WEATHER MODIFICATION FEASIBILITY STUDY FOR THE UPPER SNAKE RIVER BASIN IN IDAHO

Prepared for

Idaho Water Resource Board

by

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1.0 INTRODUCTION

North American Weather Consultants, Inc. (NAWC) received a Request for Proposals entitled "Consultant Services for the Upper Snake River Basin Weather Modification Feasibility Study." This RFP was issued by the Idaho Water Resource Board (IWRB) in July 2007. NAWC responded to this RFP with a formal proposal (NAWC # 07-209), which was due September 4, 2007. NAWC was notified on October 26, 2007 that it had been selected to perform this work. A contract to conduct the work was finalized on January 8, 2008.

As stated in the RFP: "The purpose of this study is to assess the feasibility of conducting weather modification (cloud seeding) programs in the Upper Snake River Basin for winter snowpack augmentation. The Consultant will analyze the climatology of the region, including storm frequencies and characteristics, barriers, seeding potential, and other factors. Program designs are to be developed, including methods and materials, equipment, siting issues, operational criteria, and evaluation of program results through monitoring and statistical methods. Cost estimates are to be developed. Monthly status reports will be required of the Consultant and the IWRB will review draft reports prior to report finalization." Nine tasks to be completed were identified in the RFP. Subsequent discussions between the IRWB, the High Country Resource Conservation and Development Council (HCRC&DC), and NAWC during the latter part of January 2008 led to the addition of a tenth task; the development of a statistical technique to evaluate the possible impacts of a cloud seeding program being conducted in the area of interest during the 2007-2008 winter season.

The RFP provides some background that led to the release of this RFP. This background is as follows: "The 2007 Idaho Legislature funded a series of technical studies to support a planning effort by the IWRB designed to bring the Eastern Snake River Aquifer (ESPA) water budget into balance. Due to the interconnected nature of the ESPA and the Upper Snake River, actions to increase surface water supplies have a positive effect on the ESPA water balance. Weather Modification to increase winter snowpack was identified as one alternative to increase surface water supplies."

The following sections of this report describe the work that NAWC conducted in completing the various tasks that were documented in the initial RFP and subsequent contract language. We will use the abbreviation ESRBP to refer to this Eastern Snake River Basin Program.

2.0 GENERAL DESCRIPTION OF POTENTIAL TARGET AREAS

The Request for Proposals indicated the general area of interest in this study was the "Upper Snake River Basin above Milner Dam." Figure 2.1 provides an IWRB map of this general area of interest. Discussions with the IWRB following contract award indicated that the primary areas of interest were those that contributed surface runoff to the Snake River within this general area. Informal communications with Charles Orwig of the National Weather Service's Northwest River Forecast Center located in Portland, Oregon indicated that the active snowmelt area is mostly above 7000 feet. Mr. Orwig expressed the opinion that 70 to 80 percent of the runoff comes from the area above 7000 feet. Following a contract kick-off meeting held in Boise on February 12, 2008, the IWRB prepared a map of areas of possible interest with elevation contours greater than 6500 or 7000 feet (Figure 2.2). It is NAWC's recommendation that areas above 6500 feet in elevation define the target area. There are isolated areas in Figure 2.2 above 6500 feet that NAWC recommends not be included in the specification of the final target area due to logistical and technical considerations. For example, the augmented runoff that might be derived from these relatively small, isolated areas is limited making the cost of achieving such increases higher than in larger, more consolidated areas. Figure 2.3 provides a smaller scale map of the potential target areas.

There are two rather different areas that remain in Figure 2.3. One area is located along the south slopes of the Centennial Mountains and the Lion Head and Henrys Lake Mountains in northeastern Idaho. We have denoted this area the North Area. The other area encompasses all or portions of the Big Hole Range, the Snake Range, the Grays Lake Mountains, and the Aspen Range in eastern Idaho. We have denoted this area the East Area. Figures 2.4 and 2.5 provide maps of the North and East areas. We decided to separate the proposed target area into these two areas since the mountain range orientations are more west-east in the North Area and more north-south in the East Area. We anticipated that different types of storms would be of interest in these areas due to these orientations. There could be political differences as well since different watersheds are involved.

Figure 2.6 provides a map that contains a straight line between Kilgore in Idaho and lower Red Rock Lake in Montana. Figure 2.7 provides the vertical profile along this line. This figure demonstrates the rather dramatic rise in elevation from Kilgore to the mountain crest; approximately 6300 feet to 9,500 feet in a horizontal distance of approximately 10 miles. This figure should be fairly representative of the type of terrain found in the North target area. In a similar manner, Figure 2.8 provides a map with a straight-line route from Wayan, Idaho to Palisades Reservoir. Figure 2.9 provides the vertical profile along this route. There is not quite the vertical rise in this area as that found in Figure 2.7; approximate elevations range from 6600 feet to 8300 feet but the width of the multiple mountain ranges is approximately 15 miles.

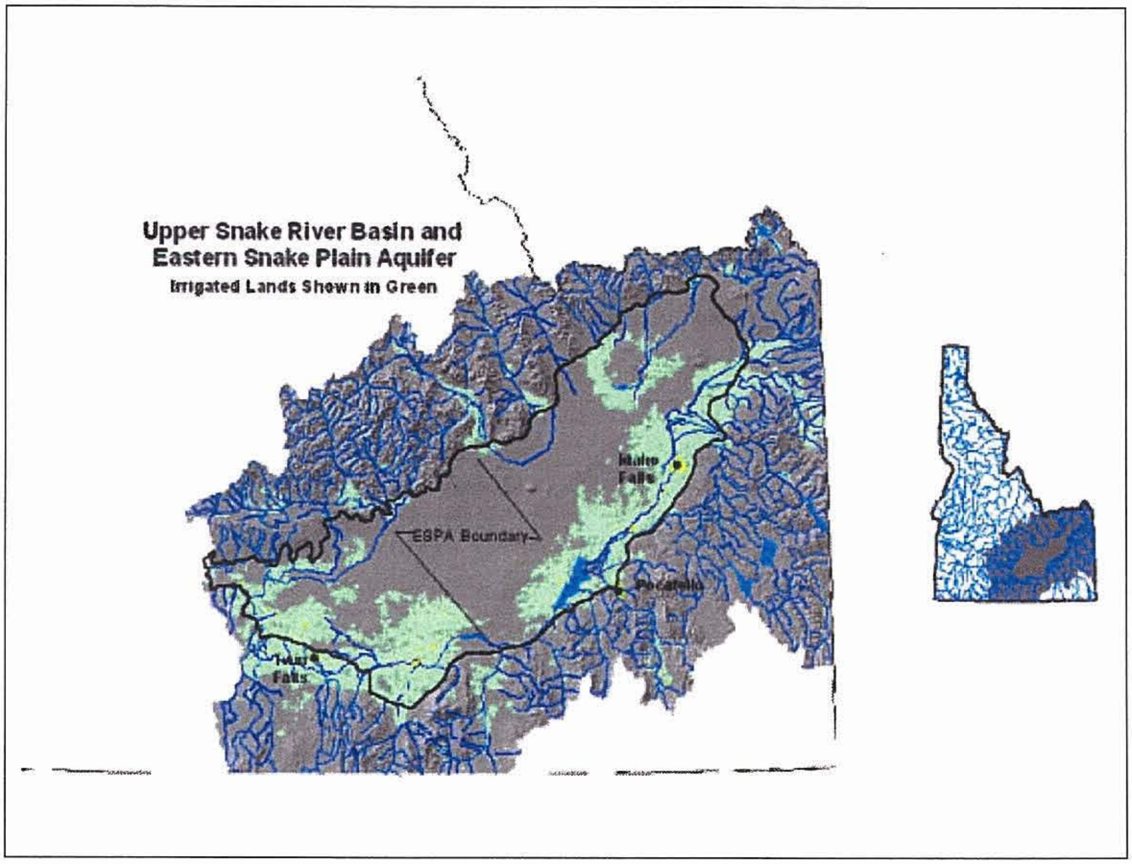

Figure 2.1 **IWRB Map of the Upper Snake River Basin and Eastern Snake River Basin in Eastern Idaho**

