additional water, respectively.

The wind data at 700-mb were used to make some generalized comparisons of cloud top temperature and lower-level stability as they relate to likely pre- and post-frontal storm situations. Figure 4 shows the results of this categorization where 700-mb wind directions with a southerly component (less than 270 degrees) may be generally representative of pre-frontal storm periods, and those with a northerly component (e.g. > than 270 degrees) of post-frontal storm periods.   This figure illustrates that southwesterly (pre-frontal) storm periods tend to have colder cloud-top temperatures and more low-level stability than the post-frontal periods. Thus, the post-frontal periods are believed to have more seedable conditions overall, particularly from ground-based sites.   This may be an important consideration for determining locations of ground-based seeding sites.

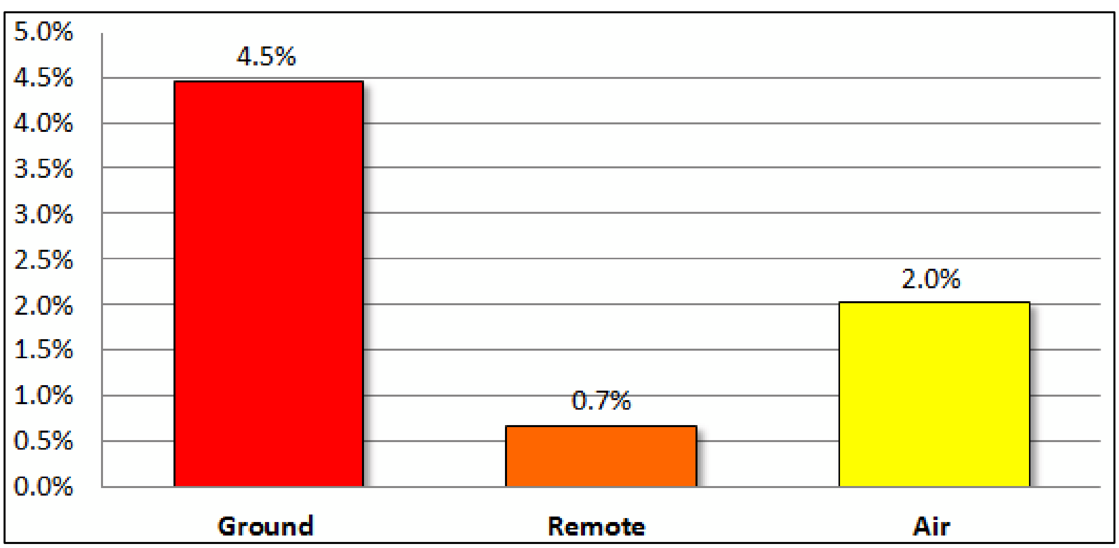

Figure 2 Estimated Percent Increases by Seeding Mode

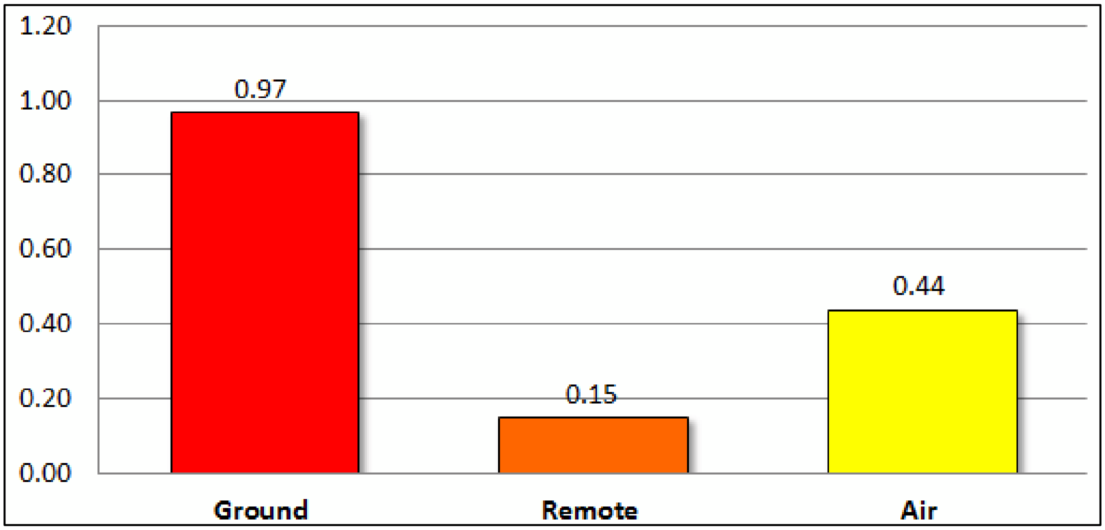

Figure 3 Estimated Average Seasonal Increases in Inches for the Three Seeding Modes