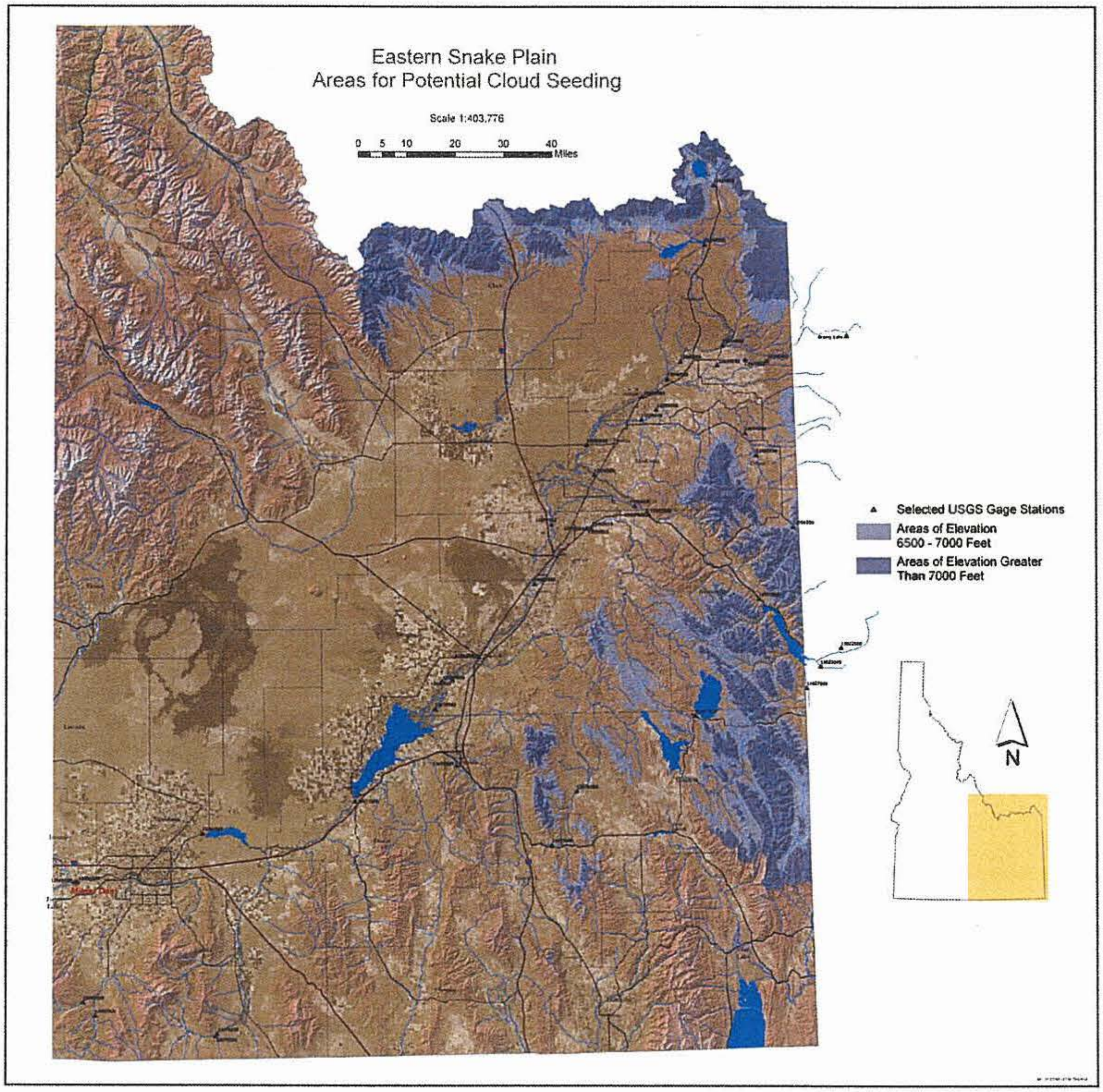

Figure 2.2 IWRB Map of Potential Target Areas above 6500 feet and 7000 feet

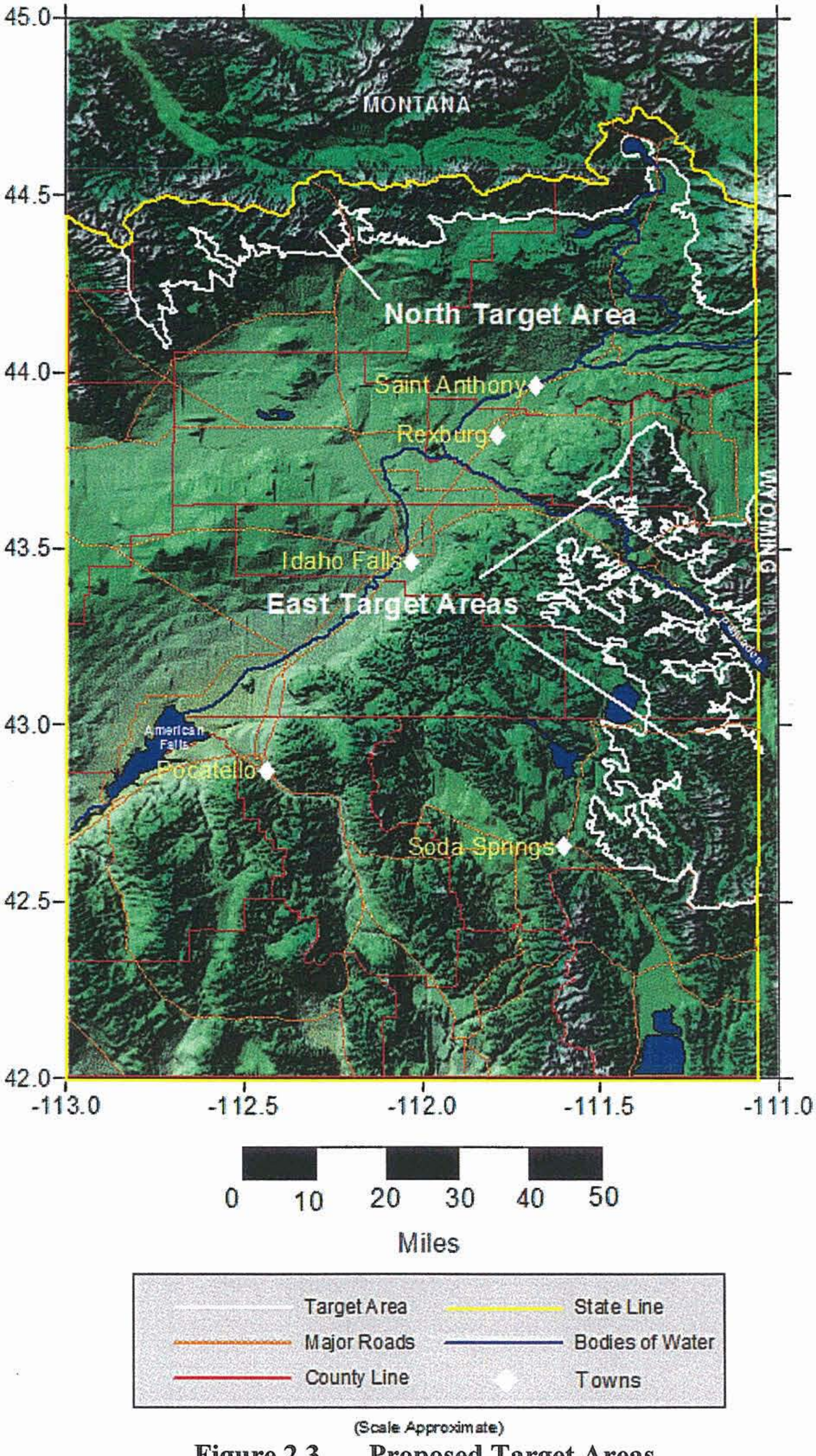

Figure 2.3 Proposed Target Areas

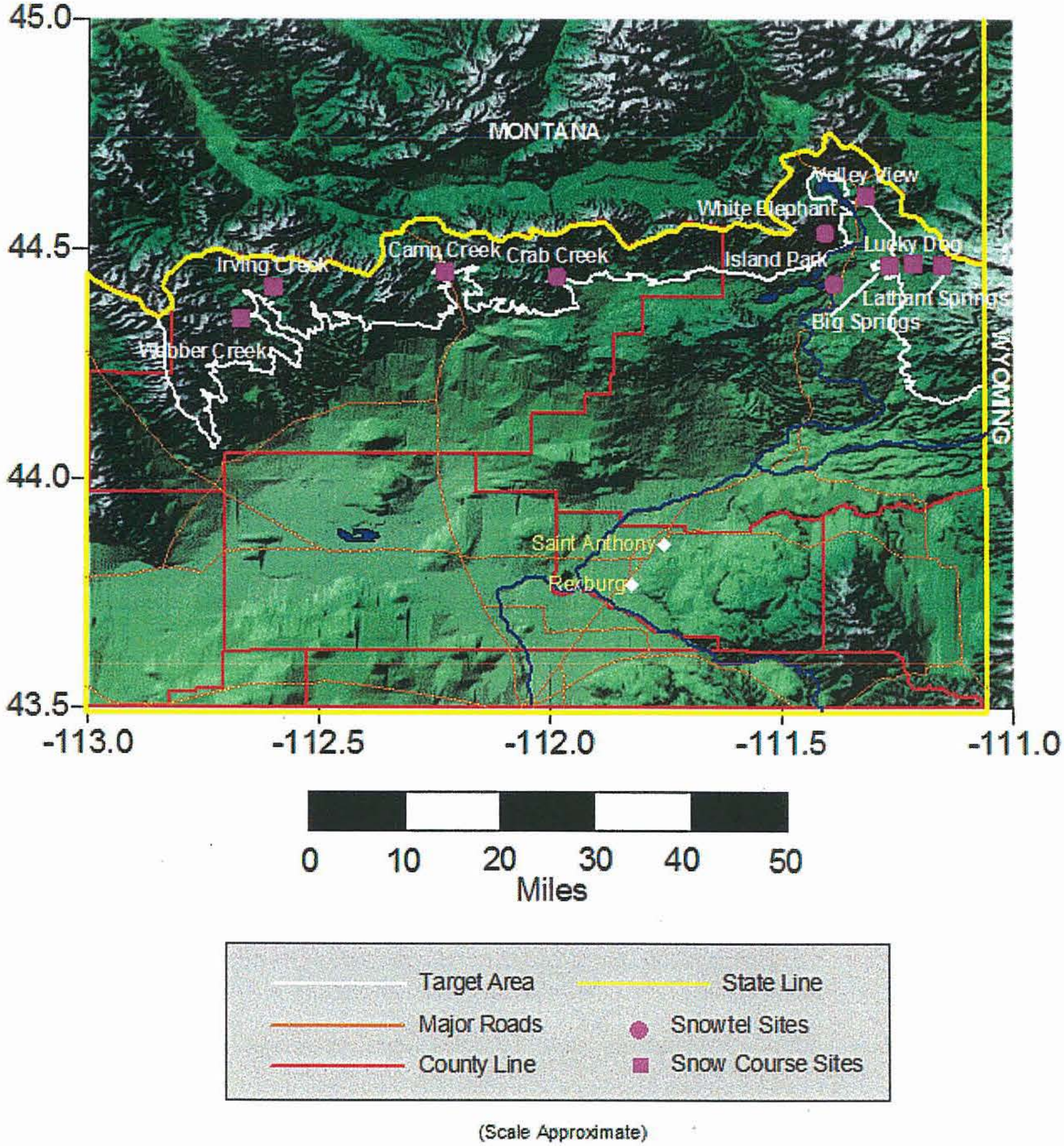

Figure 2.4 Proposed North Target Area

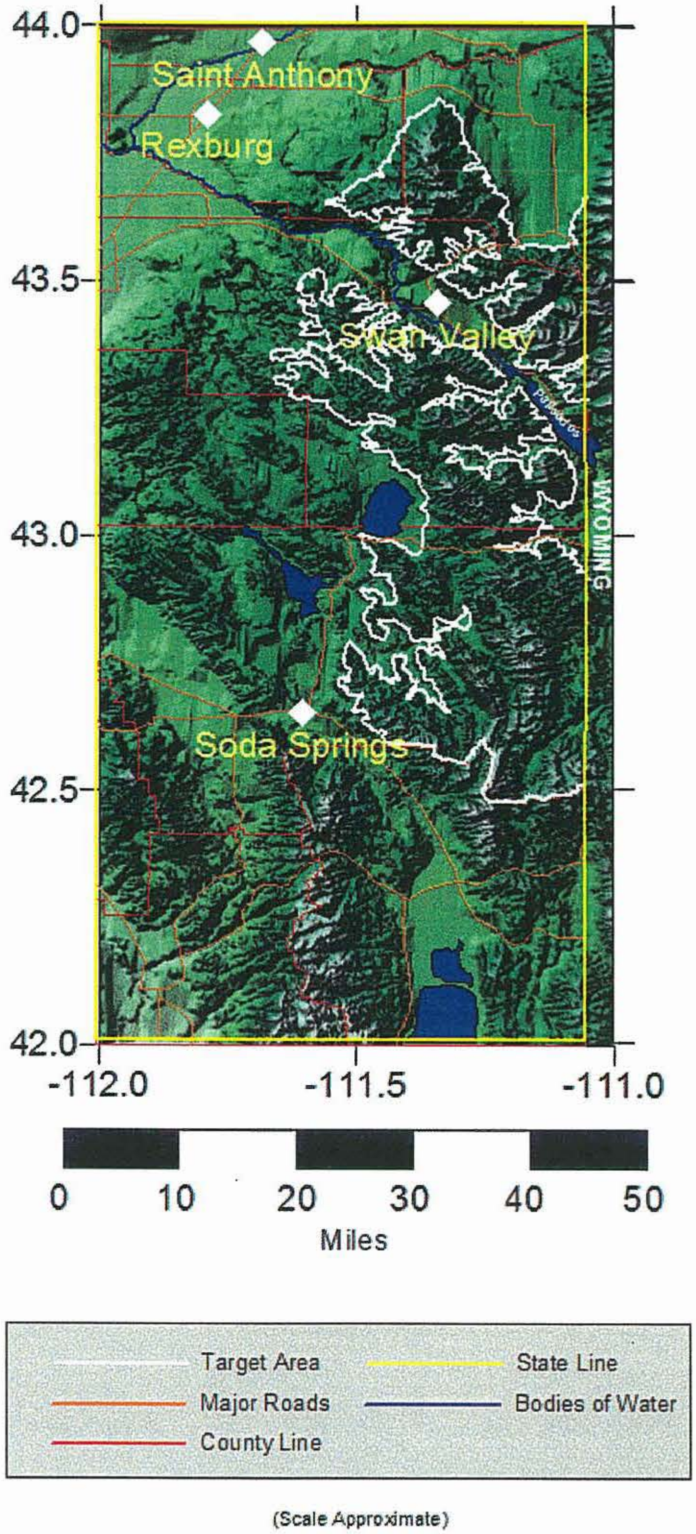

Figure 2.5 Proposed East Target Area

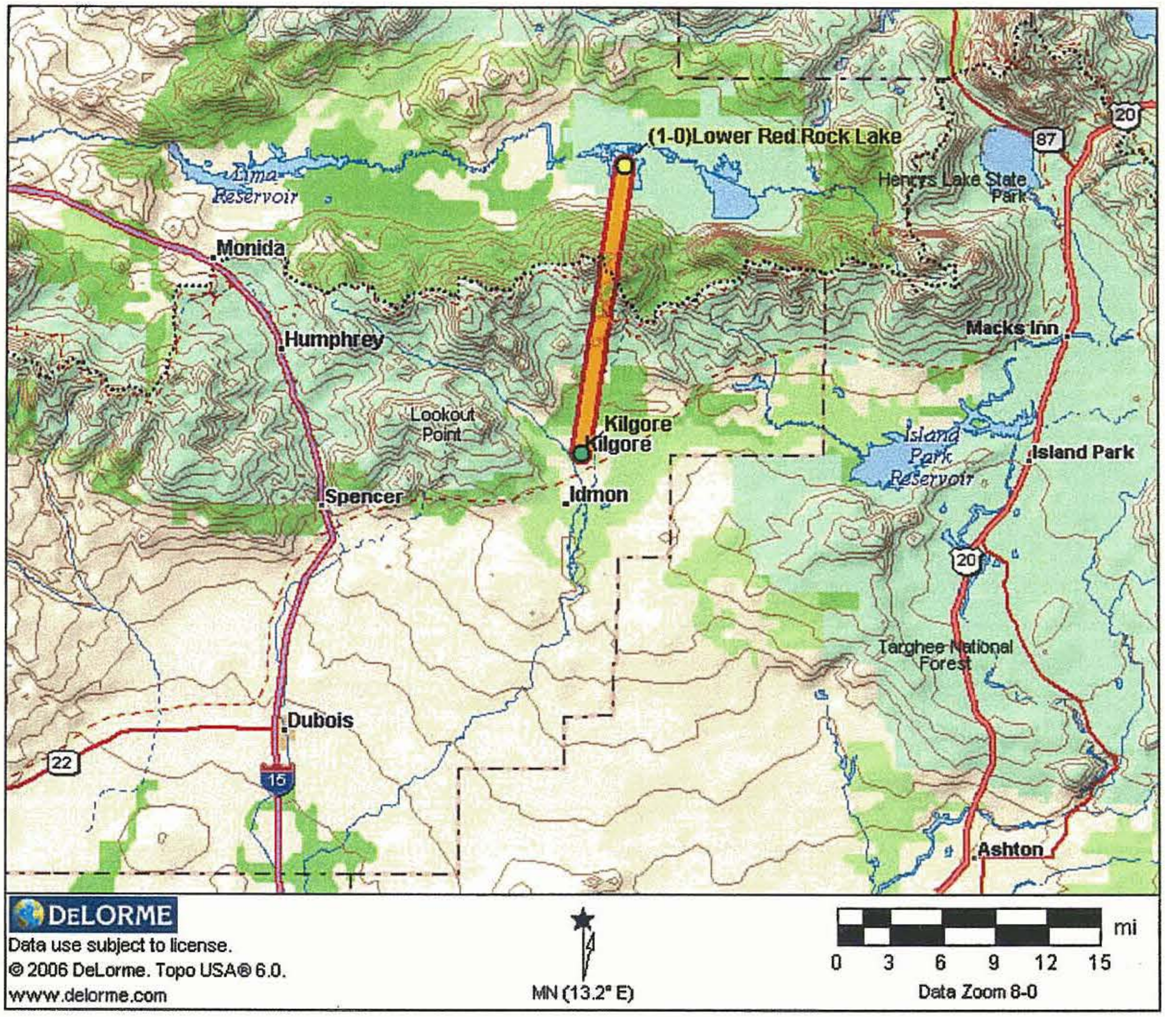

Figure 2.6 Profile Points; Kilgore, Idaho to Lower Red Rock Lake, Montana

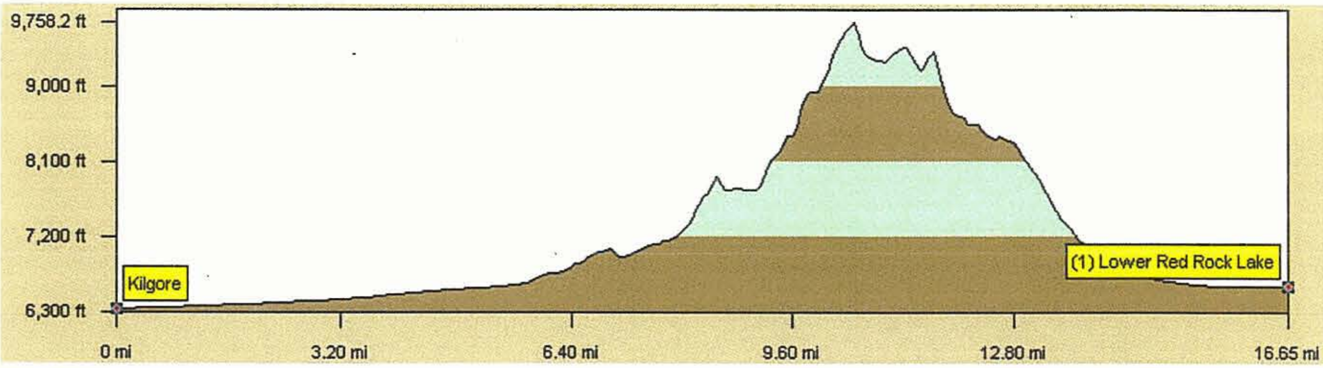

Figure 2.7 Vertical Elevation Profile; Kilgore, Idaho to Lower Red Rock Lake, Montana

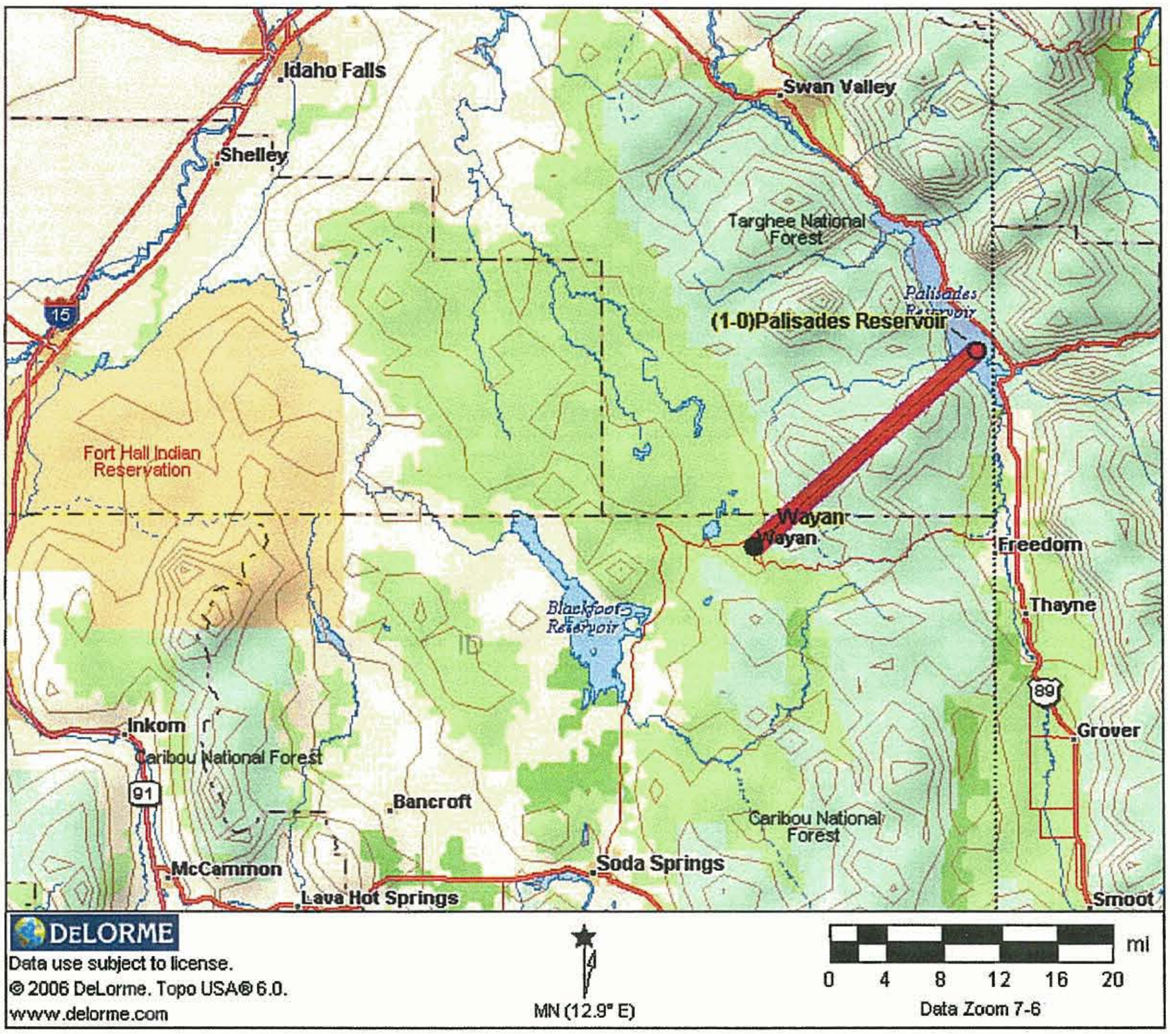

Figure 2.8 Profile Points; Wayan to Palisades Reservoir, Idaho

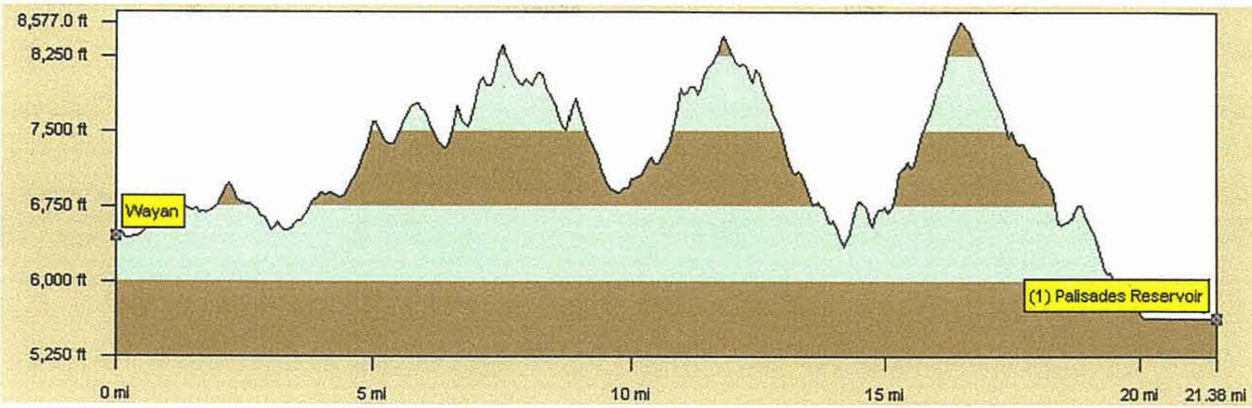

Figure 2.9 Vertical Profile; Wayan to Palisades Reservoir, Idaho

3.0 REVIEW AND SUMMARY OF PRIOR STUDIES AND RESEARCH (Task 1)

When considering the feasibility of a proposed activity, in this case the cloud seeding of winter storms to augment snowpack and resultant runoff, it is good practice to review earlier similar efforts. This can take the form of individual program reviews, but can also benefit greatly from consideration of the statements or policies of professional societies or associations concerned with such issues. In this section, we do both, beginning with the generalized indications at the organizational level, and then summarize program-specific indications from particularly relevant efforts within the realms of field operations and research. The various indications are then summarized according to what we consider to be the key relevant questions involved in a credible assessment of winter snowpack augmentation feasibility for eastern Idaho.

3.1 Relevant Winter Weather Modification Research Programs

This section contains summaries of findings from some of the weather modification research programs that we deem relevant to the design of the Eastern Snake River Basin Program (ESRBP).

3.1.1 Utah Research Programs

The Utah State government, specifically the Division of Water Resources, has been highly supportive of weather modification research in the State of Utah. Over a period of more than three decades, the State has sponsored or co-sponsored such activities, including cooperative efforts with the U.S. Bureau of Reclamation (USBR) and the National Oceanic and Atmospheric Administration (NOAA).

3.1.1.1 Utah State University

Some early investigations in Utah are reported in Hill (1980). Via analyses of supercooled water concentrations, precipitation records, aircraft icing reports and upper air soundings, it was found that winter orographic clouds over windward slopes of mountains in northern Utah, with cloud-top temperatures between 0^0 C and -22^0 C, are primarily composed of supercooled liquid water (SLW) and therefore offer high modification potential. The SLW concentrations were found to be correlated with updraft velocity. The potential precipitation yield is dependent on the SLW flux over the barriers. Hill concluded that high seedability was associated with 1) postfrontal conditions, when a) the cross-barrier flow is strong, b) high level subsidence is occurring, c) moisture remains high at mountaintop levels; and 2) weak low-level moisture systems with strong airflow and perhaps subsidence aloft. Hill also speculated that, in the absence of convection, seeding opportunity is limited, especially in well-developed cyclonic systems.

3.1.1.2 NOAA/Utah Atmospheric Modification Program (AMP)

Utah was one of two original states selected by the National Atmospheric and Oceanic Administration (NOAA) for the conduct of research superimposed on an on-going operational program (North Dakota was the other state). Research in Utah began in 1981 (Golden, 1995). A variety of remote sensing and in situ observations have been acquired in this research program in Utah in/over a variety of mountain ranges (Wasatch Plateau, Wasatch Range and Tushar Range). Some key results from the Utah Atmospheric Modification Program (AMP) are summarized in the following. Much of the work done in the 1990's is summarized in Super (1999).

- Supercooled Liquid Water

Microwave radiometer, aircraft cloud physics and ridge-top ice detector observations have indicated that supercooled liquid water commonly occurs in Utah winter storms. The amounts of liquid water are oftentimes not large but liquid water is frequently present for significant periods during the passage of winter storms. The supercooled liquid water is concentrated along the windward slopes of the Utah mountain barriers and frequently occurs at relatively low levels in the storms (i.e., near or below the crest height). Some of the liquid water occurs at relatively warm (e.g.,$>-5^0$C) temperatures. (Super and Huggins, 1993; Huggins, 1995).

- Trajectories of Ground Releases of Silver Iodide Seeding Material

In the Utah research conducted in the 1990's, increasing attention was focused upon observing the trajectories and estimated concentrations of ground releases of silver iodide seeding material. Primary observations included ground based and aircraft based National Center for Atmospheric Research (NCAR) acoustic counters and sulfur hexafluoride (SF_6) real-time analyzers.

A ground based NCAR counter (Langer, 1973) located at the 2.2 km elevation in Big Cottonwood Canyon in the Wasatch Front Mountains during the 1989-90 winter season, detected silver iodide nuclei released from two silver iodide generators located further down the canyon. One or both generators were activated during 13 separate storm events. Silver iodide nuclei were detected in significant concentrations on each of the 13 events (Super and Huggins, 1992).

SF_6 and/or silver iodide releases from valley locations upwind of the Wasatch Plateau were detected by aircraft and/or ground based analyzers over or along the ridgeline of the Wasatch Plateau in a number of different cases (Griffith, **et al.**, 1992; Super, 1995). Other cases did not indicate the transport of seeding material released from valley generators over the Wasatch Plateau. The latter cases normally corresponded with the presence of low-level stable layers or temperature inversions and light surface winds. Some cases apparently demonstrated a "pooling" of silver iodide nuclei under inversion conditions followed by the transport of these nuclei over the barrier with the passage of some weather feature. The spread of seeding plumes, as evidenced by SF_6 analyzer and NCAR counter measurements, is suggested as occurring in a sector on the order of 15^0 to 25^0 (Griffith, et al, 1992; Super, 1995).

Calculations of the spacing of valley generators to obtain overlap of plumes over the Wasatch Plateau suggest spacing on the order of 4 to 5 km. Tests of remotely controlled silver iodide generators located part way up the windward side of the Wasatch Plateau indicated more reliable transport of silver iodide material over the Wasatch Plateau than that obtained from valley based generators.

Utah research reported by Heimbach, et al, 1998) and summarized in Super, 1999 indicated that, when surface-based temperature inversions existed, valley released seeding material was sometimes transported up and over the intended mountain target area, likely by the action of gravity waves induced by an upwind mountain range. Such gravity wave effects can be migratory.

The Utah research efforts indicate that in that a large proportion of the investigations aircraft cannot (for safety reasons) reliably fly low enough relative to the underlying rugged terrain to sample the SLW pool and the ground-released seeding plumes. An extremely important finding is that the two (both the SLW and seeding material) are commonly commingled relatively (and enticingly) close to the mountainous terrain, but it is difficult to obtain in-situ measurements of the admixture.

- Propane Seeding

The results of additional experimentation on the Wasatch Plateau during the winter of 2003-04, randomized seeding trials testing the effectiveness of mid-mountain releases of unburnt propane, are reported in Super and Heimbach, 2005. Using a seeding site already demonstrated in earlier research to provide routine targeting of target gages a short distance (2.0 – 6.5 km) downwind of the seeding site, 98 short duration experimental units (EU's) and 47 randomized pairs were obtained and subjected to testing. Some of their results include:

- Statistical tests of the 98 EU's without partitioning were strongly suggestive of a seeding effect; increased snowfall at the three target gages. Results for a gage farther downwind were inconclusive.

- A partition focused on southwest flow cases was also strongly suggestive of seeding increases.

- There were suggestions that seeding may have been more effective when SLW cloud was detected, when seeding plume temperatures were warmer, when wind speeds were lighter, and when natural snowfall was lighter. The evidence for these relationships was inconclusive, requiring a larger EU sample size for rigorous testing.

- Inconclusive indications of up to 25% more snowfall for seeded EU's in one wind direction partition were reported.

- Statistical pair testing provided an average seeded EU increase of 0.014 in h^{-1}.

- The authors speculated that, via extrapolation of these suggestive, small area seeding coverage indications to a much larger area, snowfall increases of the order of 10% might result. Note: This would require installation and operation of a very large number of propane seeding sites, given the small horizontal dispersion possible, since the dispensers must be located quite close to the barrier summit in this particular location. This is an important point, since narrow barriers are typical of Utah's mountain ranges and the Salt River and Wyoming Ranges.

- Ground Generator Effectiveness

Tests were conducted on Montana State "Skyfire" and NAWC manually operated silver iodide generators. These tests were conducted at the Colorado State University Cloud Simulation Laboratory (Demott et al, 1995). These tests indicated an improvement in the performance of the NAWC generator over earlier tests conducted at the same facility in 1978 and 1981. This improvement was most noticeable at the warmer temperature ranges of -6^0 to -8^0 C. The improvement in efficiency was apparently related to some minor modifications made to the burn chamber and nozzle on the NAWC generator.

- Mesoscale Modeling

An application of the Clark Mesoscale model (Clark, 1977) has been made to the Utah Atmospheric Modification Program (AMP) Wasatch Plateau studies (Heimbach, et al, 1997; Holroyd, et al, 1995). The model appears to provide reasonable simulations of plume transport with some under prediction of plume concentrations in two different cases.

- Observations of Enhanced Ice Crystal Production

Some of the Utah AMP research cases sampled with cloud physics aircraft have indicated enhanced ice crystal production within the silver iodide plumes (Holroyd, et al, 1995; Super, 1995). Linkages of these increased ice crystals to fallout to the ground have not been adequately documented due in part to the inability to fly the aircraft near ground level in storm conditions over the Wasatch Plateau. There are limited indications of increases in precipitation measured at ground level in some of these cases.

- Application of Utah AMP Results to the Utah Operational Seeding Programs

The results from the focused research programs support the Utah operational seeding conceptual model. This is an important verification of what was assumed to be true of Utah storms based upon observations made in other geographical areas. Some refinements were made to the operations programs based on these findings.

Transport of valley released silver iodide/SF_6 over Utah mountain barriers has been documented. Since the supercooled liquid water is predominately located at low levels on the upwind slopes of mountain barriers and the generators are located in valleys upwind of these barriers, the silver iodide nuclei are encountering the preferred supercooled liquid water formation zones. In some cases, valley released silver iodide/SF_6 is not transported over the mountain barrier. These cases generally occur when there are low-level atmospheric inversions. An interesting observation from some cases was the indications that nuclei "pool" under these conditions, and are sometimes subsequently scoured from the valley and transported over the barrier with the passage of a synoptic-scale weather feature. This might suggest that valley generators should be operated under trapping inversions ahead of the passage of synoptic features. NAWC seeding criteria have typically precluded operations under these conditions.

Location of manually operated ground generators at the mouths of canyons on the windward slopes of target barriers may offer a preferred location for transport of silver iodide nuclei over the barrier when transport from valley locations is ineffective.

The plume spread from ground based releases of silver iodide and SF_6 (15^0 to 25^0) suggest that generators should be located at a spacing of 4 to 5 km apart upwind of the barrier in order to achieve plume overlap.

Remotely controlled generators may be effective during periods when valley based generators are not effective. The addition of such generators in high yield, high water value locations could offer an improvement to the current Utah operational program. Such operations are substantially more expensive than valley based networks, thus the restriction of such remote generators to high yield/high water value target locations. NAWC has installed manually operated silver iodide generators at higher elevation areas where local residents can be located to operate the units.

The improvement in efficiency of the NAWC manual silver iodide generator, as documented in the CSU tests, is an important result. The supercooled liquid water detected in Utah winter storms is frequently in the 0^0 to -10^0C range. It is in the -6^0 to -10^0C range that the recent CSU tests indicated improved efficiency over earlier tests.

Information from the Utah AMP suggested higher concentrations of seeding material and faster acting nuclei are desirable. A change has been made from a 2% to a 3% (by weight) mixture of silver iodide in acetone, along with sodium iodide and para-dichlorobenzene, so the seeding plumes now consist of silver chloro-iodide. The change to a solution using sodium iodide and para-dichlorobenzene will produce nuclei that react much faster (a condensation/freezing mechanism) than the previous formula that used a silver iodide and ammonium iodide solution, which produced nuclei that reacted slowly through a contact nucleation mechanism (Finnegan and Pitter, 1988). The density of seeding generators has been increased, further increasing the seeding material concentrations.

3.1.2 Climax I and II

Researchers at Colorado State University conducted two wintertime orographic cloud seeding experiments during the 1960's: Climax I (1960-1965) and Climax II (1965-70). The research included randomized seeding experiments and parallel physical studies of cloud and seeding processes. Climax I indicated a positive precipitation difference of about 6% and in Climax II the difference was about 18%, with a high probability that the differences were not due to chance. Evidence was found for greater increases from seeded systems when warmer orographic cloud-top temperatures prevailed (indexed by the 500 mb temperature being $\geq -20^0$C), with no difference indicated when temperatures were colder. The analysis results were reported in Mielke, et al, 1971 and a reanalysis by the same author (Mielke, et al, 1981). Re-analyses of Climax I & II by Rangno and Hobbs (1987, 1993) yielded lower, but still positive, indications of seed effect. The Climax results regarding cloud-top temperature influence on seeding effects, along with similar indications from other programs, led to the recognition of a cloud-top "temperature window" for seeding effectiveness (Grant and Elliott, 1974).

3.1.3 Colorado River Basin Pilot Program (CRBPP)

A five-year randomized cloud seeding experiment was conducted by the U.S. Bureau of Reclamation offices located in Denver, Colorado (USBR) during the early 1970's in the San Juan Mountains of southwestern Colorado, to determine whether the experimental procedures applied in the earlier Climax work would be effective in an operational mode. Seeding was accomplished using ground-based AgI generators. A formal statistical analysis based on 24hr blocks of precipitation data from 71 experimental treated days and 76 experimental control days found no significant difference between precipitation, gage-by-gage, on seeded and unseeded days. However, an *a posteriori* analyses based on shorter (6hr) data intervals indicated that strongly positive seeding effects may have been achieved during periods of relatively warm-topped cloud occurrences, as expected from the Climax experiment. The results of the *a posteriori* analyses suggested that a flawlessly conducted program of selective seeding could increase overall winter precipitation by ~10-12%. The results of the 24hr block analysis may have been negatively affected by seeding material targeting difficulties during the more stable storm phases (Elliott, et al, 1976).

Microphysical studies within the CRBPP showed that supercooled liquid water was generally found in three regions. One was located slightly upwind of the mountain barrier, one was located ~15-20 km upwind of the mountain barrier, and a third associated with an initial rise in the topography ~60-70 km upwind of the barrier. Their studies showed little or no SLW development during stable storm phases, but frequent SLW development in the neutral-unstable phases.

3.1.4 Colorado Orographic Seeding Experiment (COSE)

Researchers from Colorado State University conducted investigations in the Park Range of northwestern Colorado during the winter of 1981-82, in a program named the Colorado Orographic Seeding Experiment. The 1981-82 field campaign was a much expanded version of a field effort that was conducted during the winter of 1979-80. Airborne measurements were conducted during the 1979-80 season. The emphasis of COSE was to determine the natural physical structure of the cloud systems that affect the region toward establishment of a sound weather modification hypothesis. For that reason, no seeding was done prior to or during any of the study period storm systems. Key findings from the experiments are summarized in Rauber, et al (1986) and Rauber and Grant (1986). In 1981-82, the full suite of observations involved a scanning dual-channel microwave radiometer and supporting measurements including vertically pointing short wavelength radar, mountaintop liquid water measurements, low and high altitude measurements of ice crystal rime characteristics, rawinsonde data, and precipitation intensity measurements. Storm systems subjected to intensive case studies included prefrontal and frontal storms, postfrontal storms and orographic storms, with a particular emphasis on development of conceptual models of the structure and evolution of liquid water fields in a variety of storm situations.

Cloud top, cloud base and zones of strong orographic lift were identified as regions in stratiform systems where SLW production can occur, i.e., when the condensate supply rate exceeds the diffusional growth rate of the ice crystals present in the volume. In the aforementioned Rauber articles, SLW was found to occur in all stages of most of the storms studied, but temporal variations in the magnitude of the SLW were significant. SLW was most consistently present in relatively shallow cloud systems with warm (>-22^{0}C) cloud top temperatures and low precipitation rates. From a COSE case study reported by Sassen (1984), a deep, cold-topped storm system was found to rather consistently show the presence of SLW, leading that article's author's statement: "This raises, then, the question of the seedability of this type of storm from the standpoint of weather modification practices. On the basis of cloud-top temperature criteria, this storm would not have been a candidate for seeding… Nonetheless, in view of the documented presence of supercooled liquid water, it may be worthwhile to reexamine the criteria applied to this type of deep cloud system." Note: Similarly, analysis by NAWC of mountain-top ice detector measurements in Utah during the winter of 2003-04 (Solak, et al, 2005) found several deep, cold storms exhibiting SLW production considered adequate for seedability.

3.1.5 Grand Mesa, Colorado

The following is excerpted from a USBR report entitled *The Feasibility of Operational Cloud Seeding in the North Platte River Basin Headwaters to Increase*

Mountain Snowfall (2000). The excerpt is from Appendix A of the report, prepared by Arlin B. Super.

"Holroyd, et al (1988) discussed the results of several airborne plume tracking experiments with high altitude ground-based AgI seeding generators on the Grand Mesa of western Colorado. Sampling was done under a variety of cloud, wind and stability conditions. Ground releases were made from different sites, ranging from 650 to 2,300 feet below the 10,500 ft mesa top. Instantaneous plume widths were almost always within a factor of two of the 15-degree median angle. The instantaneous plumes meandered through a wider angle with a median of 38 degrees. With a single exception, plumes were confined to within 2,600 ft of the Mesa top, and the median vertical extent was about 1,800 ft. These results were in close agreement with earlier observations from the Bridger Range of Montana. Both mountain barriers rise about 5,000 ft above upwind valleys.

Super and Boe (1988) presented various airborne observations for two of the cases discussed by Holroyd et al (1988). They showed that the ice crystal concentrations and estimated snowfall rates were markedly increased about 2000 ft above the mesa top approximately 3.7 mi downwind from the high altitude AgI generator."

These findings provide useful information regarding seeding plume horizontal spread and vertical rise for comparison with the spatial distribution of SLW noted elsewhere in this section.

3.1.6 Wyoming

As part of a 2005 weather modification feasibility study conducted for the Wind River Range and Medicine Bow/Sierra Madre Ranges in Wyoming, investigators from NCAR conducted a number of modeling trials. The results and implications for seeding program design appear in the report prepared by Weather Modification Inc., for the Wyoming Water Development Commission (Weather Modification, Inc., 2005). A few key points, relevant to the current feasibility work include the following:

- SLW associated with orographic lifting was strongly linked to the upwind side of the mountain barriers and the amount of SLW available for seeding is tied to the strength of the cross-barrier wind component.
- Tracer/seeding material released on the upwind side of the mountain barriers was shown as spreading horizontally and being lofted over the barriers, with a vertical depth of less than 500 m above the sloping terrain.
- Gravity waves and associated SLW regions were evident, forming in lines in the lee of the mountains orthogonal to the wind direction.
- Ground-based generators should be used to target the SLW associated with orographic lifting, with the understanding that the vertical depth of the seeded plumes, in the absence of convection, would be limited to about 500 m above the terrain.

- Aircraft could be used to seed the SLW above 500 m AGL, assuming the ability to fly safely relative to the underlying terrain. Aircraft could also be used to seed the SLW associated with gravity waves.

Some interesting and relevant results from aircraft observations over the Snowy Mountains in southern Wyoming were presented at the Joint AMS/WMA 17th Conference on Planned and Inadvertent Weather Modification in April 2008 (Geerts, 2008). A downward-looking radar onboard a research aircraft operated by the University of Wyoming provided detailed data showing turbulent vertical mixing in the planetary boundary layer during stormy conditions in 2006. The measurements indicated vigorous upward and downward vertical motions in the lowest 1000 meters above ground level over the windward mountain slopes on several flight days. In such updraft areas, snow can be generated rapidly. These findings suggest very good lofting of ground-based seeding material releases, such that the seeding materials can affect the precipitation process.

Acoustic ice nucleus counter observations in the Wyoming research program, reported by Boe (2008), documented seeding material plume meander in light wind conditions. These preliminary indications support upslope transport of ground-based seeding plumes and considerable horizontal meander under certain atmospheric conditions during storm occurrences.

3.1.7 Bridger Range Experiment

A randomized exploratory seeding experiment was carried out in the Bridger Range of southwestern Montana during the winters of 1969-72. The seed mode was ground-based AgI generators located at mid-mountain or higher locations to avoid seeding material trapping by lower stable layers. Airborne plume sampling and silver-in-snow analysis provided evidence of successful targeting of the seeding material. A *post hoc* statistical analysis using control gage data indicated ~15% more seasonal target area precipitation than predicted. Snowpack data analysis indicated positive effects of the same seasonal magnitude. The experiment is summarized in Super and Heimbach (1983).

3.1.8 Nevada/Desert Research Institute Programs

Cloud seeding has been conducted in the Lake Tahoe area in the Sierra Nevada since the 1960's. The Desert Research Institute (DRI) has conducted both operational and research programs in this area. The purposes of the research programs have varied. One of the significant developments pioneered by DRI has been in snow chemistry. One of the accomplishments in recent snowpack augmentation research is the establishment of the direct link between the seeding activity and the water reaching the ground in the form of snow. The mm/hr increases in precipitation caused by silver iodide seeding have been documented several times in the reviewed scientific literature between 1988 and 1999. The link has been established by physical and chemical techniques. The snow precipitated at particular targeted sites is connected directly to the seeding material and to concurrently released chemical tracers in that snow. The advantage of this snowpack sampling work is that the scientists are dealing with solid-state precipitation that can be sampled during and after storm events and stored in the frozen state until analyzed. The methodologies used to establish this direct linkage have been described by Warburton, et al. (1985, 1995a,b, and 1996), Chai et al. (1993), Super and Holroyd (1997), and McGurty (1999). DRI has also used remote measurements (e.g., microwave radiometers) to study the "seedability" of winter storms. Other recent work at DRI has included the development of sophisticated atmospheric models to study the evolution of features of interest (e.g., supercooled liquid water) and the predicted transport and diffusion of ground released silver iodide seeding material.

3.1.9 University of Wyoming (Elk Mountain)

The University of Wyoming, Department of Atmospheric Sciences was involved in cloud seeding research in the 1960's and 1970's. A majority of this research was conducted in "cap" clouds that often occur over Elk Mountain located in south-central Wyoming. Observations were made of ice crystal and ice nuclei concentrations (Auer, et al, 1969), the presence of surface released silver iodide plumes, cloud droplet concentrations and cloud condensation nuclei (Black, 1980), ice crystal development using cloud physic aircraft (Cooper and Vali, 1981), precipitation efficiencies based upon aircraft measurements (Dirks, 1973), and condensation-freezing ice nucleation (Kelly, 1978). Whether the results obtained from this interesting research conducted in "cap" clouds are representative of larger scale winter cloud systems in Wyoming is open to question. Certainly some of the information would likely be the same in either situation. For example, the finding that ground released silver iodide plumes seldom rise to heights greater than 1500 feet (450 m) above the surface and the dispersion angle of such plumes being on the order of 10^{0} is similar to other studies conducted in Colorado and Utah.

3.2 Relevant Operational Programs

A substantial number of winter operational cloud seeding programs have been conducted in regions of the western U.S. that have relevance to the proposed ESRBP. These are largely purely operational programs, i.e., the seeding is done on a non-randomized basis. Nonetheless, mathematical evaluations (estimations of seeding effects) have been performed for essentially all of them. Further, some have included research components during at least some of their duration.

3.2.1 Utah Power and Light

A winter snowpack augmentation seeding program was conducted by NAWC for Utah Power & Light (UP&L), focused on portions of the Bear Lake watershed, including the Thomas Fork and Smiths Fork region of Wyoming. The program used ground-based solution-burning AgI generators and was conducted during the periods of 1955-1970, 1980-1982, plus 1989 and 1990. A target/control mathematical evaluation of snowpack during the 18 winter seasons through 1982 (Griffith, et al, 1983) indicated a positive difference of 11 percent, reported as statistically significant at the .055 level using the one-tailed Student's t test. That analysis also presented a convincing double-mass plot of target and control seasonal snowpack data encompassing the pre-program (statistical base period) years and the subsequent seeded and embedded not-seeded years. The double mass plotting technique is a tool frequently used in engineering circles as a means of detecting changes that may occur between two variables. That plot is shown in Figure 3.1. A distinct and sustained upward break is seen in 1955, the season marking the start of seeding operations. The trend line breaks downward during the non-seeded years in the 1970's, then upward again corresponding with the resumption of seeding operations for the winter of 1979-1980. The latter upward (seeded) slope returns to that of the earlier seeded period. The combined statistical and double-mass plot indications are quite compelling indications of an increase in precipitation in the target area that can be attributed to the cloud seeding activities.

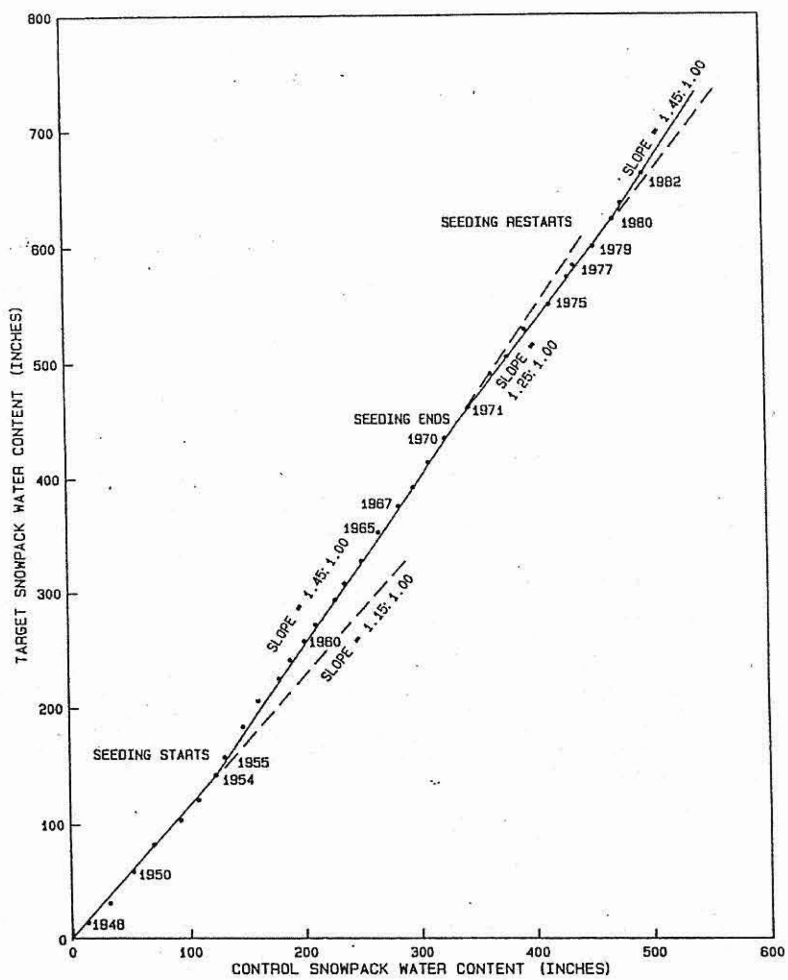

Figure 3.1 Double Mass Plot for UP&L Program

3.2.2 Boise River

NAWC has operated an operational cloud seeding program for the upper Boise River drainage in southwestern Idaho for several years beginning with the winter of 1992-93. The seed mode involves ground-based AgI solution burning generators in valley and mountain locations. Mathematical, target/control, estimations of seeding effectiveness over eight winter seasons are of average seasonal increases of the order of 5% to 8% (Griffith, et al, 2005).

A peer reviewed paper (Griffith and Solak, 2002) attempted to provide a rudimentary economic assessment of this program. The following is the abstract from this paper:

"The Boise River Drainage, located in central Idaho, is productive in terms of annual streamflow, a large majority of which is derived from accumulated winter snow pack. There are three dams on the upper river: Anderson Ranch, Arrowrock and Lucky Peak. Capacities of the three reservoirs are: 413,000, 272,000 and 306,000 acre-feet, respectively. Both Anderson Ranch and Lucky Peak have hydroelectric production capabilities. Lucky Peak is located below the first two dams. North American Weather Consultants, Inc. conducted winter cloud seeding programs over the Boise River Drainage above Lucky Peak Reservoir during the water years of 1993-1996. A target/control analysis of these four seasons of seeding indicated an average increase in target area April 1st snow water content of 12% (an average additional 2.50" of snow water content per season).

Additional analyses were performed to estimate the potential economic benefit that might be derived from the seeding program based upon the value of the estimated increased hydro-power production from Lucky Peak Dam. Lucky Peak has an installed turbine capacity of 100mw. It was estimated that a 12% increase in April 1st snow water content would result in an average 16,409 mwh of additional electricity production per year. This amount of additional electricity was estimated to have a value of $820,182. The average annual cost of the cloud seeding program during the four seasons of operations was $85,000. These values result in an average estimated benefit/cost ratio of 9.7/1. This analysis does not consider the value of the additional electricity produced from the Anderson Ranch Dam which is a Bureau of Reclamation facility or the value of the enhanced streamflow to irrigation interests downstream of the Lucky Peak Dam."

3.2.3 Idaho Power

The Upper Payette River drainage in western Idaho has undergone cloud seeding since 2003; a program conducted by Idaho Power. Automated ground-based AgI solution-burning generators and aircraft are employed to conduct the seeding. The program has included some interesting research components, including trace chemistry analyses (Furhman, et al, 2006). Gary Riley, with Idaho Power, provided the following summation of the indicated effectiveness of this program (Table 3-1).

Table 3-1

Indicated Results from the Idaho Power Company's Upper Payette River Winter Cloud Seeding Program

Water Year	Estimated Precipitation Increase %	Estimated Precipitation Increase inches	Estimated Streamflow Increase acre feet	Estimated Additional Power MWH
2003	17	2.4	120,064	60,032
2004	6	1.6	80,042	40,021
2005	7	1.7	85,045	42,523
2006	15	6.4	320,170	160,085
2007	10	2.8	142,140	71,070

3.2.4 Utah Programs

NAWC has been the cloud seeding contractor for a number of Utah winter snowpack augmentation programs covering much of the mountainous terrain in the state since the mid-1970's. Figure 3.2 shows past and current locations of operational seeding programs in Utah, and Figure 3.3 shows the target areas in Utah for the 2007-2008 winter season. These programs employ ground-based AgI solution-burning generators in valley and foothill locations. Numerous mathematical evaluations have been conducted of those programs, some now spanning more than 31 years. The results of the mathematical (non-randomized) estimations of seeding effects averaged over multiple seasons range from 3% to 21% increases, with a gradient of apparent effects increasing from south to north for the program areas located west and on the upwind slopes of the primary north-south oriented Wasatch Range. One of these operational programs was the host of research efforts described in section 4.2.1.2 of this report. For the longest-standing program, positive seasonal results (increases) have been indicated in statistical evaluations of precipitation for 28 of the 29 seeded seasons to date. A plot of the ranked ratios of observed/statistically estimated snowpack for the seeded seasons and the historic base period (non-seeded sample) is shown in Figure 3.4. The dark bars are seeded seasons, and the open bars are the historical base period years.