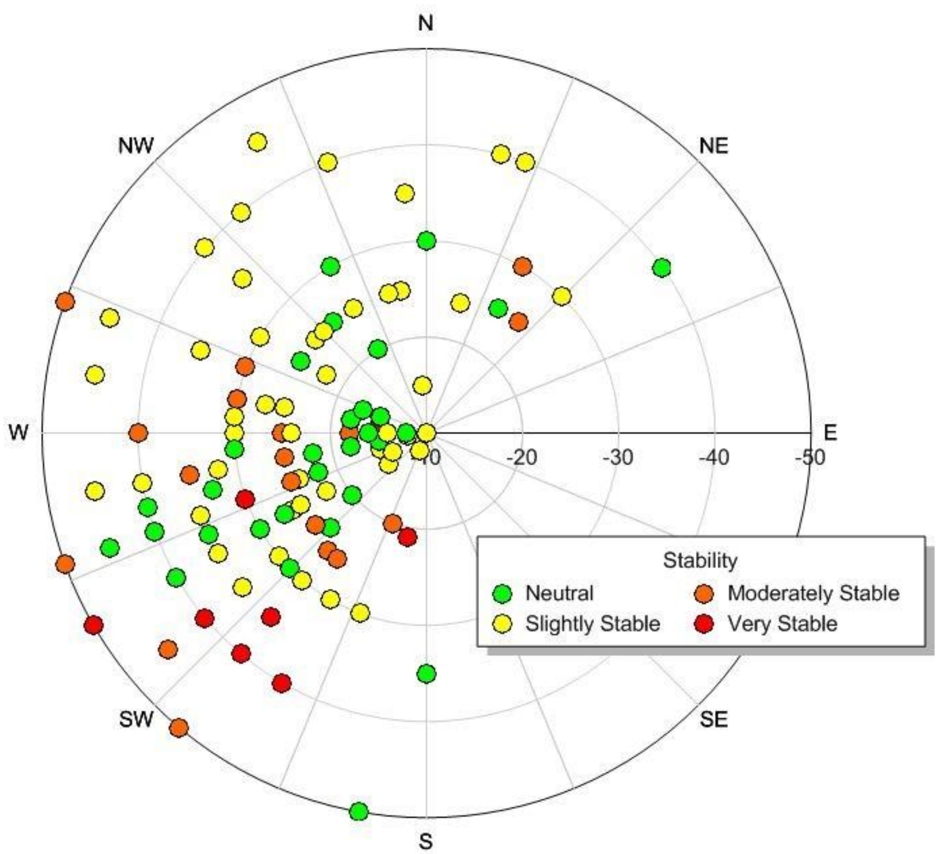

Figure 4. Plot of wind direction vs cloud top temperature and low-level stability. The cloud top temperature corresponds to the radial axis shown to the right of center (-10 to -50 C), and stability to the color of the data point as shown in the legend.

Figure 5 shows potential precipitation increases from ground-based seeding for an average November – April season, based on an estimated 4.5% increase to the natural precipitation at five representative SNOTEL sites. Natural precipitation averages for this seasonal period range from about 17.5” at Big Creek Summit in the south, to 26.2” at Jacks Peak in the north.

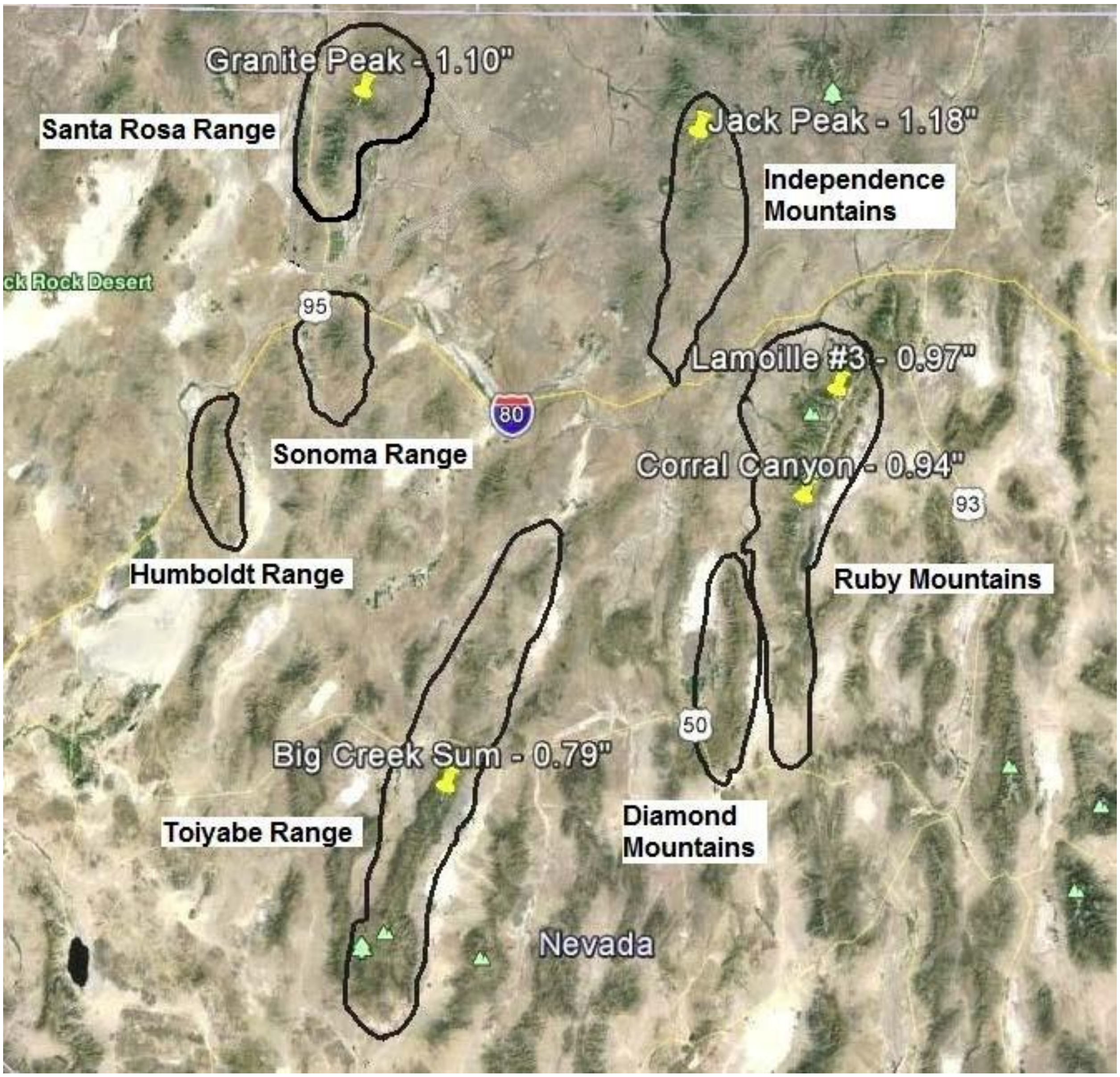

Figure 5 Potential Ground-based Seeding Precipitation Increases for November – April Based on an Estimated 4.5% increase

NAWC developed a map that provides idealized locations of ground-based seeding generators for each of the potential target areas. Based upon some results obtained in a research program conducted in Central Utah in the early 2000's, the desirable spacing between generators is approximately 5 miles. Figure 6 provides this information. As suggested in Figure 4 the low-level winds in winter storms affecting the potential target areas predominately have a westerly component. In other words these winds are generally blowing from west to east. This fact explains why all the proposed generator locations are on the west side of the mountain barriers. Seeding materials released from these locations will normally be transported over the target mountain barriers. The natural progression of wind directions during winter storms in the western United States is for surface (and low level winds) to be from the southwest in pre-frontal conditions, switching to westerly at frontal passage, and then blowing from the northwest under post-frontal conditions. NAWC meteorologists take changing wind directions into account when seeding winter storms. Some generators are turned on under pre-frontal southwesterly winds, some of these generators may be turned off and others turned on as winds switch to westerly then northwesterly directions. This approach is usually referred to as "targeting" of the seeding effects.