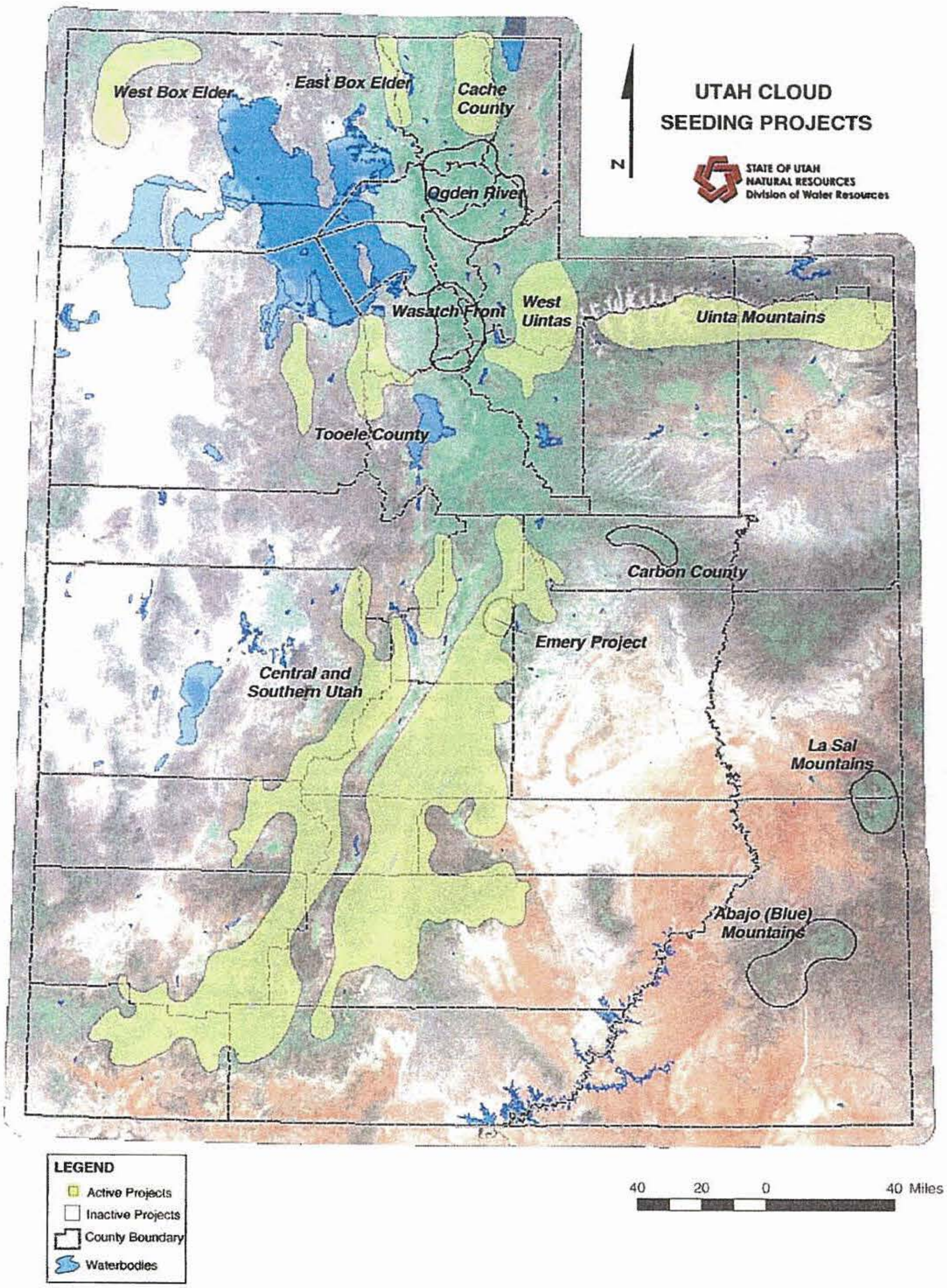

Figure 3.2 Past and Current Operational Cloud Seeding Programs in Utah

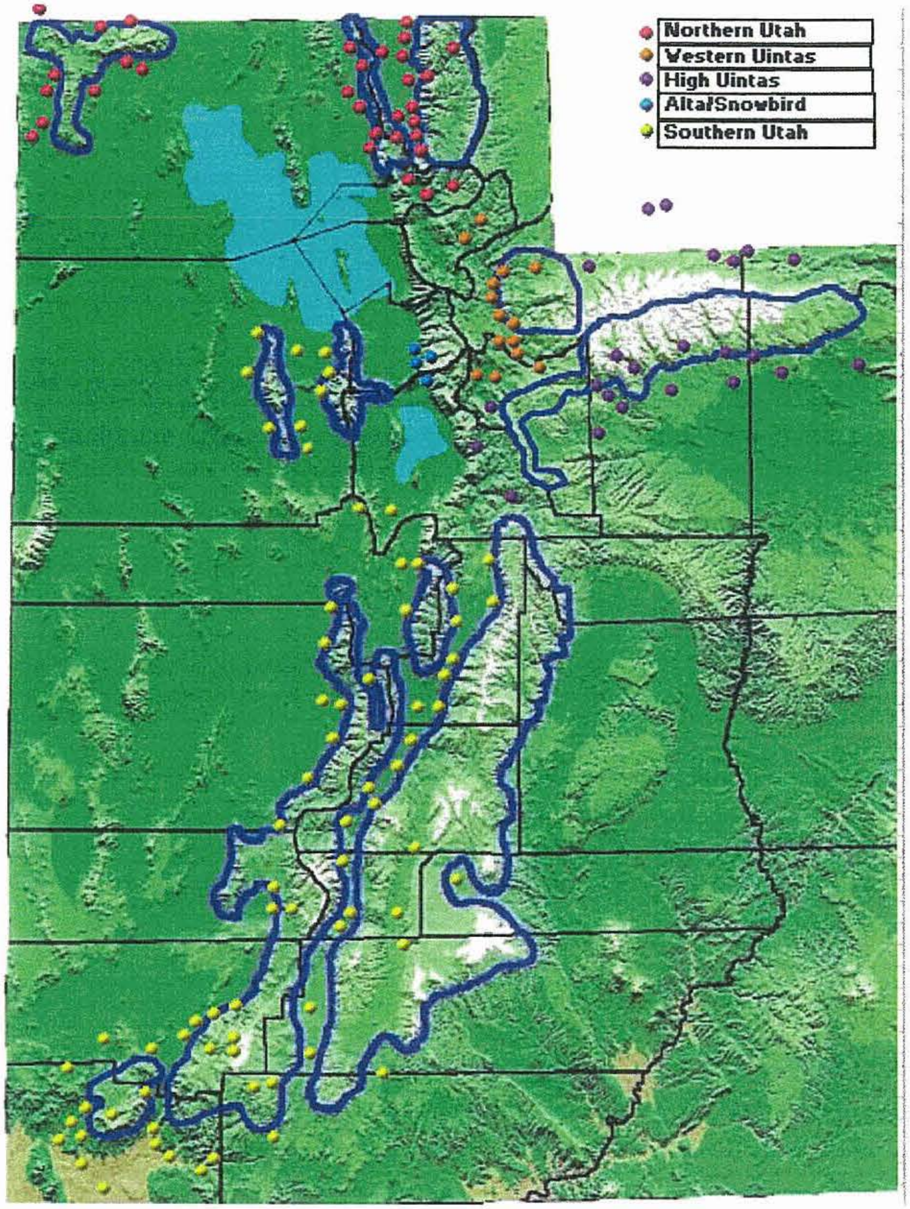

Figure 3.3 **Locations of Cloud Seeding Target Areas and Ground Generator Sites within Utah, 2007-2008 Winter Season**

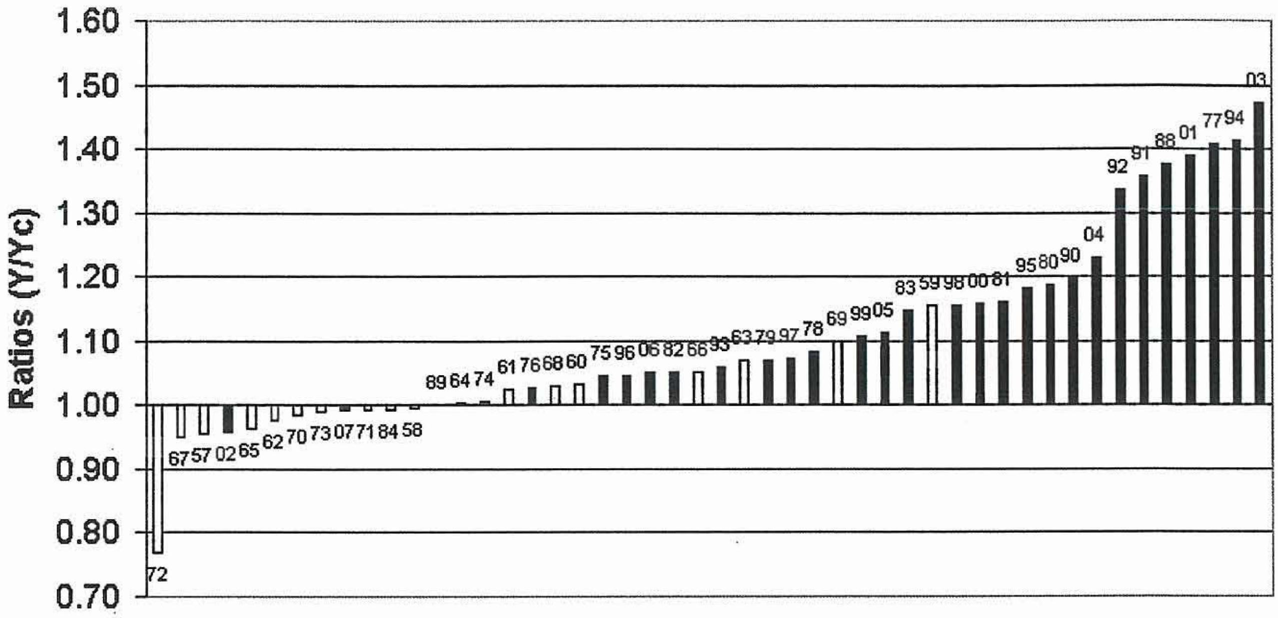

Figure 3.4 Southern Utah Seeded Year Target/Control Ratios through 2007

Effectiveness estimations for each of the Utah operational programs are shown below. All estimations are based on NAWC's standardized non-randomized target/control regression method, analyzing precipitation and snowpack data.

- Northern Utah (Cache and eastern Box Elder Counties)

Precipitation: 17% average seasonal increase; 16 of 19 seasons positive.

Snowpack: 10% average seasonal increase; 16 of 19 seasons positive.

- Northern Utah (northwestern Box Elder County)

  Precipitation: no sites available for analysis.
  Snowpack: 17% average seasonal increase; 13 of 15 seasons positive.

- Eastern Tooele County

  Precipitation: 21% average seasonal increase; 22 of 23 seasons positive.
  Snowpack: 16% average seasonal increase; 18 of 22 seasons positive.

- Western Uinta Mountains (Weber and Provo Rivers)

  Precipitation: 5% average seasonal increase; 8 of 13 seasons positive.
  Snowpack: 5% average seasonal increase; 10 of 12 seasons positive.

- High Uinta Mountains (southern slope)

  Precipitation: 3% average seasonal increase; 3 of 5 seasons positive.
  Snowpack: 3% average seasonal increase; 2 of 3 seasons positive.

- Central and Southern Mountains

  Precipitation: 14% average seasonal increase; 28 of 29 seasons positive.
  Snowpack: 4% average seasonal increase; 20 of 29 seasons positive (note, NAWC's annual program report for the 2003-2004 winter season indicated that a change (reduction) in indicated results was due to our decision to use NRCS adjusted snow water contents in this evaluation. The precipitation evaluations are considered more representative for this target area).

A recent summary of the Utah cloud seeding programs was presented at the AMS 17th Conference on Planned and Inadvertent Weather Modification Joint with the Weather Modification Association held in Westminster, Colorado, April 21-25, 2008 (Griffith, et al, 2008).

3.2.5 Nevada/Desert Research Institute Programs

The State of Nevada, through the Desert Research Institute (DRI) has conducted operational cloud seeding since the 1960's, beginning in the Tahoe area and expanding to other areas in more recent decades. These programs are an outgrowth of DRI weather modification research programs funded through the U.S. Bureau of Reclamation and the National Oceanic and Atmospheric Administration (NOAA). Most relevant to the ESRBP are the programs for the Ruby and Tuscarora Mountains in northeastern Nevada and the Toiyabe Mountains in the central portion of the state. The programs employ automated ground-based AgI solution-burning generators and have been in operation since the 1980's.

The following is quoted from a DRI web site:

"Benefits vary with the seasonal frequency of suitable weather opportunities. Research results have documented precipitation rate increases of 0.1 - 1.5 millimeters per hour due to ground-based seeding during the proper weather conditions. Estimates of augmented water from seeding have varied from 20,000 to 80,000 acre-feet over each of the last ten years. Seasonal percentage increase estimates have varied from four to 10%; generally greater in drought years; less in above normal years. The cost of augmented water, based on the cost of the program, has ranged from $7 to about $18 per acre-foot."

3.2.6 Eden Valley

The WMI Weather Modification Study (WMI, 2005) contains a description of a long-term program conducted by the Eden Valley Irrigation District headquartered in

Farson, Wyoming. The following is a description of this program contained in the referenced report:

"The Eden Valley Irrigation District is the only entity presently actively seeding clouds on an annual basis. Each winter, from 15 November through 30 April, the EVID uses three ground-based cloud seeding ice nuclei generators to seed clouds upwind of the southern Wind River Mountains. These generators are placed at 10 mile intervals along U.S. Highway 191 north of Farson. These generators which burn a silver iodide solution are complimented by two additional high-altitude propane ice crystal generators. While the generators along Highway 191 are operated manually by EVID staff, the propane generators are remote controlled and operated by the Provo, Utah office of the Bureau of Reclamation.

The EVID program was designed by the University of Wyoming's Department of Atmospheric Sciences, and for a time, also operated by the Department. However, the program is presently operated independently by the EVID, and the Wyoming State Engineer's office issues the operations permit to the irrigation district itself.

Operations have been conducted annually since 1975. The irrigation district believes it realizes an 11% to 13% increase in snowfall (water equivalent) as a result of the seeding operations."

3.3 Summary of Findings from Relevant Research and Operational Winter Cloud Seeding Programs

Key Indications

From a review of the relevant research and the large and quite consistently positive overall results of (albeit largely non-randomized) statistical estimations of the effectiveness of operational programs, the following key points emerge:

- It appears that the potential exists for winter snowpack augmentation in the mountainous west. The potential effects range from about 5% to about 15%.
- It is clear that statistically significant evaluations of seeding effects are exceedingly difficult to achieve, due to the relative magnitude of natural precipitation variability compared with the magnitude of anticipated cloud seeding effects. Carefully controlled, randomized experiments are considered necessary by some for attaining such results.
- The basic prerequisite ingredient for cloud seeding potential is the presence of supercooled liquid water (SLW), which has been observed to develop at low altitudes over the windward slopes of mountain ranges. The SLW develops during a sufficiently large proportion of the time during winter storms to constitute a credible target for cloud seeding efforts. This critical characteristic has been identified not only in the programs cited in this report, but also in numerous programs and investigations in a wide variety of locations around the world.

- A key challenge is to identify the most effective methods necessary to "tap" the SLW reservoir, such that the affected precipitation will fall to the surface within the intended area of effect.
- Critical factors regarding effective seeding methods and materials include atmospheric stability, the temperature thresholds of various seeding materials, times/distances available for growth of the seeding-induced ice particles, etc.
- AgI solution formulations incorporating sodium iodide and para-dichlorobenzene, acting more quickly via the condensation-freezing nucleation method, are available for operational use.
- Each potential cloud seeding method has benefits and limitations. A number of program-specific considerations must be factored into selection of the most appropriate seeding method(s). More than one seeding method may well be appropriate for a given program area.
- A practical approach to seeding method selection is appropriate, weighing the potential benefits each may achieve against the costs and the logistical considerations associated with each prospective method. In other words, is a given seeding method worth the effort? What is each seeding method's relative (incremental) contribution (value) versus its cost? This is a basic benefit/cost issue of the type common to every day decision-making in business, etc.

Siting of ground-based AgI generators should take into account the trapping effects of surface-based temperature inversions. The character and frequency of such inversions in the region **during seedable storm occurrences** should be determined via analysis of regional observations. **Occurrences of trapping temperature inversions during non-seedable storm periods or non-stormy periods are generally irrelevant and must not be included in such climatologies.** Modeling (using only validated model results) can be helpful in such considerations, but analysis of real data is much preferred, especially if a suitable period of record is available. The typical (range of) height of the top of the inverted layers can be used to establish a critical elevation for ground-based generators if the inversion frequency of occurrence during seedable storm occurrences is deemed significant. In any case, the critical elevation should be kept in mind during the site selection process. The frequency of occurrence issue can be used to assess the apparent seasonal benefit/cost of using lower elevation generators, given their seeding coverage advantages. The seeding formulation issue should also be addressed, with close attention to activation temperature threshold and the speed of activation of the nuclei produced.

Siting of high elevation generators (AgI or propane) should take into account the attendant constraints pertaining to their cost effectiveness. These are primarily distance-to-target issues, i.e., considerations of adequate time for the seeding-induced ice particles to grow and fall out into the intended area of effect. In the case of propane, the generators must be at sufficiently high elevations to consistently position them in-cloud to have any effect. In the case of AgI, their location in-cloud adds the potential benefit of forced condensation-freezing. The assessment issues include the precipitation rates possible, the degree of plume spread and, thus, the crosswind spacing required to produce overlapping plumes sufficiently far upwind to produce a cost effective benefit. High elevation sites typically are located strategically in areas with difficult access, necessitating the significant additional cost of high capacity, full automation, communications equipment and on-site solar power (panel) system. Obtaining site permission/leases can also be problematic. Storm-to-storm equipment reliability can be difficult to ascertain with automated systems due to less frequent on-site human involvement. The costs of repair and replenishment visits add to the benefit/cost consideration.

Use of aircraft for operational seeding, albeit costly, does offer some benefits over ground-based releases. Those include better targeting of the low altitude SLW layer above 500-1000 m AGL when safety considerations allow, seeding of SLW layers when low elevation stable layers or temperature inversions would likely trap ground-based releases from lower or even upper elevations, and seeding when the nucleation temperature threshold is significantly above a mountain barrier summit height.

Appendix A provides a variety of organizational weather modification capability statements or policies.

3.4 Relevant Feasibility Studies

There have been two recent weather modification feasibility/ design studies conducted in Wyoming. The Wyoming Water Development Commission headquartered in Laramie, Wyoming funded these studies. Weather Modification, Inc. of Fargo, North Dakota, conducted the first study. North American Weather Consultants conducted the second study. A third publication, a White paper prepared by North American Weather Consultants, also has some relevance to this ESRBP study.

3.4.1 Medicine Bow, Sierra Madre and Wind River Study

The Wyoming Water Development Commission awarded a contract to conduct a Level II weather modification feasibility study through a competitive bid process to Weather Modification, Inc. (WMI) in June 2004. The Research Application Laboratory under the National Center for Atmospheric Research located in Boulder, Colorado served as a sub-contractor to WMI to conduct atmospheric modeling work. The proposed target areas were comprised of two different mountainous areas; the Wind River Range located in west-central Wyoming and the Medicine Bow/Sierra Madre Ranges located in south-central Wyoming.

This WMI study concluded that a pilot program could be effectively conducted in the proposed target areas. Quoting from the WMI final report (WMI, 2005):

" This pilot program, as defined, would be conducted for five winter seasons and would treat clouds with silver iodide based seeding agent to increase snowpack in the Wind River and Medicine Bow-Sierra Madre Ranges. Seeding would be conducted with ground-based and airborne facilities. It is estimated that snowpack would be increased

by a minimum of ten percent, and quite possibly twenty percent, based on the findings from other recent programs whose evaluations have been published in the reviewed scientific literature.

Evaluation would be double-faceted: effects upon precipitation would be assessed, and physical measurements of cloud processes within both natural and seeded clouds would be made. Advanced numerical (computer) modeling would be included to select optimum seeding sites, predict which seeding facilities should be used in each storm, and to enable detailed analysis of program effects.

Total Programed cost for the five-year program is $8.825 million, for an annual cost of $1.765 million. Conservative estimates of programed benefits range from a minimum of 223,000 to 446,000 acre-feet per season. Cost per acre-foot is estimated to be a maximum of $7.91, to a minimum of $3.96 per acre-foot. The value of the additional water thus generated is conservatively estimated to range from $4.2 million to $8.3 million per season, however these estimates do not include any benefits that might be realized through increased hydro-electric power generation, improved recreation and fisheries, tourism, slowing the melting of glaciers, improved water quality and conditions for certain endangered species, or by meeting downstream water requirements.

Value of the additional water generated is estimated to range from $10-$12 per acre-foot for agricultural areas, and from $75-$100 per acre-foot for municipal and industrial uses. However, water demand, and thus values are constantly increasing. According to Ed Harvey, Inc., an economic consulting firm that has contributed significantly to Wyoming river basin planning, the City of Ft. Collins is presently paying $400 per acre-foot for water rights to satisfy its municipal demands, and in some industrial applications the value is known to be up to $5,000 per acre-foot. The above mentioned estimates reflect only the current, conservative values, however."

The results from WMI's final report were presented to the Wyoming legislature. The Wyoming legislature approved the proposed five-year pilot program in the fall of 2005. Request for proposals for two different contractors to perform the operations, final design, modeling and evaluation phases of the program were released. WMI was selected to perform the operations and the National Center for Atmospheric Research, located in Boulder, Colorado, was selected to perform the design, modeling and evaluation phases of the program. Limited activities began in the latter part of the 2005-2006 winter season. Activities on this program have continued to the present time. No preliminary results from this program have been published. Final results will not be available until after completion of the five-year field experimentation.

3.4.2 <u>Salt River and Wyoming Ranges Study</u>

In January 2005 the Wyoming Water Development Commission released a Request for Proposals (RFP) for the conduct of a Level II weather Modification Feasibility study. The area of interest was the Salt River and Wyoming Ranges located in western Wyoming. NAWC responded to this RFP and was ultimately awarded the contract in June 2005. NAWC completed a final report on the study in December 2006 (Griffith et al, 2006). Some of the findings include:

The feasibility/design study has determined that an effective winter cloud seeding program can be established and operated for the Salt River and Wyoming Ranges. The program has the potential to enhance the snowpack by ~10% during an average winter season, with the resultant additional annual runoff estimated to be about 109,573 acre feet utilizing the combination of three different seeding methods. Conduct of a proposed single winter season of area-specific meteorological monitoring prior to the start of operational seeding would serve to refine the preliminary program design.

A preliminary seeding program design was developed. Some of the key elements of the proposed design are as follows:

- The suggested target area includes elevations above 8,000 feet located in Lincoln and Sublette Counties.
- A "core program" is proposed, utilizing ground-based manually operated silver iodide generators. This "core program" could be augmented through the addition of remotely controlled ground generator and/or aircraft seeding modes.
- Supplemental mid-high elevation remotely controlled silver iodide generators are recommended for consideration, subject to benefit/cost considerations.
- Fast-acting silver iodide seeding solution formulations are recommended.
- Airborne seeding may be considered, subject to benefit/cost considerations.
- Seeding operations should be conducted full-time, with no randomization.
- Seeding suspension criteria will be followed with primary emphasis on percent of normal snowpack values and avalanche conditions.
- The primary seeding season will be November through March, with possible extension into April.
- Radar data from the National Weather Service radars can be used to view storms approaching the program area; a program-specific radar is not considered necessary.
- A one-season campaign of rawinsonde, radiometer and ice detector measurements are recommended. Analysis of the one-season specialty measurements, in conjunction with other routinely available meteorological information, will assist in completion of the final program design.
- Surface snow chemistry sampling and analyses should be used to verify seeding material targeting.
- Historical target and control regression methods should be used to estimate seeding effectiveness.

A peer reviewed paper was prepared that summarized this study (Griffith, et al, 2007).

3.4.3 Upper Colorado River Commission White Paper

NAWC prepared a White paper in 2006 entitled "The Potential Use of Winter Cloud Seeding Programs to Augment the Flow of the Colorado River" (Griffith and Solak, 2006). The Executive Summary from this paper is reproduced in the following:

"Recent drought conditions and the associated drop in Lake Powell storage has generated renewed interest in means that might be used to better manage the water supplies for the seven basin states that share water from the Colorado River system through the 1922 compact. Means of augmenting the flows of the Colorado are also being examined. One technique that has been frequently mentioned is that of weather modification or "cloud seeding" as it is more commonly known. The Upper Colorado River Commission contracted for the preparation of this White Paper. The goals of this paper were to consider the status of the weather modification field and how cloud seeding could potentially be used to augment streamflows in the Colorado River region.

The potential for use of cloud seeding to increase the amounts of naturally occurring precipitation dates back to some early discoveries and experiments, first conducted in the laboratory and then in the atmosphere, in the late 1940's. Early enthusiasm for such applications led to the conduct of a number of research and operational programs during the 1950's. Some of this early enthusiasm diminished due to difficulties in detecting the effects of seeding on precipitation. In a sense, the potential of cloud seeding was oversold during this period. Additional research and operations were conducted with more realistic expectations beginning in the 1960's and continuing to the present time. Some skepticism remains regarding the effectiveness of cloud seeding, although several professional societies now state that winter time precipitation in mountainous areas can be increased on the order of 10%. Compelling evidence exists for the positive effects of cloud seeding in augmenting water supplies in the west, although proof in the strict scientific sense is elusive.

Several operational winter cloud seeding programs have been conducted in the Sierra Nevada Mountains of California dating back to the early and mid-1950's in a couple of cases and the early to mid 1960's in several other cases. Winter cloud seeding programs have also been operated for a number of years in portions of Colorado, Utah, and Wyoming. For example, programs in Utah date back to 1974. Estimations of the effects on precipitation commonly indicate seasonal increases of the order of 5% to 15%.