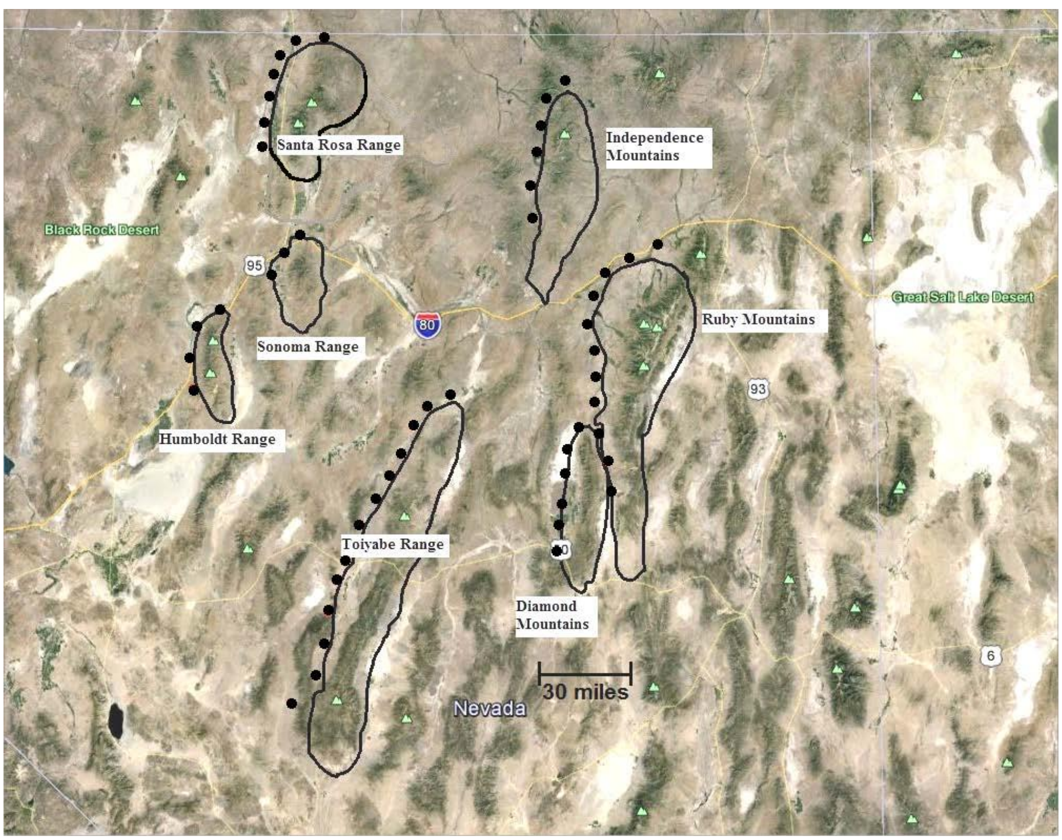

Figure 6 Map showing idealized ground-based seeding locations (approximately every 5-7 miles, 50 sites shown)

3.0 Summary and Preliminary Project Design

Information in section 2.0 suggests there is cloud seeding potential in some winter storms or portions of winter storms that impact the seven potential mountainous target areas in the Humboldt River Basin. Better seeding potential is expected under post-frontal conditions due to lowering cloud tops, decreasing atmospheric stability concerns and lowering temperatures favoring silver iodide particles released from ground sources reaching the silver iodide activation temperature of -5^{0} C sooner. The estimated seeding potential of the three possible seeding modes; manually operated ground-based generators (4.5%), higher elevation remotely controlled ground-based generators (0.7%) and airborne seeding (2.0%) suggest that a seeding design using manually operated ground-based generators would achieve 63% of the total precipitation increases as opposed to if all three seeding modes were used. This fact coupled with the higher costs associated with remotely controlled generators and seeding aircraft would argue in favor of a project design that relies upon networks of manually operated ground-based generators.

Figure 6 provided idealized generator networks for the seven potential target areas. The hypothetical number of generators for each area was:

- Independence Mountains 6
- Ruby Mountains 11
- Toiyabe Range 13
- Santa Rosa Range 7
- Sonoma Range 3
- Humboldt Range 4
- Diamond Range 6

These are idealized numbers. One concern is the low populations in the areas on the west sides of the mountains or ranges. NAWC needs local residents at these locations that are willing to be trained and then to operate our generators when they are called by our meteorologists to do so. Because of the population density we are likely not to find operators at all these locations. An alternate approach might be possible where generators are installed in areas without any habitation. A technician could then be hired to travel to these sites to turn them on and off during storm periods. The feasibility of this approach may depend on the land ownership of these uninhabited locations. Approval to site them on private property could hopefully be arranged. Placing them on State or Federal property may be more problematic possibly raising licensing or permitting questions and possibly some form of environmental review process.

Considering the size and proximity of these areas it may make sense to consider combining some of these areas into larger project areas. For example, combining the Diamond and Ruby Mountains into one program and the Humboldt and Sonoma Ranges into one program could result in some economy of scale. One could go even further with this approach by combining the:

- Diamond, Independence and Ruby Mountains
- Independence Mountains and Santa Rosa Range
- Humboldt and Sonoma Ranges

Combining areas would not only need to be considered in the terms of technical feasibility but also in terms of the political feasibility. Can partnerships between different districts be developed to support this economy of scale approach? How would the program costs be allocated between the participating districts? It might even be feasible to conduct a program designed to seed all seven potential target areas for additional economies of scale. This approach has been used successfully in central and southern Utah to represent 11-12 separate counties since 1974. Perhaps the HRBWA could administer such a program. Additional questions would no doubt arise when considering the above approaches.

Another technical question could be important; can the estimated potential increase in precipitation be applied equally to the seven potential target areas? Our professional judgment is that these seeding increases would be more likely to occur over the longer, wider, higher target areas. **Our subjective rating of the overall "seedabilty" of these areas using manually operated ground generators would be, in the order of <u>most</u> to <u>least</u> "seedable":**

- Toiyabe Range
- Ruby Mountains
- Independence Mountains
- Santa Rosa Range
- Diamond Mountains (should probably be considered joined to the Ruby Mountains).
- Sonoma Range
- Humboldt Range

This subjective listing does not mean there is no seeding potential in those areas lower on the list, but these areas likely have less seeding potential than those higher on the list. Several meteorological considerations went into the ranking order in the above list. For example, when considering small barriers, the low level wind flow may flow around instead of over the barrier.

Seeding materials released at ground level would be carried by these winds going around instead of over the barrier. Wider barriers would provide for more time for the creation, growth and fall out of snowflakes making it more likely these snowflakes would fall on the barrier while carried along by the lower elevation winds passing over the barrier. Aircraft seeding to impact the smaller barriers might provide better seeding results but would be considerably more expensive than a manually operated ground generator program. An economy of scale might be possible linking several adjacent areas into one program area that could be treated by one seeding aircraft.

In order to conduct such programs in Nevada, NAWC would need to obtain a license from the Nevada State Department of Conservation and Natural Resources according to NRS Chapter 544 – Modification of Weather. This regulation is split into two parts; one for research programs and one for operational programs. The key part for operational programs is worded as follows:

NRS 544.140 Qualifications of licensees; issuance and renewal of licenses; fee. [Effective until the date of the repeal of 42 U.S.C. § 666, the federal law requiring each state to establish procedures for withholding, suspending and restricting the professional, occupational and recreational licenses for child support arrearages and for noncompliance with certain processes relating to paternity or child support proceedings.]

1. Licenses to engage in activities for weather modification and control must be issued to an applicant who:

(a) Pays the fee required pursuant to subsection 2;

(b) If the applicant is a natural person, submits the statement required pursuant to NRS 544.132; and

(c) Demonstrates, to the satisfaction of the Director, competence in the field of meteorology reasonably necessary to engage in activities for weather modification and control.

2. If the applicant is an organization, the requirements set forth in paragraphs (a) and (c) of subsection 1 must be met by the person or persons who are to be in control and in charge of the operation for the applicant.

3. The Director shall issue licenses in accordance with such procedures and subject to such conditions as the Director may by regulation establish to effectuate the provisions of NRS 544.070 to 544.240, inclusive. Each license must be issued for a period to expire at the end of the calendar year in which it is issued and, if the licensee possesses the qualifications necessary for the issuance of a new license, the license must, upon application, be renewed at the expiration of that period. A license must be issued or renewed only upon the payment to the Director of $100 for the license or the renewal thereof.

Other parts of this regulation outline procedures to be followed in order to obtain a license (e.g. notice of intent, proof of financial responsibility, etc.).

Concerning cloud seeding feasibility studies to augment precipitation, a recent publication from the American Society of Civil Engineers (ASCE 2016) contains the following recommendations:

1. *"When possible, the feasibility study for a program should draw significantly from previous research and well-conducted operational programs that are similar in nature to the proposed program (e.g. similar topography, similar precipitation occurrences, etc.)."*
2. *"The primary purpose of the feasibility study is to answer two questions. First, does it appear that a cloud seeding program could be implemented in the intended target area that would be successful in achieving the stated objectives of the program? Second, are the estimated increases in precipitation expected to produce a positive benefit-cost ratio?"*

NAWC's response to the first recommendation (technical feasibility) is positive for winter cloud seeding programs conducted in the Humboldt River Basin of Nevada using ground-based manually operated silver iodide generators. This seeding technique has been used in several similar mountainous target areas in Utah one of which has operated nearly continuously since 1974. Evaluations of this program have consistently shown an average seasonal increase in precipitation of 14% (Griffith, et al, 2009). In addition, several years of research conducted in central and southern Utah identified seeding potential in winter storms that impact these areas as well as the transport of seeding material into the seedable portions of these storms (Super 1999).

Response to the second recommendation (economic feasibility) is more difficult to assess. NAWC typically estimates seasonal increases in precipitation from a proposed program then correlates target area precipitation with streamflow. Average increases in precipitation are then inserted into the regression equation correlating precipitation with streamflow to estimate an average increase in streamflow. If the value of the additional streamflow can be estimated, a benefit/cost ratio can be established based upon the estimated costs of conducting the program. NAWC did not attempt this type of analysis. It would require long-term unimpaired streamflow records from the target areas and estimated values of the augmented streamflow. The ASCE recommends a 5/1 ratio for a program to be considered economically feasible.

NAWC did perform a less comprehensive analysis to estimate the amount of runoff that might be produced from some of the potential target areas from cloud seeding. This analysis is covered in the following section.

4.0 Preliminary Cost Estimates

We have made some preliminary cost estimates for some of the proposed target areas. NAWC typically contracts to conduct operational cloud seeding programs on both a fixed price and cost reimbursable fashion. Our fixed costs cover 1) the set-up, take-down and reporting (state and federal reports and a seasonal final report on operations) and 2) Cost reimbursement for actual hours of generator usage (a unit cost per hour and an estimated number of generator hours is established in an agreement. The following cost estimates could be used for:

1. The combined Diamond and Ruby Mountains Target Areas
2. The Toiyabe Range Target Area
3. The combined Independence Mountain and Santa Rosa Range Target Areas.

Diamond and Ruby Mountains or Toiyabe Range or Independence Mountains and Santa Rosa Range

1. Set-Up, Take-down, reporting fixed costs	$64,000
2. Monthly Fixed Costs	$10,000
3. Estimated Reimbursable Costs,	
2000 generator hours @ $9.00/hr.	$18,000
Total Estimated Costs for a five-month program	$132,000

Important note, the above costs assume that NAWC would need to fabricate additional ground based manually operated generators. If NAWC had generators in stock for a given up-coming winter season, the set-up costs could be reduced.

Humboldt and Sonoma Ranges

1. Set-Up, Take-down, reporting fixed costs	$36,000
2. Monthly Fixed Costs	$ 9,000
3. Estimated Reimbursable Costs,	
1200 generator hours @ $9.00/hr.	$10,800
Total Estimated Costs for a five-month program	$91,800

4.1 Preliminary Estimates of Runoff Increases and Estimated Costs per Acre Foot

The estimated average increases in precipitation for some of the potential target areas, as provided in Figure 5, may be used to develop some ballpark estimates of the amount of surface runoff that might be produced from these potential target areas. The HRBWA provided NAWC with some estimates of the size of some of the proposed target areas expressed in acres. There were no size estimates for the Humboldt or Sonoma Ranges. This information can be combined with the estimated average precipitation increases to provide ballpark average annual runoff values. For example, for the Ruby Mountains target area: 880 $mi.^2$ x 1.00 inch/12 inches/foot x 640 $ac./mi.^2$ = 46,930 acre-feet. Table 2 provides these calculated increases for barriers for which we were provided size estimates. These estimates are for an average year both in terms of estimated increases in precipitation and runoff.