This paper identifies areas within the Colorado River Basin where a) new operational winter cloud seeding programs could be developed and b) existing programs enhanced through additional funding to provide additional runoff in the Colorado River system. These activities would include new or expanded programs in the States of Arizona, Colorado, Utah and Wyoming. Streamflow that contributes to Colorado River flows in these areas is primarily generated via melting snow from the higher elevation areas of these states, thus the recommendation for the focus on winter time programs.

A distinction is made between operational programs and research programs. Operational programs are conducted to achieve a specific objective or objectives; in this case, increases in streamflow in the Colorado River Basin. Cloud seeding research programs are conducted to advance knowledge; perhaps to gain a better understanding of how cloud seeding works or to demonstrate the effectiveness of a new seeding approach. Research programs are inherently more costly than operational programs. Research activities could be superimposed on some of the operational programs, as has been done in programs such as the Bureau of Reclamation's Weather Damage Modification Program that is currently active and the earlier National Oceanic and Atmospheric Administration's Atmospheric Modification Program conducted in the 1980's and 1990's. Additional federal funds would be needed to perform such "piggyback" programs, if desired.

The anticipated effects from well designed and conducted operational seeding programs range from 5-15% increases in precipitation. Streamflow model simulations performed by the National Weather Service, River Forecast Center located in Salt Lake City, Utah for the Upper Basin States of Colorado, Utah and Wyoming predict increases of 650,500 acre feet of April through December runoff into Lake Powell during an average year resulting from the conduct of new cloud seeding programs assuming a 10% increase in October through March precipitation. Similar programions for existing operational seeding program areas indicate an estimated average increase of 576,504 acre feet of October through March runoff into Lake Powell in an average year, assuming a 10% increase in precipitation. The total from new and existing areas would be 1,227,004 acre feet. Obviously, the same percentage increases in precipitation in wet years would produce higher amounts of runoff and lower amounts in dry years. Seeding suspensions in very wet winters would limit the expected total increase from such winters. Ample storage would typically be available in the tributary and especially the main stem reservoirs such as Lake Powell to contain any amounts of expected increases in runoff even from wet and very wet winters. It is estimated that an additional 154,000 acre feet of annual runoff could be generated from new seeding programs in the lower Colorado River Basin of Arizona. ***The total estimated average potential would therefore be 1,381,004 acre feet.*** *Some of this potential is currently being realized through the conduct of existing programs in Colorado and Utah, but no attempt has been made in this study to quantify the amount of runoff being generated by these programs. Means of augmenting some of these existing programs are contained in this study. No attempt was made in this study to quantify the additional streamflow that might be generated through such augmentation of existing programs. In a sense, these latter two issues are offsetting; some increases in streamflow from existing programs are currently being realized which would lower the estimated increases whereas enhancements of existing programs operations would increase these estimates.*

A preliminary estimate of the costs associated with developing new operational programs and augmenting existing ones for the four states on an annual basis is $6,965,000. Design studies for each of the new potential operational areas are advisable in order to customize cloud seeding activities for specific areas. The above estimated costs include a reservation of 15% of the total funds for evaluations of the effectiveness of *the cloud seeding in the new operational areas. Both statistical studies and physical measurements (e.g., detection of silver in snow that could be attributed to the seeding agent, silver iodide) could be performed.* ***The approximate cost of the estimated additional water which could be produced through cloud seeding is estimated to average $ 5.00 /acre-foot.*** *Estimates of the value of the additional water could be used to assess the benefit/cost aspect of the proposed programs.*

An attractive aspect of cloud seeding programs is that they can be implemented and, if needed, terminated comparatively quickly, since they generally do not involve the development of large permanent infrastructure. Further, operations can readily be suspended during very wet periods and restarted when appropriate.

No significant negative environmental impacts are anticipated from the conduct of such programs, based upon the findings from a number of large-scale office and field environmental programs funded by the Denver offices of the Bureau of Reclamation. Several of the field programs have been conducted in the winter environments of California, Colorado, Utah and Wyoming.

When objective assessments of various water resource management and supply options are conducted in similar situations, the weather modification option typically emerges as a most attractive avenue. It appears that this is true for the Colorado River system. This White Paper describes various aspects of the winter cloud seeding option in some detail including a list of recommendations in Section 18.

Recommendations shown in the text are also listed here.

- *New operational winter cloud seeding programs should be established in suitable areas in the states of Arizona, Colorado, Utah and Wyoming that are currently not part of active operational programs. This will enhance runoff into the Colorado River Basin. The term "operational" is used to denote programs whose primary goal is to produce additional precipitation. In other words, these programs would not be research oriented, although some research activities might be "piggybacked" on some of these programs should additional Federal or state funding become available. There is precedent for this approach in earlier "piggyback" research activities being added to operational programs in Colorado, Nevada and Utah through Federal funding.*
- *The development of new programs should follow the existing regulations that are concerned with weather modification activities within each State in which the program is to be conducted. All four states (Arizona, Colorado, Utah and Wyoming) have such regulations.*
- *Design studies should be conducted to guide the development of potential programs in new areas. Such studies will allow a customized approach to the development of each new program, taking into consideration area-specific factors such as climatology, topography, presence and frequency of seedable conditions, and seeding targeting and social considerations. The State of Wyoming, through their Water Resources Development Commission, has recently adopted this*

approach in their consideration of new programs in the Wind River, Sierra Madre, Medicine Bow, Salt and Wyoming Mountain Ranges.

- *Existing operational programs within the Upper Colorado River Basin could be potentially enhanced. Means of enhancing these effects should be coordinated by the existing program sponsors and operators. Modifications might include additional seeding equipment, different types of seeding equipment (e.g. aircraft in addition to ground seeding and/or remotely controlled ground generators), and longer operational periods if the full seasonal window of seeding opportunity is not currently being seeded.*
- *Approximately 10-15% of the budget to conduct new programs should be devoted to evaluations of the effectiveness of the new programs. Two general types of evaluations should be considered; statistical (e.g. historical target/control analyses) and physical (e.g. chemical analysis of snow to detect the presence of silver associated with the release of the silver iodide seeding agent). Additional evaluations of existing programs are not proposed since the program sponsors and/or operators are currently performing their own evaluations.*
- *Additional simulations of impacts of assumed seeding increases on streamflow should be performed. Such simulation work should be a part of any design studies conducted for potential new seeding areas.*
- *It is recommended that a multi-year research program be conducted to determine the effectiveness of propane seeding in generating increases in precipitation over large-scale areas the size of typical operational winter programs. It is recommended that the funding for this research program be obtained from federal sources and consequently the costs of conducting such a research program are not included in the cost estimates contained in Section 15.*
- *It is recommended that the Seven Basin States support any Congressional Bills that relate to the development of a "coordinated national weather modification research program" such as that proposed in HR 2995 and S 517.*
- *The Upper Basin States should develop cooperative agreements that feature the development of a "basin-wide water augmentation via cloud seeding program."*
- *Representatives of the Seven Basin States should consider convening an ad hoc committee to develop the scope of a short-term (3 year) program to augment and fund some of the existing operations and develop and fund some of the potential new programs.*
- *Representatives of the Seven Basin States should consider beginning discussions regarding cost-sharing and administration of new programs and augmentation of existing programs."*

4.0 REVIEW AND ANALYSIS OF CLIMATOLOGY OF THE PROPOSED TARGET AREAS (Task 2)

The RFP specified as Task 2 that "The contractor will provide a review and analysis of the climatology of the Upper Snake River Basin above Milner Dam, focusing on the aspects of climatology that are important goals of this study including storm frequencies and characteristics, barriers, seeding potential, and other factors."

There are certain aspects of the climatology of the area that are important to the exploration of the feasibility/preliminary design aspects of this study. Several relevant sections from a National Oceanic and Atmospheric Administration Climate Narrative of the States (Ruffner, 1985) are provided verbatim in Section 4.1. This general information provides a backdrop to more specific climate information regarding the potential program area contained in section 4.2.

4.1 Climate of Idaho

4.1.1 Topographic Features

"Idaho lies entirely west of the Continental Divide, which forms its boundary for some distance westward from Yellowstone National Park. With a maximum north-south extent of 7° of latitude, its east-west extent of 6° of longitude at latitude 42° N., but only 1° of longitude at 49° N. The northern part of the State averages lower in elevation than the much larger central and southern portions, where numerous mountain ranges form barriers to the free flow of air from all points of the compass. In the north the main barrier is the rugged chain of Bitterroot Mountains forming much of the boundary between Idaho and Montana. The extreme range of elevation in the State is from 738 feet of the confluence of the Clearwater and Snake Rivers to 12,655 feet at Mt. Borah in Custer County. Comprising rugged mountain ranges, canyons, high grassy valleys, arid plains, and fertile lowlands, the State reflects in its topography and vegetation a wide range of climates. Located some 300 miles from the Pacific Ocean, Idaho is, nevertheless, influenced by maritime air borne eastward on the prevailing westerly winds. Particularly in winter, the maritime influence is noticeable in the greater averagae cloudiness, greater frequency of precipitation, and mean temperatures, which are above those at the same latitude and altitude in mid-continent. This maritime influence is most marked in the northern part of the State, where the air arrives via the Columbia River Gorge with a greater burden of moisture than at lower latitudes. Eastern Idaho's climate has a more continental character than the west and north, a fact quite evident not only in the somewhat greater range between winter and summer temperatures, but also in the reversal of the wet winter-dry summer pattern.

TEMPERATURE *– The pattern of average annual temperatures for the State indicates the effect both of latitude and altitude. The highest annual averages are found in the lower elevations of the Clearwater and Little Salmon River Basins, and in the stretch of the Snake River Valley from the vicinity of Bliss downstream to Lewiston, including the* *open valleys of the Boise, Payette, and Weiser Rivers. At Swan Falls the annual mean is 55° F, highest in the State. Obsidian, at an elevation of 6,780 feet in Custer County, has the lowest annual average, 35.4° F, of any reporting station, with such places as Sun Valley, Chilly Barton Flat, Grouse, Island Park Dam, and Big Creek not far behind. The range between the mean temperature of the coldest and warmest months of the year varies from less than 40° F at a number of northern stations, to well over 50° F at stations in the higher elevation of the central and eastern parts of the State. In the basin of the Snake River and its tributaries, between Twin Falls and Idaho Falls, monthly mean temperatures of 32° F or lower persist from December through February, while downstream from Twin Falls, at the lower elevations, monthly mean temperatures are freezing or below only in December and January. Low-level stations like Riggins and Lewiston show no month in the year with mean temperature 32° F or lower. In general, it can be said that monthly means are 32° F or lower at stations above 5,000 feet from November through March; between 4,000 and 5,000 feet, November through February; 3,000 to 4,000 feet, December through February; and 2,000 to 3,000 feet, only one or two months. The diurnal range of temperature is, of course, most extreme in high valleys and in the semiarid plains of the Snake River Valley. The magnitude of diurnal range varies with the season, being lowest in winter when cloudiness is much more prevalent, and greatest in the warmer part of the year. At Boise, for example, the average diurnal range is only 14° F in January, but exceeds 30° F in July through September. Temperatures can range from -60° to 118° F. The coldest monthly mean minimum temperature has been -20° F, and the warmest monthly mean maximum 104° F. The highest long-term annual average has been 55°F at Swan Falls Power House, and the lowest long-term average 35° F at Obsidian. In summer, periods of extreme heat extending beyond a week are quite rare, and the same can be said of periods of extremely low temperatures in winter. In both cases the normal progress of weather systems across the State usually results in a change at rather frequent intervals. In the realm of extremely low temperatures, two winters stand out in the records for the State: 1937-38 and 1948-49. The lowest monthly mean temperatures on record occurred throughout the State in January 1949, and many stations registered the absolute lowest temperature on record during that month.*

PRECIPITATION *– To a large extent the source of moisture for precipitation in Idaho is the Pacific Ocean. In summer there are some exceptions to this when moisture-laden air is brought in from the south at high levels to produce thunderstorm activity, particularly in the eastern part of Idaho. The source of this moisture from the south is apparently the Gulf of Mexico and Caribbean region. The average precipitation map for Idaho is as complex as the physiography of the State. Partly because of the greater moisture supply in the west winds over the northern part of the State, (less formidable barriers to the west) and partly because of the greater frequency of cyclonic activity in the north, the average valley precipitation is considerably greater than in southern sections. Peaks on the average annual precipitation map are found, however, in nearly all parts of the State at higher elevations. Sizeable areas in the Clearwater, Payette, and Boise River Basins receive an average of 40 to 50 inches per year, with a few points or small areas receiving in excess of 60 inches. Large areas including the northeastern valleys, much of the Upper Snake River Plains, Central Plains, and the lower elevations* *of the Southwestern Valleys receive less than 10 inches annually. Seasonal distribution of precipitation shows a very marked pattern of winter maximum and midsummer minimum in the northern and western portions of the State. In the eastern part of the State, however, many reporting stations show maximum monthly amounts in summer and minimum amounts in winter. In the Northeastern Valleys and Eastern Highlands, more than 50 percent of the annual rainfall occurs during the period April through September. Over nearly all of the northern part of the State, however, less than 40 percent of the annual rainfall occurs in this same period, and in portions of the Boise, Payette, and Weiser River drainages less than 30 percent of the annual amount comes in that six-month period.*

SNOWFALL *– Snowfall distribution is affected both by availability of moisture and by elevation. Annual snowfall totals in Shoshone County have reached nearly 500 inches. The greatest long-term (1942-56) seasonal average was 182 inches at Mullan Pass, while the greatest snow depth (also 182 inches) was recorded at that station on February 20, 1954. The major mountain ranges of the State accumulate a deep snow cover during the winter months, and the release of water from the melting snowpack in late spring furnishes irrigation water for more than two million acres, mainly within the Snake River Basin above Weiser. Irrigation water supplies are nearly always plentiful, except on some of the smaller programs where storage facilities are inadequate. Electric power in increasing amounts is generated by the waters of the many rivers of the State.*

FLOODS *– Floods in Idaho occur most often during the period of seasonal snowmelt in spring, particularly in April and May. A few areas in the State are actually flooded or threatened by flood waters nearly every year. The Kootenai River Valley, in the vicinity of Bonners Ferry, is one such area, and another is the Snake River upstream from Idaho Falls in the vicinity of Roberts and Menan. Much has been done to minimize the damage from such seasonal floods through the construction of reservoirs and other flood-control facilities. So-called "out of season" floods do occur occasionally at a number of points in the State. For example, wintertime floods occurred on the Payette, Weiser, Little Salmon, and Wood Rivers and portions of the upper Boise and Payette Basins in 1955, 1957, and 1958. Flash floods on small streams, or occasionally in ravines or dry gulches, occur a few times each year as the result of heavy rains associated with thunderstorms. Two areas that seem to be particularly susceptible to this type of flooding lie between Downey and Pocatello in the southeast, and in the north-central part of the State between Grangeville and Moscow."*

4.2 Relevant Climatological Features of the Eastern Snake River Basin

The meteorological parameters of greatest interest in this feasibility study are: precipitation, surface and upper-level wind directions and velocities, temperatures at the surface and aloft, and the structure of the lower to mid-levels of the atmosphere. Information on these parameters during winter storm periods that impact the proposed target areas is of primary interest. Two factors drive these considerations: 1) the likely presence of "seedable" conditions, and 2) the potential ability to target these seedable regions. Considerations involving the first factor (seedability) may be focused on the temperatures and winds within the storms. To be seedable, a portion of the cloud system needs to be colder than freezing. Also, the height of certain temperature levels such as the 23^0 F (-5^0 C) are important for one of the primary seeding materials (silver iodide), since this is the warmest temperature at which silver iodide begins to be active as an ice or freezing nuclei (a topic to be discussed further in section 5.4). Another consideration may be the speed and direction of the lower level winds. If winds are blowing up and over the mountain barrier and the cloud top temperatures are not too cold, then supercooled liquid water droplets will likely be present in the storm clouds. It is the presence of these supercooled water droplets that determine whether there is any seeding potential within the clouds (more on the theory of cloud seeding is contained in section 5.1). A photograph illustrating the extreme build up of ice that was formed from supercooled water droplets impacting structures on the top of Mt. Washington in New Hampshire is provided in Figure 4.1. Targeting considerations are related to the likely transport and diffusion of seeding materials, which becomes a function of seeding mode (ground based, aerial), the lower level wind speed and direction, and lower level atmospheric stability. These targeting issues are also discussed in a later section (section 5.5).

Information on these parameters of interest is provided in the following sections. This feasibility study was defined as a wintertime activity. We have therefore provided information for the October through April time frame.

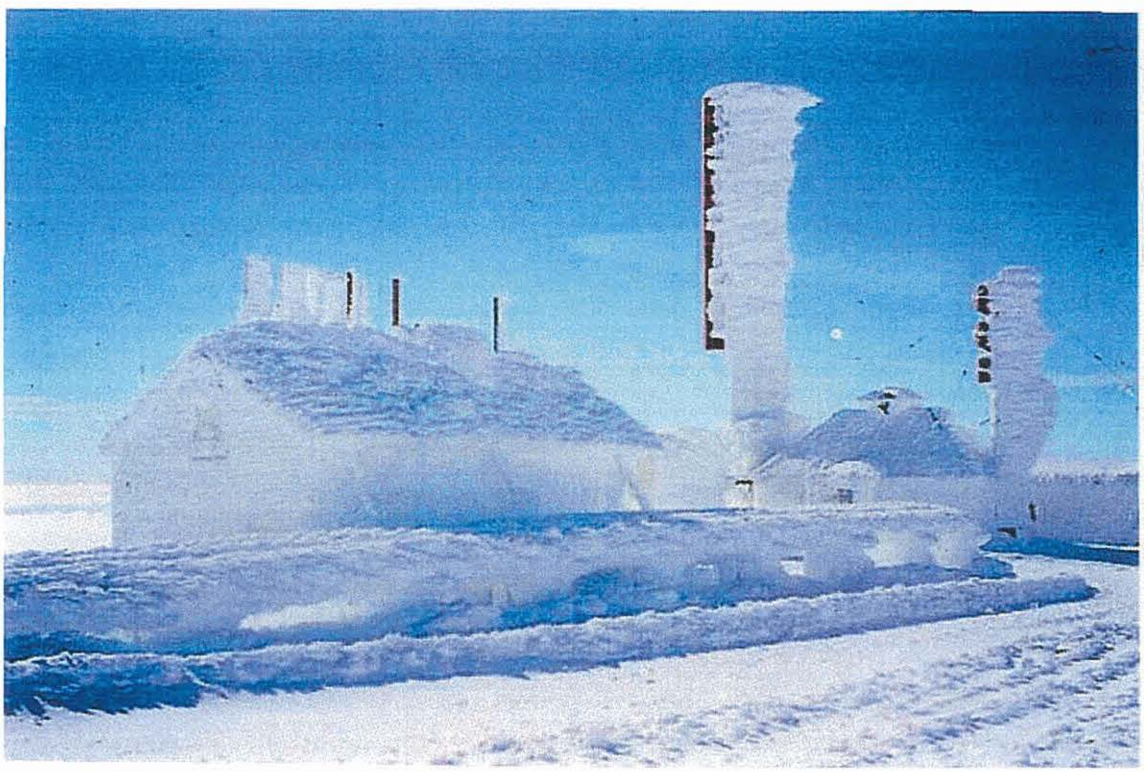

Figure 4.1 Riming on Mt. Washington, NH

4.2.1 Precipitation and Snow Water Content

Data on the natural precipitation of the program areas provides useful information concerned with the different types of storms that impact these areas. Such data also provide a baseline for estimation of the magnitude of precipitation increases that may be possible through cloud seeding. For example, if a potential target site receives an average 30 inches (76 cm) of precipitation during the winter months and if our analyses indicate that a 12% increase in precipitation is possible from cloud seeding, then the estimated increase in an average winter season at this site would be 4.5 inches (11.4 cm) of additional precipitation. This estimate may then be used to provide estimates of resultant increases in steamflow. Observations of precipitation in the higher elevation areas that will be considered as potential target areas have been made primarily by the Natural Resources Conservation Service (formerly the Soil Conservation Service). These observations are of two basic types: 1) measurements of snow water content and 2) measurements of rainfall and melted snowfall.

Manual observations of the water content of snowfall throughout the mountainous areas of the west began in 1906 through the pioneering work of manual snow water measurement techniques by Dr. Church in the Reno, Nevada area (Church, 1918). These measurements were mandated by Congress to "measure snowpack in the mountains of the West and forecast the water supply." Sampling locations were established throughout the mountain ranges of the west. Typically a high elevation snow course was visited approximately once per month during the winter months and ten vertical measurements of the snowpack were taken each month with a hollow tube that converted the weight of the snow into a water content measurement in inches. The ten observations were then averaged to give an estimate of the snow water content in inches for the snow course. Some of these snow course sites were also equipped with stand pipe storage gages. These storage gages were charged with an anti-freeze solution, which melted the snow as it fell into the gage. A pressure transducer provided the resultant precipitation amount in inches of water. The crews making the snowcourse measurements would also record the standpipe storage gage precipitation amounts at those sites equipped with such devices. The Soil Conservation Service implemented a major improvement to this measurement technique in the early to mid-1980's. This new technique was called SNOTEL (for SNOwpack TELemetry). SNOTEL utilizes a unique data transmission system that relies upon meteor burst technology. VHF radio signals are reflected at a steep angle off the ever-present band of ionized meteorites existing from about 50 to 75 miles (80-120 km) above the earth. With the advent of the SNOTEL system, data are available with approximately hourly resolution. The data typically consist of snow water content, precipitation and temperature. A snow pillow, which is a cylindrical metal device approximately 8 feet (2.4m) in diameter and 4 inches in thickness, measures snow water content. Precipitation is measured with the same standpipe storage gages described previously.

Figure 4.2 provides a photo of an NRCS SNOTEL site taken in the fall, to allow the reader a better understanding of the two types of observation systems. The vertical tube is the standpipe storage gage, which is approximately 12" (30.5cm) in diameter. The gages are approximately 20' (6.1m) in height so that their sampling orifices remain above the snowpack surface. In the fall, the storage gage is charged with antifreeze, which melts the snow that falls to the bottom of the gage. A pressure transducer records the weight of the solution. The weight of the antifreeze is subtracted from the total weight, giving the weight of the water, which is then converted into inches.

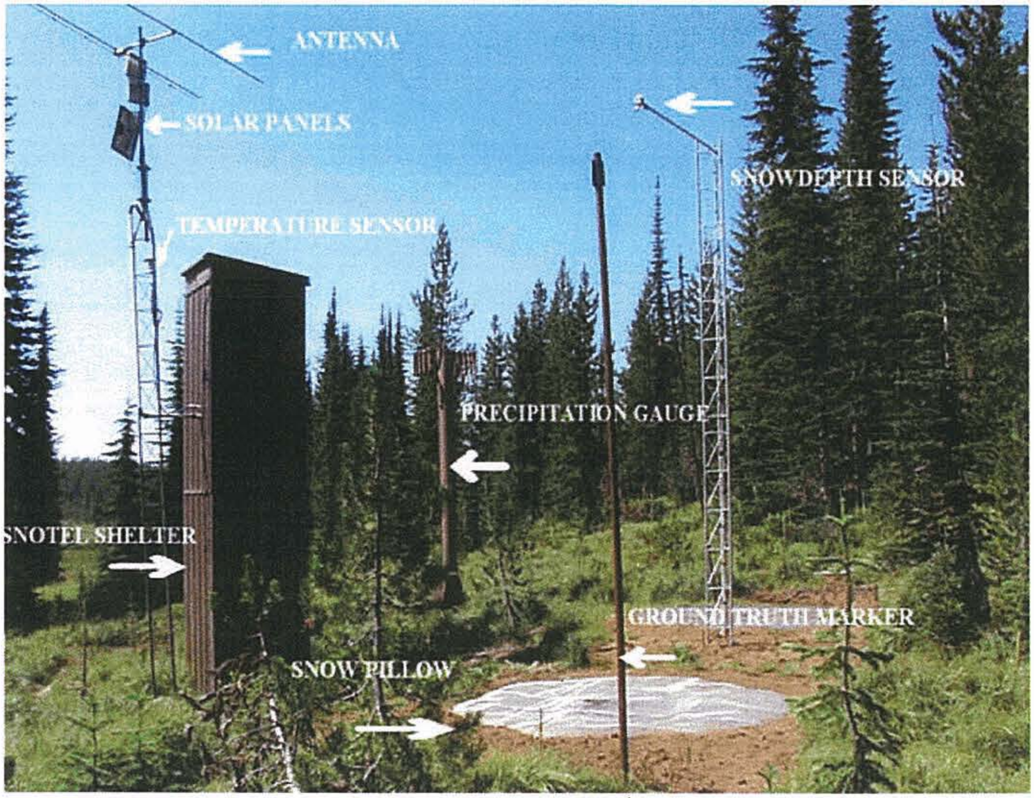

Figure 4.2 Example of an NRCS SNOTEL Site

There are at least two types of problems associated with high elevation observations of the water equivalent of snowfall. There are potential problems associated with each type of observation. The two areas of concern are clogging at the top of the standpipe storage gage, and blow-by of snowflakes past the top of the standpipe gage. Either situation would result in an underestimate of the actual precipitation that fell during such periods. Heavy, wet snow may accumulate around the top of the standpipe storage gage, either reducing or stopping snow from falling into the standpipe and resulting in an underestimate of precipitation. Snow that falls with moderate to strong winds may blow past the top of the gage, which can also result in an underestimate of precipitation. NRCS sites are normally located in small clearings in forested areas to help reduce the impacts of wind problems. Sites that are near or above timberline are more likely to be impacted by wind since sheltered sites may be difficult to find in these higher elevation areas. The snow pillow pictured in the foreground in Figure 4.2 is filled with antifreeze. This system weighs the snowpack, providing time-resolved records of the snowpack water content. Snow pillows can also have difficulty in providing accurate measurements of snow water content, because of wind either adding or removing snow from the measurement site when snow conditions are favorable for drifting. Consequently, either measurement should be considered an estimate of the actual amount of precipitation that falls.

Tables 4-1 and 4-2 provide information on NRCS SNOTEL and manual snow course sites that provide snow water content information for the two target areas. Figures 4.3 and 4.4 provide the locations of these sites. It should be noted that there are only a limited number of SNOTEL sites within the potential target areas (three in the North area and one in the East area) but considerably more manual snow course sites that are still active within the proposed target areas. Table 4-3 provides average monthly amounts of precipitation at the four SNOTEL sites. Table 4-4 provides the average amounts of accumulated snow water content on a monthly basis beginning on or about January 1st at some North Target sites. Table 4-5 provides the average amounts of monthly snow water content at the North sites derived by subtracting an amount on the beginning of one month from the amount at the same site on the beginning of the following month. Tables 4-6 and 4-7 provide similar information for the East Target area. Figures 4.5 and 4.6 provide the average snow water content accumulation through the period of October 1st to May 1st for the White Elephant site (North area) and the Pine Creek Pass site (East area) respectively.

Table 4-1

SNOTEL and Snow Course Sites, North Area

Site	Lat (N)	Long (W)	Elevation	Start Date
Big Springs	44⁰ 28'	111⁰ 16'	6400'	1936
Camp Creek	44⁰27'	112⁰ 14'	6580'	1936
Crab Creek*	44⁰26'	111⁰ 59'	6860'	1982
Irving Creek	44⁰25'	112⁰ 36'	7280'	1960
Island Park*	44⁰25'	111⁰ 23'	6290'	1982
Latham Springs	44⁰28'	111⁰ 09'	7630'	1961
Lucky Dog	44⁰28'	111⁰ 13'	6860'	1961
Valley View	44⁰37'	111⁰ 19'	6680'	1936
Webber Creek	44⁰21'	112⁰ 40'	6700'	1960
White Elephant*	44⁰ 31'	111⁰ 24'	7710'	1982

* SNOTEL Site

Table 4-2

SNOTEL and Snow Course Sites, East Area

Site	Lat (N)	Long (W)	Elevation	Start Date
Allen Ranch	42^0 46'	111^0 25'	6470'	1961
Fall Creek	43^0 28'	111^0 33'	6820'	1984
Lava Creek	43^0 18'	111^0 31'	7350'	1961
Packsaddle Spr.	43^0 43'	111^0 21	8200'	1981
Pine Creek Pass*	43^0 34'	111^0 12'	6720'	1989
Somsen Rch.*	42^0 57'	111^0 22	6800'	1936
State Line	43^0 33'	111^0 03'	6660'	1936

* SNOTEL Site

Table 4-3

North and East Target Area SNOTEL Average Monthly Precipitation

Site	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Oct.-Apr.	Annual
Crab Creek	1.7	2.5	2.9	3.0	3.2	3.4	2.8	19.5	30.6
Island Park	1.7	3.0	3.9	3.9	3.5	3.1	2.5	21.6	31.1
Pine Creek Pass	2.0	3.7	4.4	4.1	3.4	3.2	2.8	23.6	33.2
Somsen Rch.	1.8	2.8	3.3	3.3	2.7	2.7	2.3	18.9	26.8
White Elephant	2.8	5.2	5.9	5.6	5.5	5.6	4.0	29.0	47.4

Table 4-4

Average Cumulative Snow Water Content, North Area, First of Month Amounts (inches)

Site Name	Nov. 1	Dec. 1	Jan.1	Feb. 1	Mar. 1	Apr. 1	May 1
Big Springs	--	--	8.1	13.1	17.5	19.3	12.1
Camp Creek	--	--	3.9	6.1	8.2	9.8	--
Crab Creek *	0.4	3.0	6.4	9.6	12.7	16.4	11.9
Irving Creek	--	--	--	--	4.9	5.7	--
Island Park *	0.4	3.7	6.5	10.6	13.7	15.7	8.9
Latham Springs	--	--	--	--	28.4	33.0	--
Lucky Dog	--	--	--	--	21.8	25.2	--
Valley View	--	--	6.2	9.9	13.4	15.4	9.3
Webber Creek	--	--	--	--	4.7	5.9	--
White Elephant *	1.3	6.4	11.8	18.0	23.4	29.2	27.7

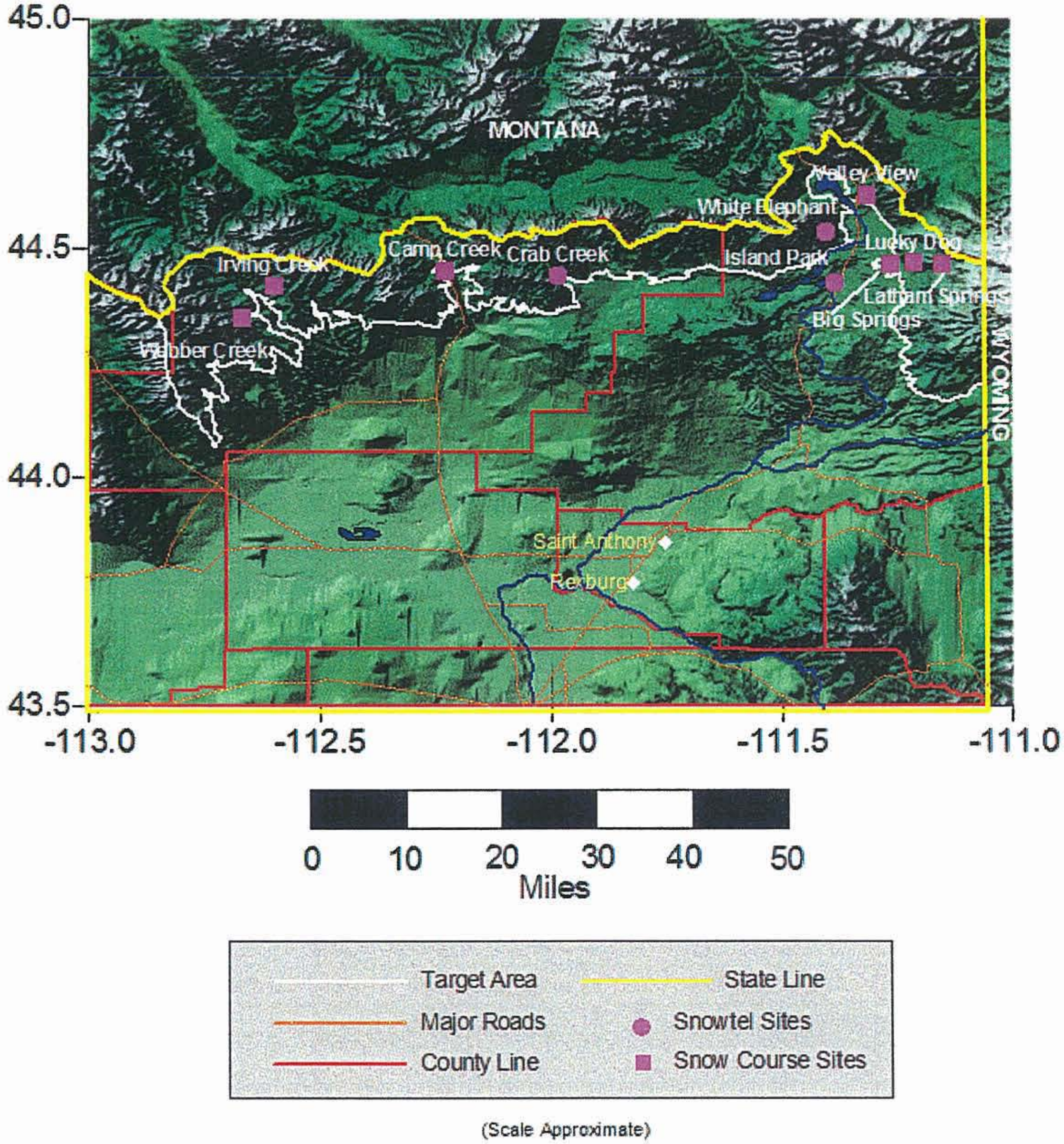

Figure 4.3 Snow Course and SNOTEL Site Locations, North Area

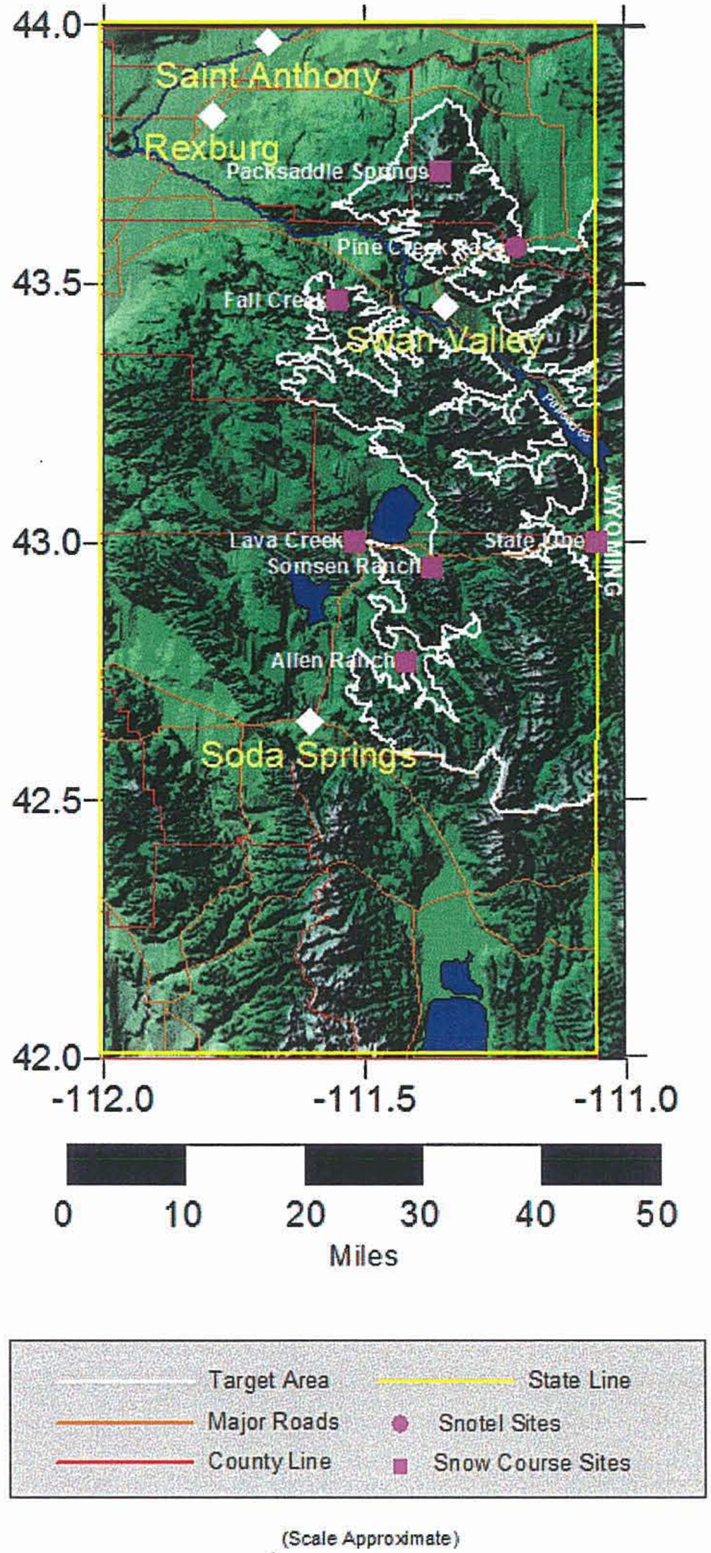

Figure 4.4 Snow Course and SNOTEL Site Locations, East Area

Table 4-7

Average Monthly Snow Water Content Amounts (inches), East Area

Site	November	December	January	February	March
Allen Ranch	--	--	--	2.6	--
Fall Creek	--	--	2.9	1.5	--
Lava Creek	--	--	4.0	3.7	1.0
Packsaddle Spr.	--	--	6.8	6.0	4.1
Pine Creek Pass*	2.8	3.6	4.0	3.3	1.8
Somsen Rch.	2.3	2.8	3.9	2.7	1.5
State Line	--	--	3.8	3.0	1.8

Note: Some of the March amounts may be low due to snowmelt effects at some of the lower elevation sites.

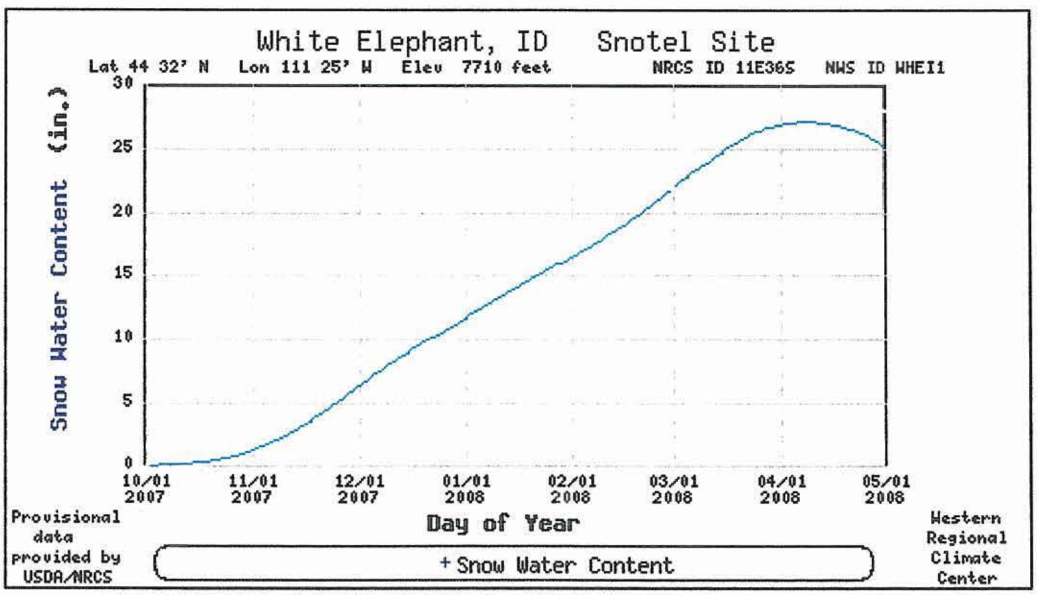

Figure 4.5 **Average White Elephant Snow Water Content Accumulation, Oct. 1 to May 1, North Area**

Table 4-5

Average Monthly Snow Water Content Amounts (inches), North Area

Site Name	Nov.	Dec.	Jan.	Feb.	Mar.
Big Springs	--	--	5.0	4.4	1.8
Camp Creek	--	--	2.2	2.1	1.6
Crab Creek *	2.6	3.4	3.2	3.1	3.7
Irving Creek	--	--	--	--	0.8
Island Park *	3.3	2.8	4.1	3.1	2.0
Latham Springs	--	--	--	--	4.6
Lucky Dog	--	--	--	--	3.4
Valley View	--	--	3.7	3.5	2.0
Webber Creek	--	--	--	--	1.2
White Elephant *	5.1	5.4	6.2	5.4	5.8

Note: Some of the March amounts may be low due to snowmelt affecting some of the lower elevation sites.

Table 4-6

Average Cumulative Snow Water Content, East Area, First of Month Amounts (inches)

Site	Nov. 1	Dec. 1	Jan. 1	Feb. 1	Mar. 1	Apr.1	May 1
Allen Ranch	--	--	--	7.7	10.3	10.5	--
Fall Creek	--	--	3.8	6.7	8.2	7.3	--
Lava Creek	--	--	7.0	11.0	14.7	15.7	8.0
Packsaddle Spr.	--	--	12.4	19.2	25.2	29.3	29.1
Pine Creek Pass*	0.5	3.3	6.9	10.9	14.2	16.0	10.1
Somsen Rch.*	0.2	2.5	5.3	9.2	11.9	13.4	6.8
State Line	--	--	6.4	10.2	13.2	15.0	9.0

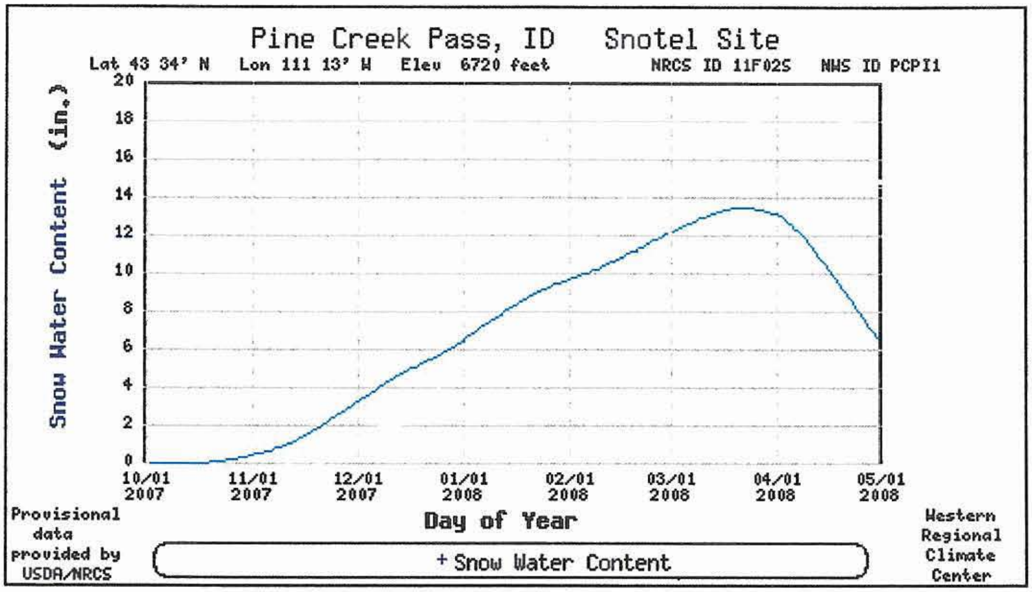

Figure 4.6 Average Pine Creek Pass Snow Water Content Accumulation, Oct. 1 to May 1, East Area

Figures 4.7 and 4.8 provide plots of the average April 1st snow water content amounts for the North and East target areas. Figure 4.7 indicates significantly less snow water content on the western side of the North target area. The reason for this decline may be due to a "rainshadow effect" produced by the Lemhi mountain range to the west. Rainshadows, reduction in amounts of precipitation, are frequently produced on the downwind sides of mountain ranges. This is due to the lower-level air that has been lifted on the upwind side of the barrier being able to descend on the downwind side. This descent allows the air to warm and often results in the evaporation of some of the snowflakes or rain drops that have formed as air is lifted on the windward slopes, meaning less precipitation reaches the ground on the leeward slopes. Since the prevailing wind directions are from the west during winter storms in the North area (as documented in 4.2.3.2), this effect could explain the low precipitation amounts in the western end of the North target area depicted in Figure 4.7. Figure 4.7 indicates the maximum snowpack accumulation in the North area occurs in the eastern portion of the area in the Henrys Lake area. Figure 4.8 indicates the maximum snowpack accumulation occurs in the northern portion of the East area east of Rexburg with lower amounts further south. Figure 4.9 provides a plot of the average monthly precipitation at the White Elephant site. Table 4-8 indicates that approximately 61 to 71% of the precipitation in the target areas occurs during the October through April period.