Table 2 Estimated Increases in Runoff (Acre-Feet)

Target Area	Target Size Miles ^{2}	Est. Precipitation Increase inches	Est. Runoff Increase Acre-feet
Independence Mts.	280	1.18	17,620
Ruby Mts.	880	1.00	46,930
Toiyabe Range	1200	0.80	51,200
Santa Rosa Range	375	1.10	22,000
Diamond Range	290	1.00	15,470

The estimated runoff increases may be combined with the annual estimates of conducting these programs to provide preliminary estimates of the costs per acre foot of producing the additional runoff in an average year. These calculations are provided in Table 3.

There are several assumptions being made to provide the information contained in Tables 2 and 3 including the following:

- That the estimated precipitation increases for the Ruby Mountains can be applied to the Diamond Mountains.
- That the estimated increases summarized in Figure 5 can actually be achieved.
- That these estimated increases in additional precipitation will be spread evenly over the entire targeted mountain barrier.
- That the estimated increases in precipitation end up generating additional runoff and are not subject to increasing underground aquifer storage or evapotranspiration processes.

- That these estimates are for an average year. In an above average year, the additional runoff numbers would likely increase and the estimated costs per acre foot would decrease. The reverse would be true in a below average year.

Due to the uncertainties, it might be wise to cut the estimated runoff increases in half to hopefully provide conservative estimates. This would have the effect of doubling the cost per acre-foot numbers which would then be in the approximate range of $4.20 to $6.60 per acre-foot range. If there were some estimates of the value of surface runoff from these mountain barriers, rough benefit/cost estimates could be developed. For example, let's say the value of the water originating in the Diamond and Ruby Mountains has a value of $15.00/acre-foot then the estimated benefit to cost ratio would be: $15.00/$2.11 or 7.1 to 1. This would mean for each dollar spent on cloud seeding the benefits would be roughly seven dollars. It is easy to look at the cost of conducting a cloud seeding program but it is important to put these costs in their proper perspective by comparing costs versus the likely return on the investment.

Table 3   Estimated Cost per Acre Foot of Additional Runoff

Target Area(s)	Est. Runoff Increase Acre Feet	Est. Annual Cost	Est. Cost/Acre Foot
Diamond & Ruby	62,400	$132,000	$2.11
Independence & Santa Rosa	39,620	$132,000	$3.33
Toiyabe	51,200	$132,000	$2.58

5.0 NAWC Experience and Qualifications

Corporate Background of
North American Weather Consultants

North American Weather Consultants (NAWC) is one of the longest-standing private meteorological consulting firms in the United States. In 1970, NAWC received the American Meteorological Society's prestigious *Award for Outstanding Services to Meteorology by a Corporation* "for its pioneering the practice of private meteorology in the United States..." We have been providing high quality, innovative consulting services to clients domestically and abroad for more than 50 years. This page provides some background on NAWC, describes who we are, what we do, and the underlying philosophy that drives our business approach and corporate standards.

Corporate History - NAWC has provided meteorological, weather modification, and air quality consulting services since its establishment in 1950. We have a long, proud history of providing our clients with complete, focused consulting services. Our underlying corporate philosophy and business approach have withstood the test of time. NAWC operated as a private corporation until being acquired by a large, publicly-traded corporation in 1992. In 1999, NAWC separated from the parent firm, resuming its operations as a private corporation.

NAWC was established in the Santa Barbara, California area in 1950 and maintained its headquarters there until 1980, when the corporate offices were relocated to Salt Lake City, Utah. Our offices are currently located in Sandy, Utah, a suburb of Salt Lake City.

Our Corporate Philosophy - NAWC's corporate philosophy hinges on pride in our work and a clear focus on our clients' specific needs. Clients hire consultants to help them find answers to their problems/needs, each within a context of specific circumstances. Our simple approach is to listen very closely to our clients from the outset, and then tailor our work to address their specific needs. This approach leads to focused, timely, and cost-effective solutions for our clients.

Our Corporate Structure - NAWC consists of two primary divisions: 1) Weather Modification, including a broad spectrum of operations and research projects and 2) Applied Meteorology, involving a wide variety of activities in the areas of extreme precipitation (probable maximum precipitation), forecasting, climatology, and forensics.

---NAWC FAST FACTS---

- Incorporated in 1950, NAWC has nearly 60 years of continuous involvement in weather modification.
- NAWC was founded as a weather modification company. Weather modification has always been NAWC's primary specialty.
- NAWC is recognized internationally as a leader in the weather modification field, in research and operations.
- NAWC received the American Meteorological Society's prestigious "Award for Outstanding Services to Meteorology by a Corporation" in 1970 for pioneering the practice of private meteorology in the United States.
- NAWC has conducted weather modification projects and provided consulting services in many countries outside the United States, including Europe, South America, Central America, Asia, and the Middle East.
- Our weather modification activities and contributions are well known, through our hundreds of publications and reports.
- Our extensive client list includes hydroelectric utilities, government agencies, water districts, universities and private entities.
- NAWC's client satisfaction rating is consistently very high, due to NAWC's ongoing commitment to carefully determine and fully address each client's specific needs. We always tailor our services to our clients' interests and circumstances.
- NAWC offers the full spectrum of weather modification services, ranging from basic research to feasibility studies and reviews of existing projects, and from start-up services to full-service operational projects.
- We offer the full range of cloud seeding capabilities, including ground-based and airborne seeding systems, appropriate support systems, and ground-based and airborne seeding plume tracking, using tracer technology.

NAWC is well known in the weather modification arena for designing, operating and evaluating winter cloud seeding programs. We operate long-term programs in California, Colorado, and Utah. Our staff members are certified by the Weather Modification Association (WMA) and NAWC’s President is also certified by the American Meteorological Society as a Certified Consulting Meteorologist (CCM). NAWC staff members have published numerous technical papers in professional journals and staff members also make technical presentations at meteorological conferences. Our company is active in the non-profit Weather Modification Association: www.weathermodification.org. Our web site provides additional information on our company: www.nawcinc.com. Table 4 provides work references for some of our cloud seeding clients. Appendix A provides a summary of previous and on-going operational cloud seeding programs.

Table 4

Some Representative NAWC Weather Modification Programs

- Santa Barbara County operational winter seeding program, 2001-2016 winter seasons. Airborne seeding and ground seeding using three to six high output, ground based flare sites and a cloud seeding aircraft. NEXRAD weather radar output used in place of project specific radar.