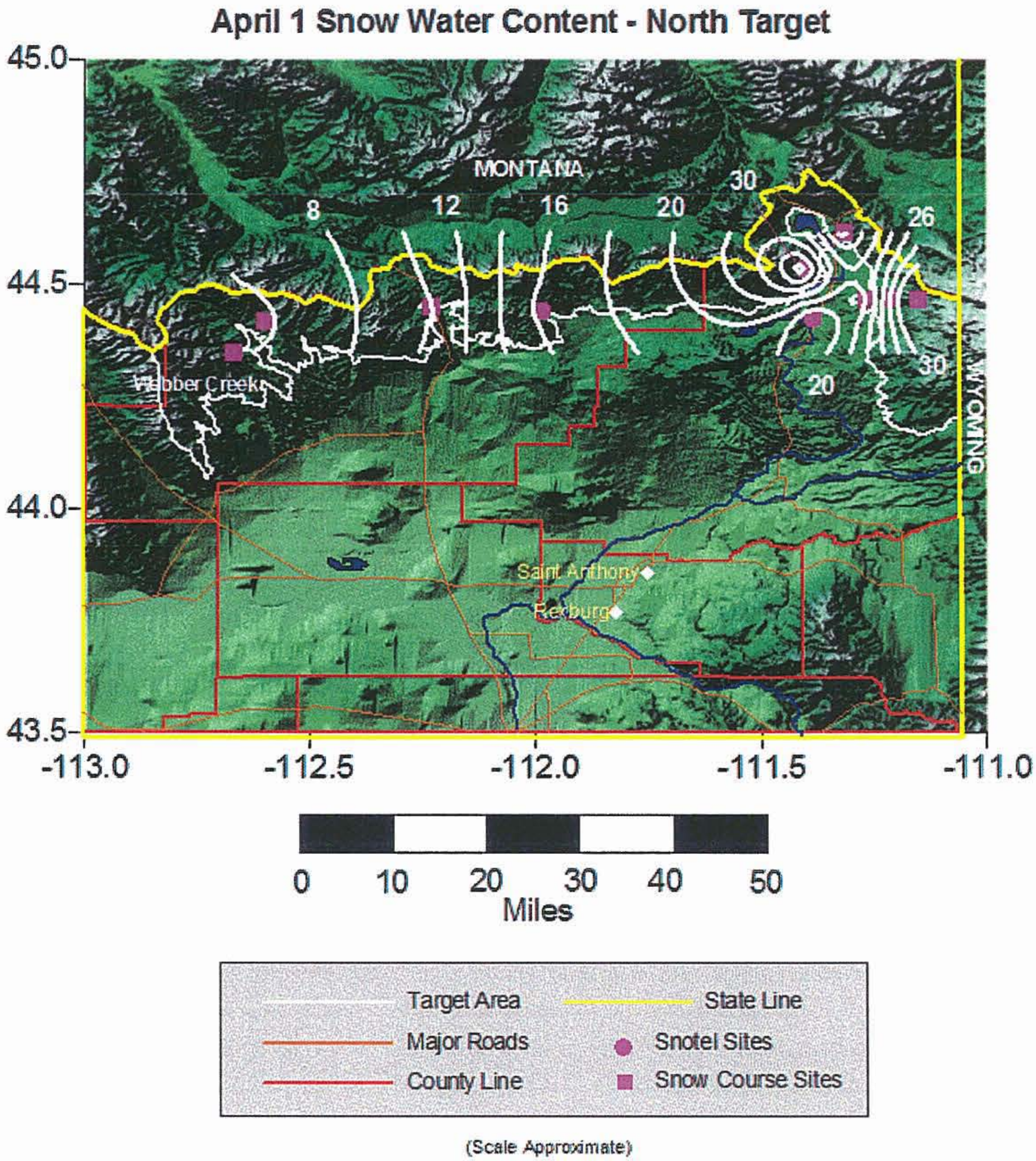

Figure 4.7 Isohyets of Average April 1st Snow Water Content, North Area

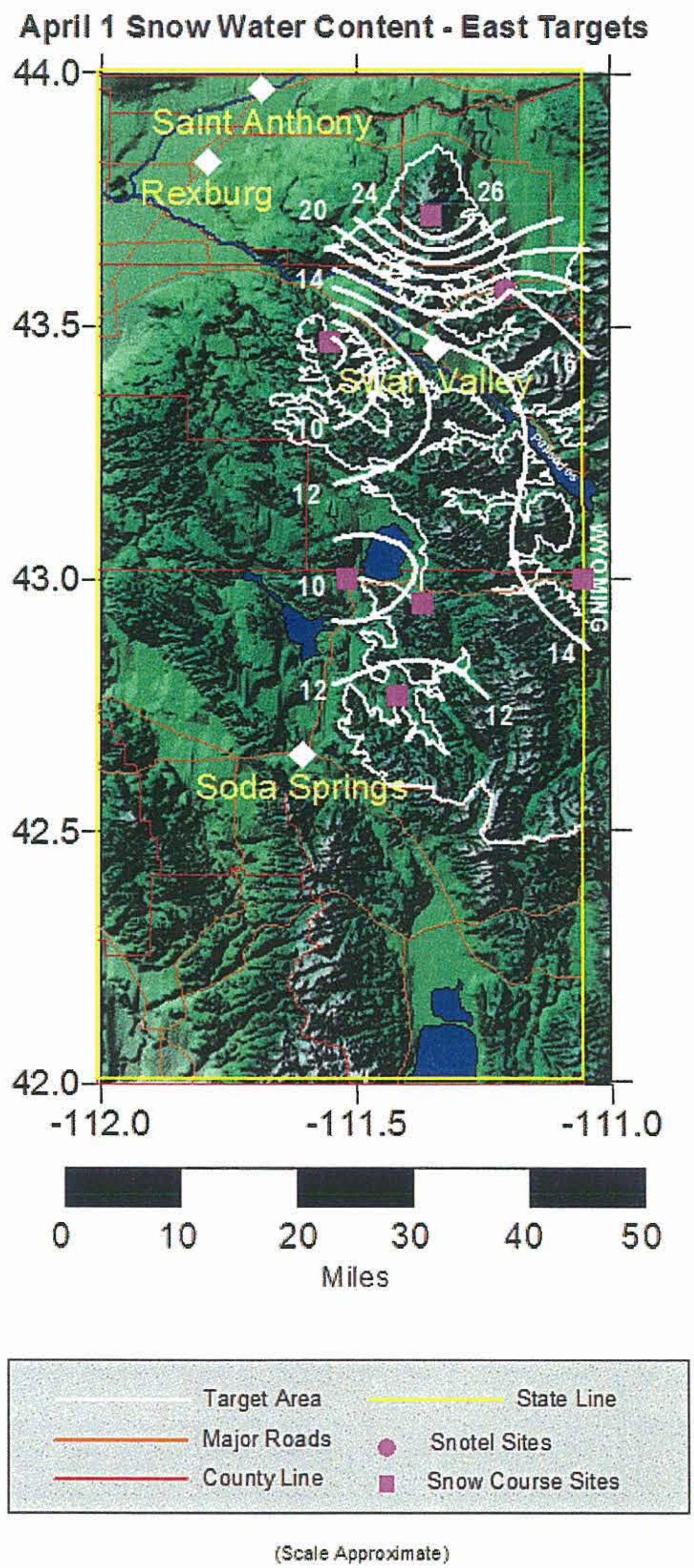

Figure 4.8 Isohyets of Average April 1st Snow Water Content, East Area

Table 4-8

Seasonal Distribution Of Precipitation at the Four SNOTEL Sites

Site	Oct – Apr Precip. (inches)	Water Year Precip. (inches)	% Oct – Apr vs. Water Year
Crab Creek	19.5	30.6	64
Island Park	21.6	31.1	69
Pine Creek Pass	23.6	33.2	71
White Elephant	29.0	47.4	61

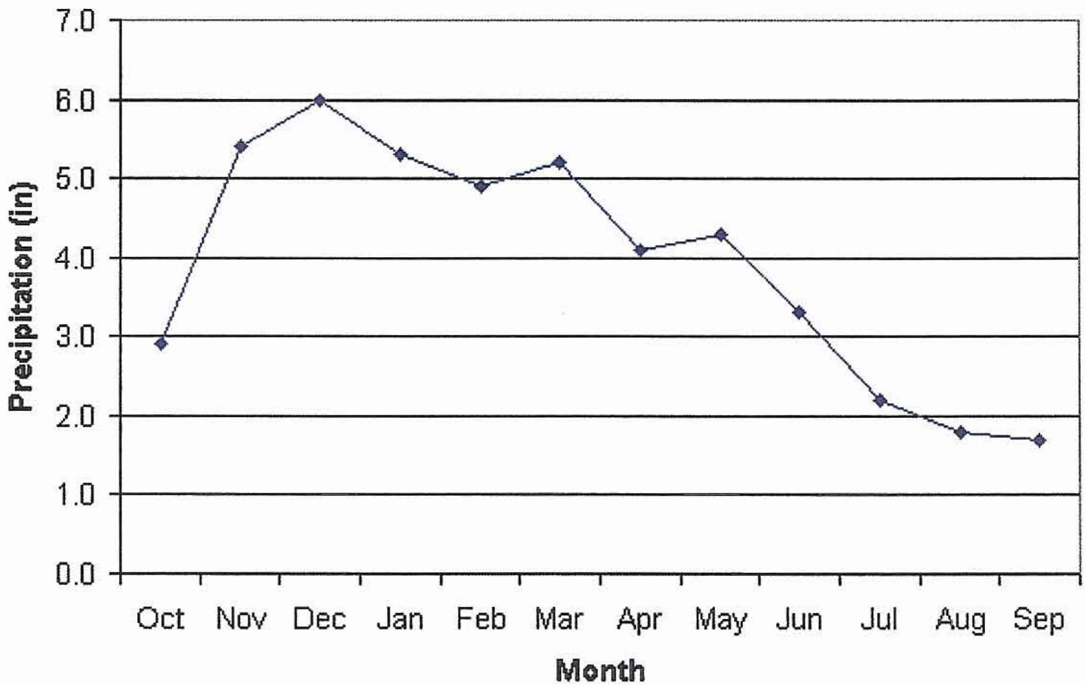

Figure 4. 9 Average Monthly Precipitation at the White Elephant SNOTEL Site

Data from the above tables and figures indicate the following:

- Though precipitation occurs during the month of October, there is little snowpack accumulation during the month of October.
- The peak monthly precipitation amounts seem to occur primarily during the three-month period of December, January and February with December receiving the most precipitation at the wetter, high elevation sites.
- Significant precipitation also occurs during the months of November, March and April.
- The highest precipitation and snow water accumulations for the winter season

generally occur at the highest elevations in the target areas.

- On average, the maximum snow water accumulations occur a little before April 1st at lower elevation sites and a little after April 1st at higher elevation sites.
- Approximately 65-70% of the target area precipitation occurs in the fall, winter and spring months, October through April.

4.2.2 Temperature

The temperatures observed in the proposed target areas during the winter are a function of a number of factors including elevation, time of year, cloud cover, and the origin and type of air masses present over these areas at a given time. Normally, temperatures in the free atmosphere decrease ~ 2.7 ^{0} F (1.5 ^{0} C) per 1000 foot (300 meter) rise in altitude. Figures 4.10 and 4.11 provide average maximum and minimum temperatures for two SNOTEL sites, one in the North area (White Elephant) and Pine Creek Pass in the East area. These average values are of general interest but the temperatures of special importance are those associated with the winter storm periods that impact the proposed target areas. The storm-specific type of information will be provided in the following section.

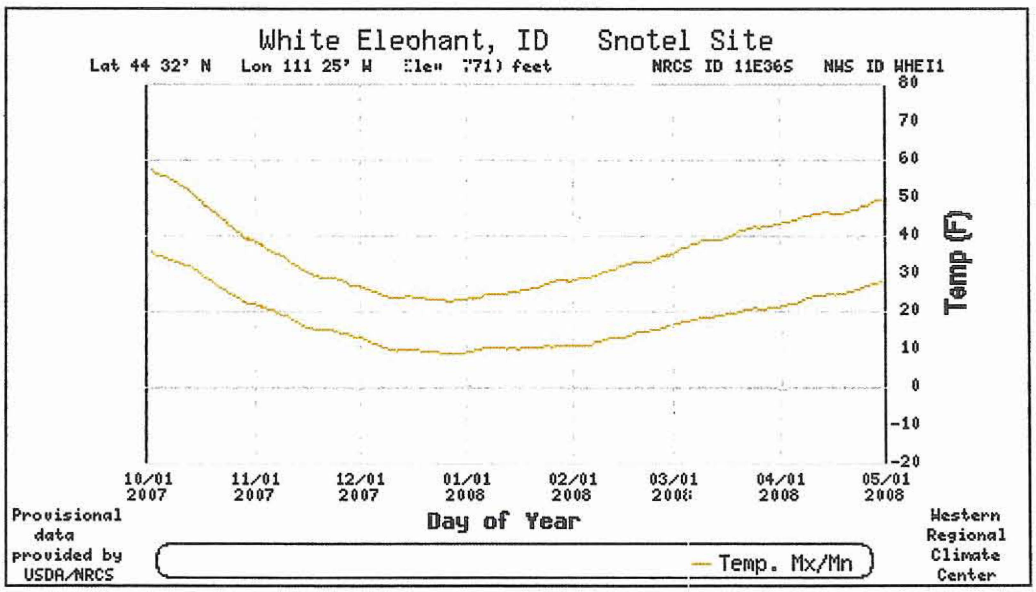

Figure 4.10 Average Maximum and Minimum Temperatures by Month, White Elephant Site

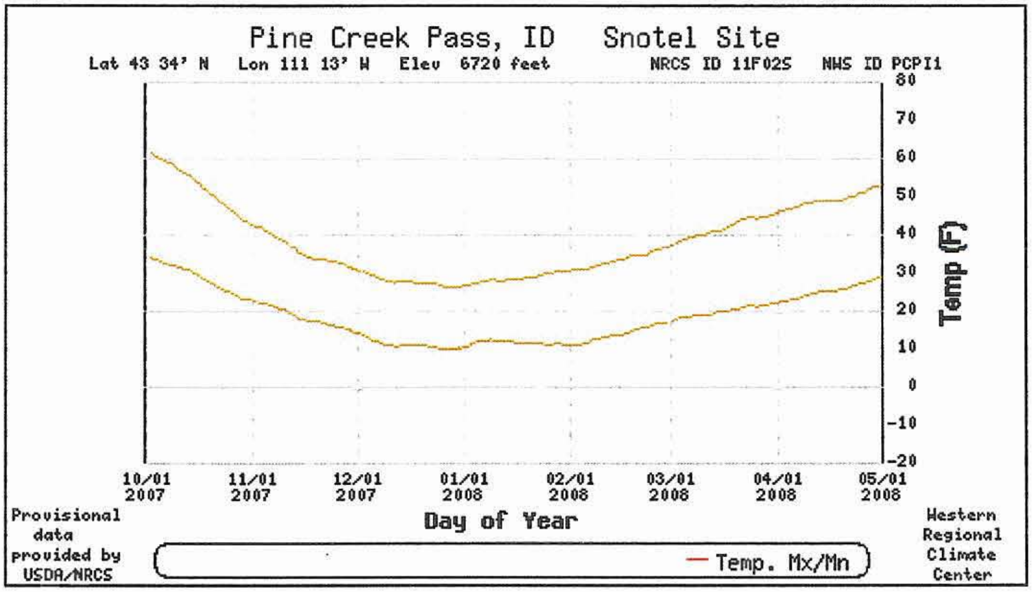

Figure 4.11 Average Maximum and Minimum Temperatures by Month, Pine Creek Pass Site

4.2.3 Specialized (Storm Period-Specific) Climatological Information

A detailed analysis of storm periods affecting the potential target areas was conducted for five winter seasons (water years 2003-2007) for the October-April period. Precipitation data from several SNOTEL sites were considered, and six-hour time blocks were selected when precipitation was clearly occurring in the target areas (in general, at least 0.10 inches of precipitation during the six hour period reported at one or more of the target SNOTEL sites). As discussed previously, the potential target area was divided into two sections, the North area and the East area, which are depicted on the map provided in Figure 2.3. Data from two SNOTEL sites (Pine Creek Pass and Sheep Mountain) were considered for the East area, and from three SNOTEL sites (Crab Creek, White Elephant and Island Park) for the North area. The SNOTEL data ranged from hourly to six hours in resolution. Data were obtained from the Natural Resources Conservation Service (NRCS) offices in Portland.

The 6-hour periods selected correspond roughly to available National Center for Environmental Prediction (NCEP) reanalysis data, from which vertical sounding profiles were created. These profiles are available for selected points throughout the United States (a grid with 2.5 degree resolution). One of these points was selected for proximity to the eastern portion target (42.5 N, 112.5 W, south of Pocatello) and another was used to represent conditions in the northern portion (45.0 N, 112.5 W, in far southwestern Montana). These atmospheric soundings were used to derive temperature and wind data at the 500- and 700-mb levels, which are at approximately 18,000 and 9,500 feet MSL.

These soundings also provided moisture (dewpoint) values, and a general idea of low- to mid-level atmospheric stability. Estimates of the –5 C isotherm height and cloud-top temperature were obtained based on these sounding profiles as well.

Although useful in many respects, the reanalysis sounding profiles provide a rather crude dataset with poor resolution. Even through the sounding profiles contain data for the 850-mb (approximately 5,000 feet MSL or near-surface) level, the low-level data tend to be poor in mountainous regions such as Idaho because of sharp low-level variations in the weather due to terrain, etc. Because of this, surface observation data (temperature, wind and dewpoint) were also utilized in conjunction with the sounding profiles to obtain better estimates of low-level stability issues and wind patterns. After examination of the availability and quality of surface data, three sites were utilized. For the eastern portion of the target area, one suitable site was found (Wayan, WYNI1, at 6391' elevation) to represent potential areas for ground-based seeding. For the northern portion, two sites (DUB, Dubois, at 5465' and Three-Mile, THMI1, at 6625') were utilized. These data were obtained through the MesoWest observation network maintained by meteorology staff at the University of Utah. The availability of data at these three sites helped in making estimations of the presence and depth of any inversion/stability layers that may affect ground-based seeding from sites in the upper Snake River Basin. Low-level stability (which could prevent seeding material from reaching the –5 C level over the target areas) was classified into four categories: Well-mixed (no stability problems evident), slightly stable, moderately stable, and very stable. These categories correspond roughly to situation when less than 2 C of surface heating would be necessary to mix out the atmosphere (slightly stable), 2-4 C (moderately stable), and more than 4 C (very stable). Cases that were well mixed or slightly stable were considered suitable for lower elevation ground-based seeding, while more stable cases would require remote high-elevation or aircraft seeding.

In all, 170 6-hour periods were identified and analyzed for the northern portion of the target, and 239 periods for the eastern portion. There was only approximately a 40% overlap in time periods identified for the two different portions, suggesting significant meteorological differences in precipitation patterns between the two areas.

4.2.3.1 Precipitation

A plot of the number of the average number of six-hour events by month for the North and East target areas are provided in Figures 4.12 and 4.13. These figures indicate the month of December has significantly more events in both of the areas than in the other fall, winter and spring months.

Figures 4.14 and 4.15 provide the average number of 6-hour events per winter season by month for four different ranges of precipitation amounts in inches (0.10-0.19, 0.20-0.29, 0.30-0.39 and 0.40 or greater) for the North and East areas. The most common range in the North area is 0.20-0.29 while in the East area it is 0.10-0.19. This suggests that the precipitation intensities are somewhat higher in the North area compared to the East area.

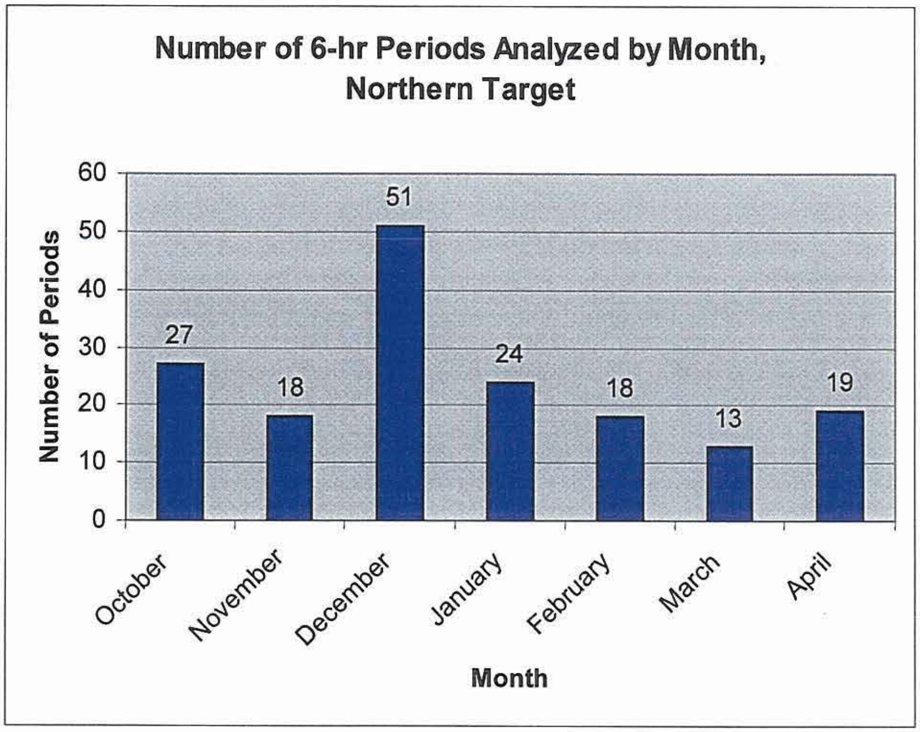

Figure 4.12 Number of Six-Hour Precipitation Events by Month, North Area

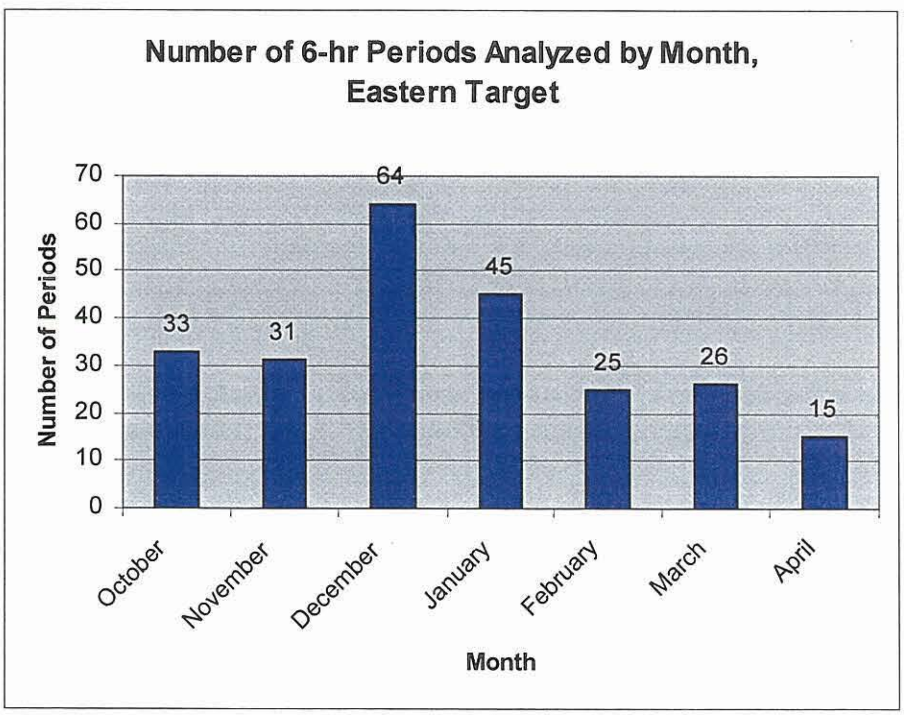

Figure 4.13 Number of Six-Hour Precipitation Events by Month, East Area

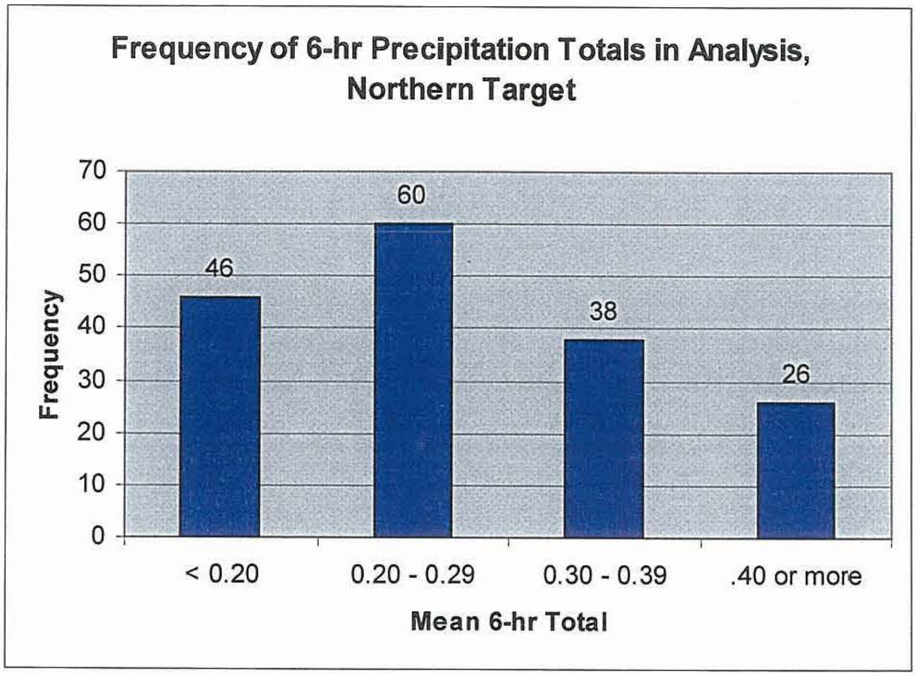

Figure 4.14 Precipitation Occurrences as a Function of Six-Hour Amounts, North Area