- Santa Barbara County operational winter seeding program, most winters 1978-1997. Seeding conducted using both ground based and aerial seeding. Weather radar support was provided by the Air Force from Vandenberg Air Force base until 1988. NAWC installed independent weather radar for program operations beginning in 1989.

- Upper Kings River winter seeding program for the Kings River Conservation District, ground based and aircraft seeding with weather radar control, 1988-1993, 2007-2016. NAWC recently awarded a new five year contract under a competitive bid process. Contact Mr. Steve Stadler, 559-237-5567 main x 115.

- Southern California Edison winter and summer seeding program for the Upper San Joaquin River Basin in the southern Sierra Nevada 1951-1987; 1990-1992. Ground based and airborne seeding.

- Los Angeles County Flood Control District winter operational seeding program in the San Gabriel Mountains. Ground based seeding program conducted each winter from 1961-1975. Program began again in spring of 1991 and continued in 1992, 1993, and 1997 to 2002 then suspended due to fire burn areas. This program was re-started last winter. Contact Mr. Keith Hala, .

- Sacramento Municipal Utility District winter weather forecast support and recommendations of silver iodide generators to be used during storm periods for their internally operated cloud seeding program; three year contract which began in the spring of 2004. Contract renewed and work continued through 2014 (contact, Dudley McFadden, 916-732-5953).

- California Department of Water Resources, Northern California Drought relief program conducted during the 1988-89 winter season. NAWC conducted airborne seeding utilizing two seeding aircraft and supported with on-site weather radar.

- Southern and Central Utah, State of Utah Division of Water Resources, operational winter cloud seeding program 1974-1983 and 1984-present. Ground generators used supplemented with aircraft seeding (up to four aircraft) in some of the winters. (contact, David Cole, 801-538-7269).

- Northern Utah, State of Utah Division of Water Resources, operational winter cloud seeding program 1988-present. Ground generator program (contact, David Cole, 801-538-7269).
- High Uinta Mountains, Utah, State of Utah Division of Water Resources, operational winter cloud seeding program 1977, 1989, 2003-2011 (contact, David Cole, 801-538-7269).
- Upper Boise River, Idaho, Boise Project Board of Control, operational winter cloud seeding program 1992-1996, 2007-2009, 2010-2011, 2013-2014 (contact Tim Page, 208-344-1141).
- Upper Gunnison River, Colorado, operational winter cloud seeding program 2002-2014 (contact Jane Wyman, 970-641-7671).

- El Cajon Dam drainage area, Honduras, 1993-95, and 1997. Airborne and ground based seeding program supported with on-site weather radar

Additional information can be furnished upon request.

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Appendix A

NORTH AMERICAN WEATHER CONSULTANTS OPERATIONAL CLOUD SEEDING PROGRAMS
Partial Listing (through April 2016)

Project Area: **Gunnison County, Colorado**
Sponsor: Gunnison County
Technique: Ground based silver iodide seeding
Time Period: 2003-present
Goal: Enhanced winter precipitation for irrigation water supplies

Project Area: **Little Cottonwood Canyon, Utah**
Sponsor: Alta and Snowbird Ski Areas
Technique: Ground based silver iodide seeding
Time Period: 1996 - present
Goal: Enhanced winter snowfall for skiing

Project Area: **Wellsville and Wasatch Mountains of Northern Utah**
Sponsor: Utah Division of Water Resources and Cache County
Technique: Ground based silver iodide seeding
Time Period: 1997 - 2000, 2002-present
Goal: Enhanced winter precipitation for irrigation water supplies

Project Area: **Upper Ogden River and Lost Creek Watersheds, Utah**
Sponsor: Weber Basin Water Conservancy District and Utah Division of Water Resources
Technique: Ground based and airborne silver iodide seeding
Time Period: 1991 - 1993
Goal: Enhanced winter precipitation for irrigation water supplies

Project Area: **Upper San Joaquin River Drainage, Southern Sierra Nevada of California**
Sponsor: Southern California Edison Company
Technique: Ground based and airborne silver iodide seeding with radar surveillance
Time Period: 1951 - 1987 and 1990 - 1992
Goal: Enhanced winter and summer precipitation for hydroelectric power production

Project Area: **Mountain Watersheds in Central and Southern Utah**
Sponsor: Utah Water Resources Development Corporation Utah Division of Water Resources, 13 Utah
Counties
Technique: Airborne and ground based silver iodide seeding
Time Period: 1973 - 1983, 1987, 1988-present
Goal: Enhanced winter precipitation for irrigation water supplies

Project Area: **Bear Lake Drainage, Smith & Thomas Forks, Southwestern Wyoming and Southeastern Idaho**
Sponsor: Utah Power and Light Company
Technique: Ground based silver iodide seeding
Time Period: 1954 - 1970; 1979 - 1982, 1989 - 1990
Goal: Enhanced winter precipitation for hydroelectric power production

Project Area: **Santa Barbara County, California**
Sponsor: Santa Barbara County Water Agency
Technique: Ground based and airborne silver iodide seeding with radar surveillance; ground-based flare seeding
Time Period: 1950-1953; 1955; 1956-1960; 1978; 1982 – 1997; 2002-2007; 2008-present
Goal: Enhanced winter precipitation for municipal and agricultural water supplies

Project Area: **Grouse Creek, Raft River, Wellsville and Wasatch Mountains of Northern Utah**
Sponsor: Utah Water Resources Development Corporation,Utah Division of Water Resources, and Cache and Box Elder Counties
Technique: Ground based silver iodide seeding
Time Period: 1989 - 1997, 2001-present
Goal: Enhanced winter precipitation for irrigation water supplies

Project Area: **Provo and Weber River Drainages in Western Uinta Mountains of Utah**
Sponsor: Utah Water Resources Development Corporation, Utah Division of Water Resources, Provo River Water Users Association and Weber Basin Water Conservancy District
Technique: Ground based silver iodide seeding
Time Period: 1989 - 1995, 2000-present
Goal: Enhanced winter precipitation for irrigation water supplies

Project Area: **Wasatch Mountains in Eastern Salt Lake County, Utah**
Sponsor: Utah Water Resources Development Corporation; Utah Division of Water Resources; Salt Lake City Water Division; and Alta, Brighton, and Snowbird Ski Areas
Technique: Ground based silver iodide seeding
Time Period: 1989 - 1996
Goal: Enhanced winter precipitation for municipal water supplies

Project Area: **Upper Kings River Drainage in the Southern Sierra Nevada of California**
Sponsor: Kings River Conservation District and Kings River Water Users Association
Technique: Airborne and ground based silver iodide seeding with radar surveillance
Time Period: 1989 – 1993, 2007-present
Goal: Enhanced winter precipitation for irrigation water supplies

Project Area: **Upper Feather River Drainage in the Northern Sierra Nevada of California**
Sponsor: California Department of Water Resources
Technique: Airborne silver iodide seeding with radar surveillance
Time Period: 1989
Goal: Enhanced winter precipitation for municipal and irrigation water supplies

Project Area: **Grand Mesa and West Elk Mountains of Western Colorado**
Sponsor: Grand Mesa Water Users Association
Technique: Ground based silver iodide seeding
Time Period: 1990 - 1991
Goal: Enhanced winter precipitation for irrigation water supplies

Project Area: **San Gabriel Mountains, California**
Sponsor: Los Angeles County Flood Control District
Technique: Ground based silver iodide seeding
Time Period: 1959 - 1973, 1991 - 1993, 1997-2001, 2016.
Goal: Enhanced winter precipitation for municipal water supplies

Project Area: **Bannock, Portneuf and Bear River Mountain Ranges of Southeastern Idaho**
Sponsor: Bear River RC&D and Bannock, Bear Lake, Caribou, Franklin, and Oneida Counties
Technique: Ground based silver iodide seeding
Time Period: 1988 - 1989, 1992, 1993
Goal: Enhanced winter precipitation for irrigation water supplies

Project Area: **Uinta Mountains of Northeastern Utah**
Sponsor: Uinta County, Duchesne County and Utah Division of Water Resources
Technique: Airborne and ground based silver iodide seeding
Time Period: 1977, 1989, 2003-present
Goal: Increased winter spring, and summer precipitation for irrigation water supplies

Project Area: **Boise River Drainage, Idaho**
Sponsor: Boise Project Board of Control
Technique: Ground based silver iodide seeding
Time Period: 1992 - 1996, 2002-2005, 2007-present
Goal: Enhanced winter precipitation for irrigation water supplies and hydroelectric power production

Project Area: **Willow Creek Drainage, Colorado**
Sponsor: Northern Colorado Water Conservancy District
Technique: Ground based silver iodide seeding
Time Period: 1992 - 1995
Goal: Enhanced winter precipitation for irrigation water supplies

Project Area: **Higher Elevation Watersheds of Nine Eastern Idaho Counties and One Western Wyoming County**
Sponsor: High Country RC&D
Technique: Ground based silver iodide seeding
Time Period: 1993, 1995
Goal: Enhanced winter precipitation for irrigation water supplies

Project Area: **Santa Clara County, California**
Sponsor: Santa Clara Valley Water District
Technique: Airborne silver iodide seeding with radar surveillance
Time Period: 1992
Goal: Enhanced winter precipitation for municipal water supplies

Project Area: **Mornos River Drainage, Greece**
Sponsor: Greater Athens Water Authority
Technique: Airborne silver iodide seeding with radar surveillance
Time Period: 1992, 1993
Goal: Enhanced winter precipitation for municipal water supplies

Project Area: **Chixoy River Drainage, Guatemala, C. A.**
Sponsor: Empresa Electrica and Instituto Nacional de Electrificacion
Technique: Airborne and ground based silver iodide seeding with radar surveillance
Time Period: 1991, 1992, 1994
Goal: Enhanced summer precipitation for hydroelectric power production

Project Area: **El Cajon Drainage Basins, Honduras, C. A.**
Sponsor: Empresa Nacional De Energia Electrica
Technique: Airborne and ground based silver iodide seeding with radar surveillance
Time Period: 1993, 1994, 1995, 1997
Goal: Enhanced summer precipitation for hydroelectric power production

Project Area: **Tsengwen Dam Drainage, Taiwan**
Sponsor: Taiwan Central Weather Bureau
Technique: Ground based silver iodide seeding
Time Period: 1992, 1994
Goal: Enhanced summer precipitation for irrigation water supplies

Project Area: **West Central Texas Near San Angelo**
Sponsor: City of San Angelo, Texas
Technique: Airborne silver iodide seeding with radar surveillance
Time Period: 1985, 1986, 1987, 1988
Goal: Enhanced summer precipitation for municipal water supplies

Project Area: **Edwards Plateau Northwest of San Antonio**
Sponsor: Edwards Underground Water District, San Antonio, Texas
Technique: Airborne silver iodide seeding with radar surveillance
Time Period: 1985, 1986
Goal: Enhanced summer precipitation for municipal water supplies

Project Area: **South Central Texas North of Corpus Christi**
Sponsor: City of Corpus Christi, Texas
Technique: Airborne silver iodide seeding with radar surveillance
Time Period: 1985
Goal: Enhanced summer precipitation for municipal water supplies

Project Area: **Pine Valley Mountains in Southwestern Utah**
Sponsor: Washington County Water Conservancy District and Utah Division of Water Resources
Technique: Ground based silver iodide seeding
Time Period: 1985-1987
Goal: Enhanced winter precipitation for municipal and irrigation water supplies

Project Area: **Southern Delaware**
Sponsor: Delaware Department of Agriculture
Technique: Airborne silver iodide seeding with radar surveillance
Time Period: 1985
Goal: Enhanced summer precipitation for agricultural water supplies

Project Area: **Abu Dhabi, United Arab Emirates**
Sponsor: Abu Dhabi Municipality
Technique: Airborne silver iodide seeding with radar surveillance
Time Period: 1982
Goal: Enhanced winter precipitation for agricultural water Supplies

Project Area: **Catalina Island, California** Sponsor: Southern California Edison, Co.
Technique: Airborne silver iodide seeding with radar surveillance
Time Period: 1977 - 1978
Goal: Enhanced winter precipitation for municipal water supplies

Project Area: **Bulloch County, Eastern Georgia**
Sponsor: Drought Relief Fund
Technique: Airborne silver iodide seeding with radar Surveillance
Time Period: 1977
Goal: Enhanced summer precipitation for agricultural water supplies

Project Area: **Southern Georgia**
Sponsor: Southern Georgia Rain Gain
Technique: Airborne silver iodide seeding with radar surveillance
Time Period: 1977
Goal: Enhanced summer precipitation for agricultural water supplies

Project Area: **Burke County, Eastern Georgia**
Sponsor: Burke County
Technique: Airborne silver iodide seeding with radar surveillance
Time Period: 1977
Goal: Enhanced summer precipitation for agricultural water supplies

Project Area: **Polk County, Oregon**
Sponsor: Polk County
Technique: Airborne dry ice seeding
Time Period: 1977
Goal: Enhanced winter precipitation for agricultural water supplies

Project Area: **Deschutes River Drainage, Central Oregon**
Sponsor: Portland General Electric Company Technique: Ground based silver iodide seeding
Time Period: 1964-1965; 1974-1976
Goal: Enhanced winter precipitation for hydroelectric power production

Project Area: **Chelan Lake Drainage, Central Washington**
Sponsor: Chelan Public Utility District
Technique: Airborne dry ice seeding
Time Period: 1976 - 1977
Goal: Enhanced winter precipitation for irrigation water supplies

Project Area: **Baker River Drainage, Northern Washington**
Sponsor: Puget Power Company
Technique: Airborne dry ice seeding
Time Period: 1976 -1977
Goal: Enhanced winter precipitation for hydroelectric power production

Project Area: **Skagit River Drainage, Northern Washington**
Sponsor: Seattle City Light Company
Technique: Airborne dry ice seeding
Time Period: 1976 - 1977
Goal: Enhanced winter precipitation for hydroelectric power production

Project Area: **Lake Spalding Drainage, in the Northern Sierra Nevada of California**
Sponsor: Pacific Gas and Electric Company
Technique: Airborne silver iodide seeding
Time Period: 1976 - 1977
Goal: Enhanced winter precipitation for hydroelectric power production

Project Area: **Heritage and Mona Reservoir Areas, Central Jamaica**
Sponsor: Kingston Water Commission
Technique: Airborne silver iodide seeding
Time Period: 1976
Goal: Enhanced summer precipitation for municipal water supplies

Project Area: **Port of Ensenada, Mexico**
Sponsor: Insisa
Technique: Ground based silver iodide seeding
Time Period: 1970 - 1976
Goal: Enhanced winter precipitation for municipal water supplies

Project Area: **Northwestern South Dakota**
Sponsor: South Dakota Weather Control Commission
Technique: Airborne silver iodide seeding
Time Period: 1975
Goal: Enhanced summer precipitation and hail suppression for agricultural crops

Project Area: **Coeur D'Alene Lake Watershed, Northern Idaho**
Sponsor: Washington Water and Power Company
Technique: Ground based silver iodide seeding
Time Period: 1950-1951; 1952-1960; 1966-1971; 1973-1974
Goal: Enhanced fall - early winter precipitation for hydroelectric power production

Project Area: **Hungry Horse Reservoir Area, Northwestern Montana**
Sponsor: Bonneville Power and Light Company
Technique: Ground based silver iodide seeding
Time Period: 1966 - 1971
Goal: Enhanced winter precipitation for hydroelectric power generation

Project Area: **San Benito County, California**
Sponsor: San Benito County
Technique: Ground based silver iodide seeding
Time Period: 1964 - 1966
Goal: Enhanced winter precipitation for irrigation water supplies

Project Area: **Owyhee Reservoir, Southwestern Idaho**
Sponsor: Board of Control - Owyhee Project
Technique: Ground based silver iodide seeding

Time Period: 1954-1956; 1959-1962
Goal: Enhanced winter precipitation for irrigation water supplies

Project Area: Ventura County, California
Sponsor: Ventura County
Technique: Ground based silver iodide seeding
Time Period: 1957 - 1960
Goal: Enhanced winter precipitation for irrigation and municipal water supplies

Project Area: Santa Ana River Basin, California
Sponsor: Santa Ana River Weather Corporation
Technique: Ground based silver iodide seeding
Time Period: 1956 - 1960
Goal: Enhanced winter precipitation for municipal water supplies

Project Area: Lake Almanor Drainage, in the Northern Sierra Nevada of California
Sponsor: Pacific Gas and Electric Company
Technique: Ground based silver iodide seeding
Time Period: 1952 - 1960
Goal: Enhanced winter precipitation for hydroelectric power production

Project Area: Mokelumne & Stanislaus Rivers, in the Central Sierra Nevada of California
Sponsor: Pacific Gas and Electric Company
Technique: Ground based silver iodide seeding
Time Period: 1952 - 1960
Goal: Enhanced winter precipitation for hydroelectric power production

Project Area: Campbell River Drainage, British Columbia
Sponsor: British Columbia Hydro Company
Technique: Ground based silver iodide seeding
Time Period: 1954 - 1960
Goal: Enhanced winter precipitation for hydroelectric power production

Project Area: Southern Cascades, Oregon
Sponsor: California-Oregon Power Company
Technique: Ground based silver iodide seeding
Time Period: 1951 - 1960
Goal Period: Enhanced winter precipitation for hydroelectric power production

Project Area: Crane Valley in the Central Sierra Nevada of California
Sponsor: Pacific Gas and Electric Company
Technique: Ground based silver iodide seeding
Time Period: 1954 - 1959
Goal: Enhanced winter precipitation for hydroelectric power production

Project Area: San Diego County, California
Sponsor: San Diego County Weather Corporation
Technique: Ground based silver iodide seeding Time Period: 1950-1951; 1956-1957
Goal: Enhanced winter precipitation for municipal water supplies

Project Area: Ocean Falls, British Columbia
Sponsor: Crown-Zellerbach Paper Company
Technique: Ground based silver iodide seeding
Time Period: 1955 - 1957
Goal: Enhanced winter precipitation for hydroelectric power production

Project Area: Decatur and Clarke Counties, Iowa
Sponsor: The Decatur County Weather Modification Association
Technique: Ground based silver iodide seeding
Time Period: 1957
Goal: Enhanced summer precipitation for agricultural water supplies

Project Area: Greene, Boone and Story Counties, Iowa
Sponsor: Central Iowa Modification Association
Technique: Ground based silver iodide seeding
Time Period: 1957
Goal: Enhanced summer precipitation for agricultural water supplies

Project Area: Dallas County, Iowa
Sponsor: Dallas County Weather Modification Group
Technique: Ground based silver iodide seeding
Time Period: 1957
Goal: Enhanced summer precipitation for agricultural water supplies

Project Area: Southeastern Idaho
Sponsor: Salmon River Canal Company,
Oakley Canal Company,
Cedar Mesa Reservoir and Canal Company
Technique: Ground based silver iodide seeding
Time Period: 1953 - 1955
Goal: Enhanced winter precipitation for irrigation water supplies

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