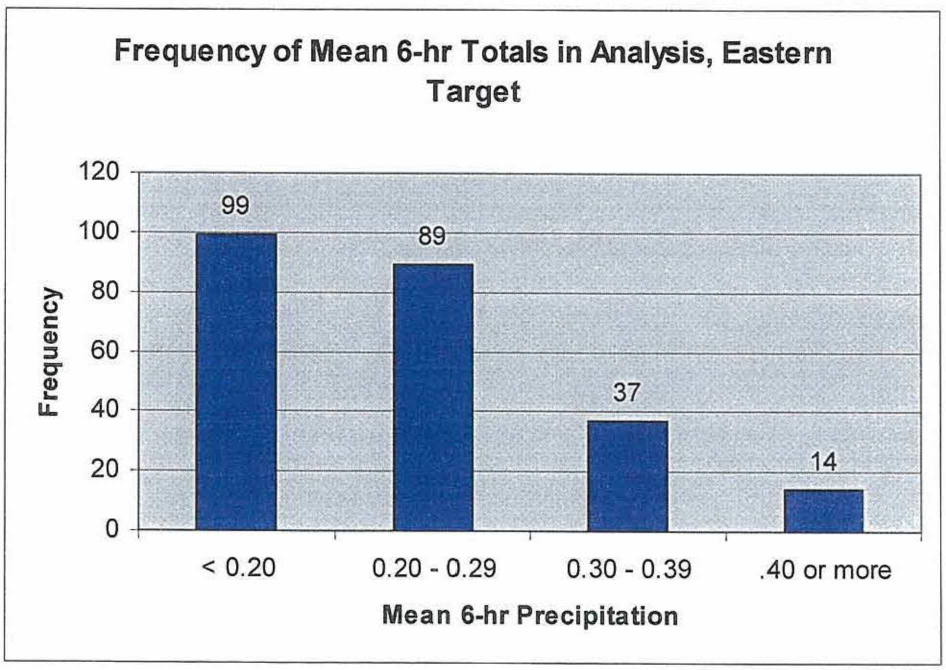

Figure 4.15 Precipitation Occurrences as a Function of Six-Hour Amounts, East Area

4.2.3.2 700 mb Winds

NAWC has utilized the 700 mb level (approximately 9,500 feet MSL) as an index for a couple of important meteorological features regarding targeting of the seeding effects. First, the 700 mb wind is considered a good steering level winds indicator, i.e., an approximation of the direction which storm elements will move along. NAWC has also used this level as guidance in the selection of ground -based generator sites. The 700 mb wind directions and speeds for the 6-hourly, five-season sample described above were used to generate wind roses that graphically display the average information by month and for the entire winter season (October – April). The wind roses provide the frequency of wind direction and speeds by 22.5 ^{0} wind sectors. Recall that wind directions in meteorology are reported according to the direction from which the wind is blowing. For example, a wind direction of 270 ^{0} means the wind is blowing directly out of the west towards the east. The velocities on these wind roses are plotted in meters per second. Figures 4.16 through 4.29 provide the storm period-specific monthly wind roses for the North and the East areas and Figures 4.30 and 4.31 provide the seasonal (October – April) wind roses for the two areas. These figures show some variation from month to month, with the April storm periods having by far the most variable wind conditions. The storm period wind directions in this five-season sample favored a southwesterly direction in October, west-northwesterly in November, westerly in December, west-southwesterly in January and February, westerly in March, and west-southwesterly in April. The plots (Figures 4.30 and 4.31) for the entire winter season (October through April) indicate the predominant storm-period wind direction is from the west. This information is used in a later section in discussions concerning the potential siting of ground generators.

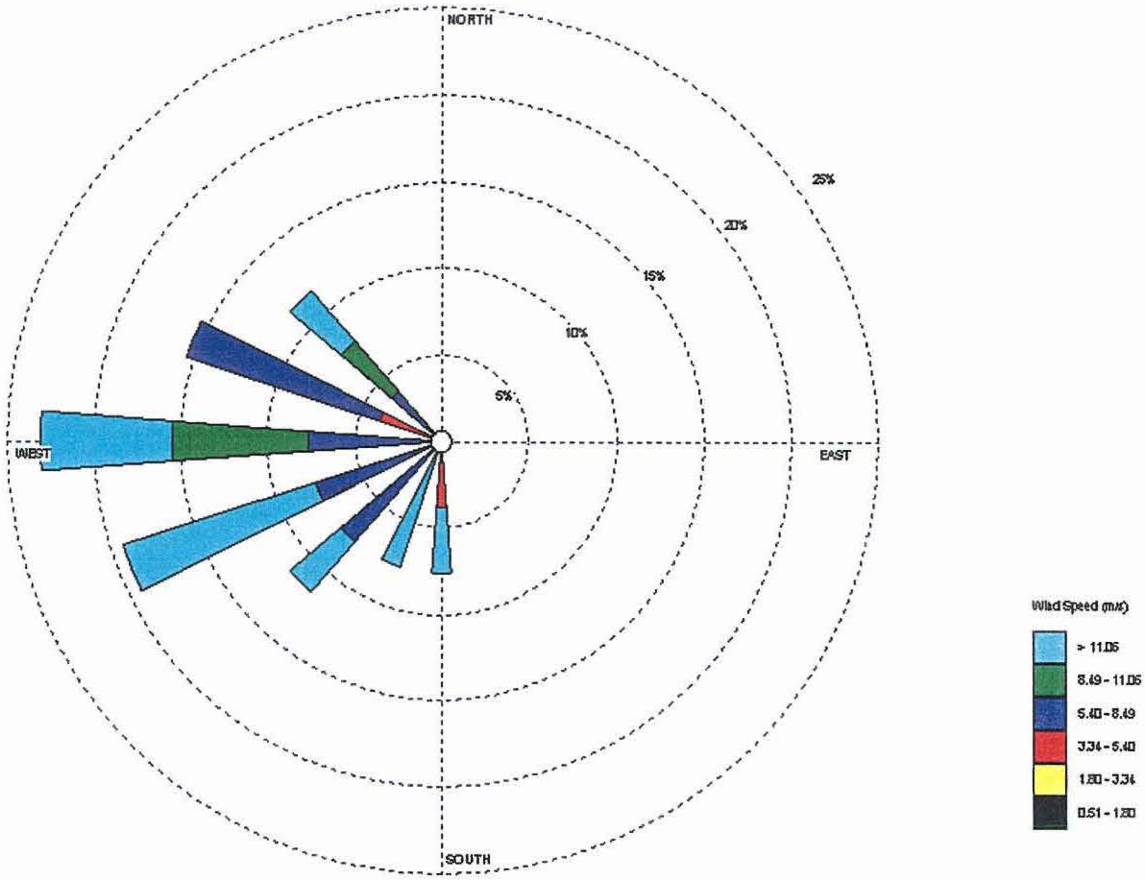

Figure 4.16 October 700 mb Wind Rose, North Area

This wind rose tells us that the most common wind direction at the 700 mb level is from the west, ~23% of the six hour events; and that the most common velocity ranges associated with this west wind direction are 8.5-11 and > 11 mps.

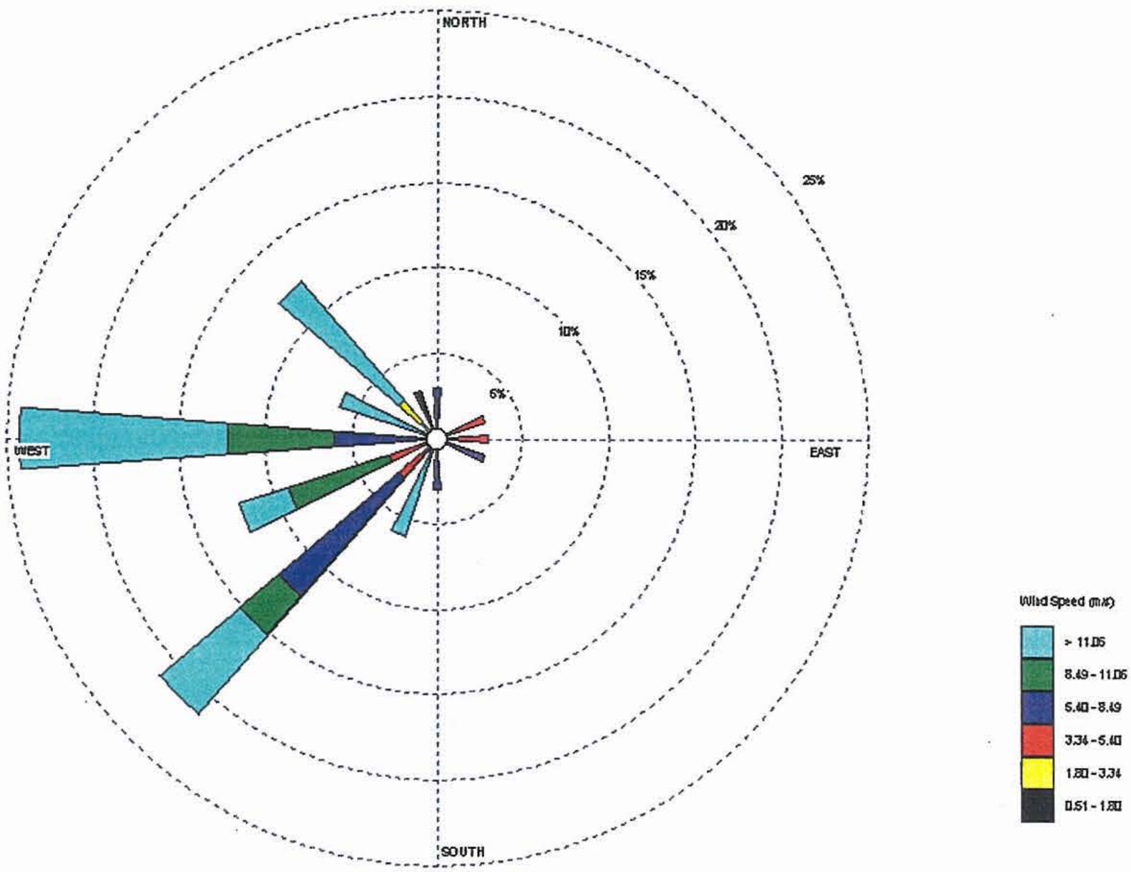

Figure 4.17 October 700 mb Wind Rose, East Area

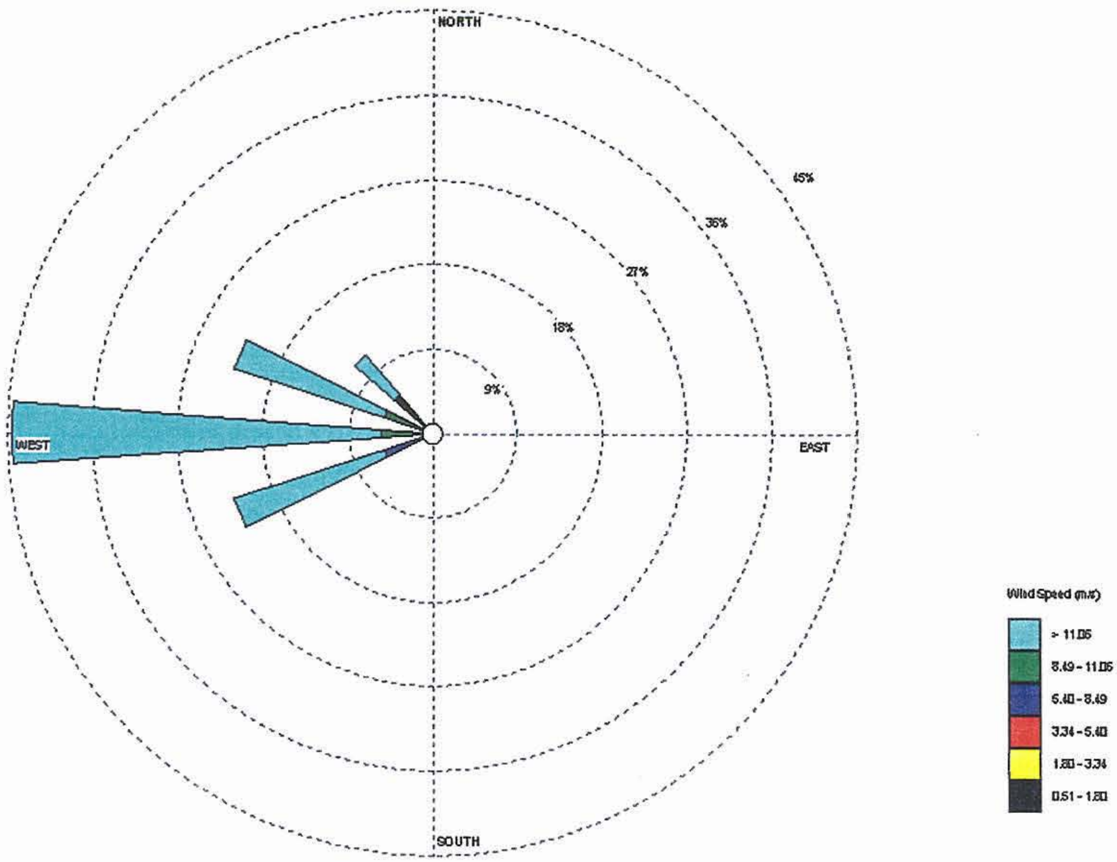

Figure 4.18 November 700 mb Wind Rose, North Area

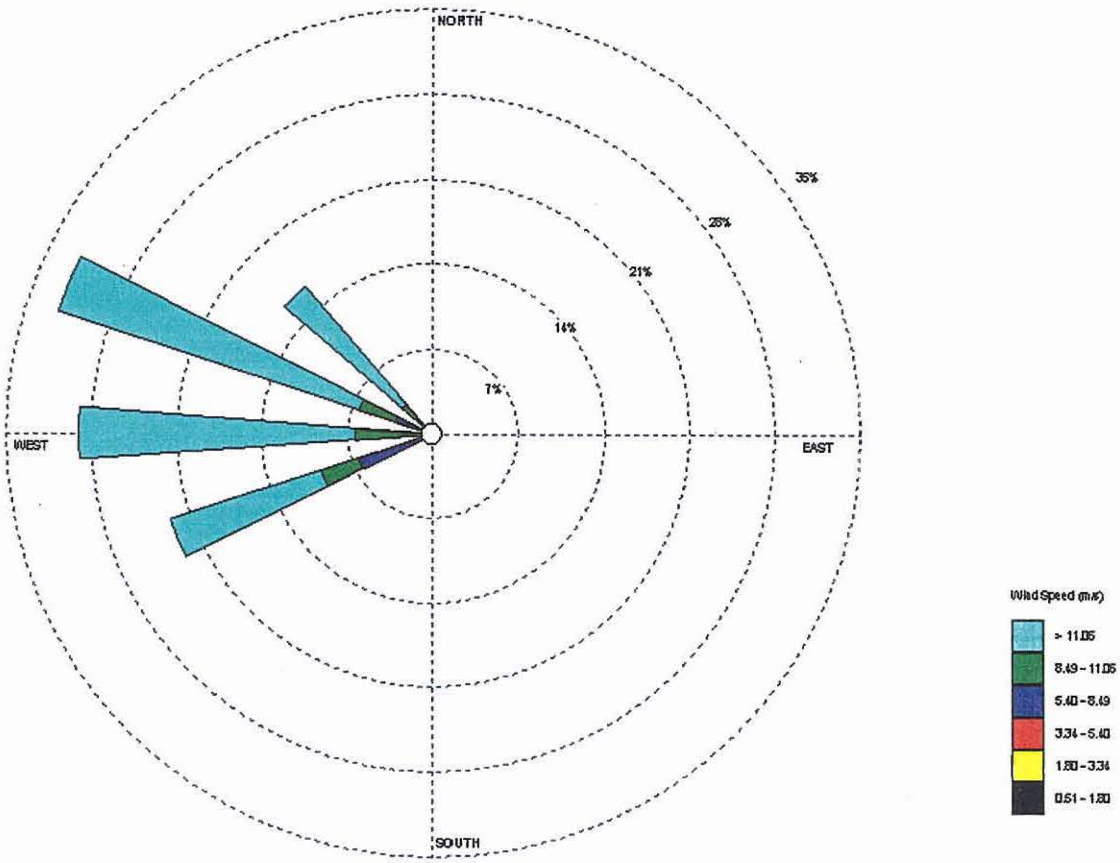

Figure 4.19 November 700 mb Wind Rose, East Area

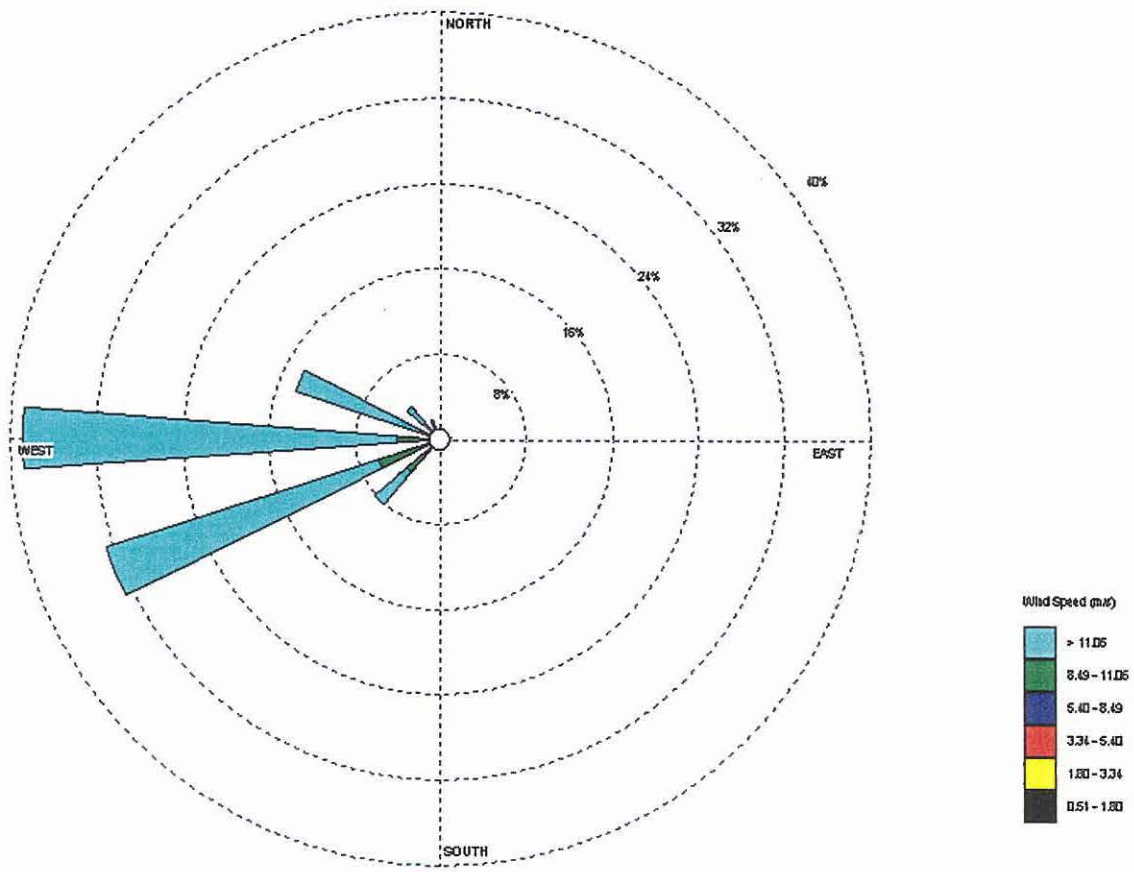

Figure 4.20 December 700 mb Wind Rose, North Area

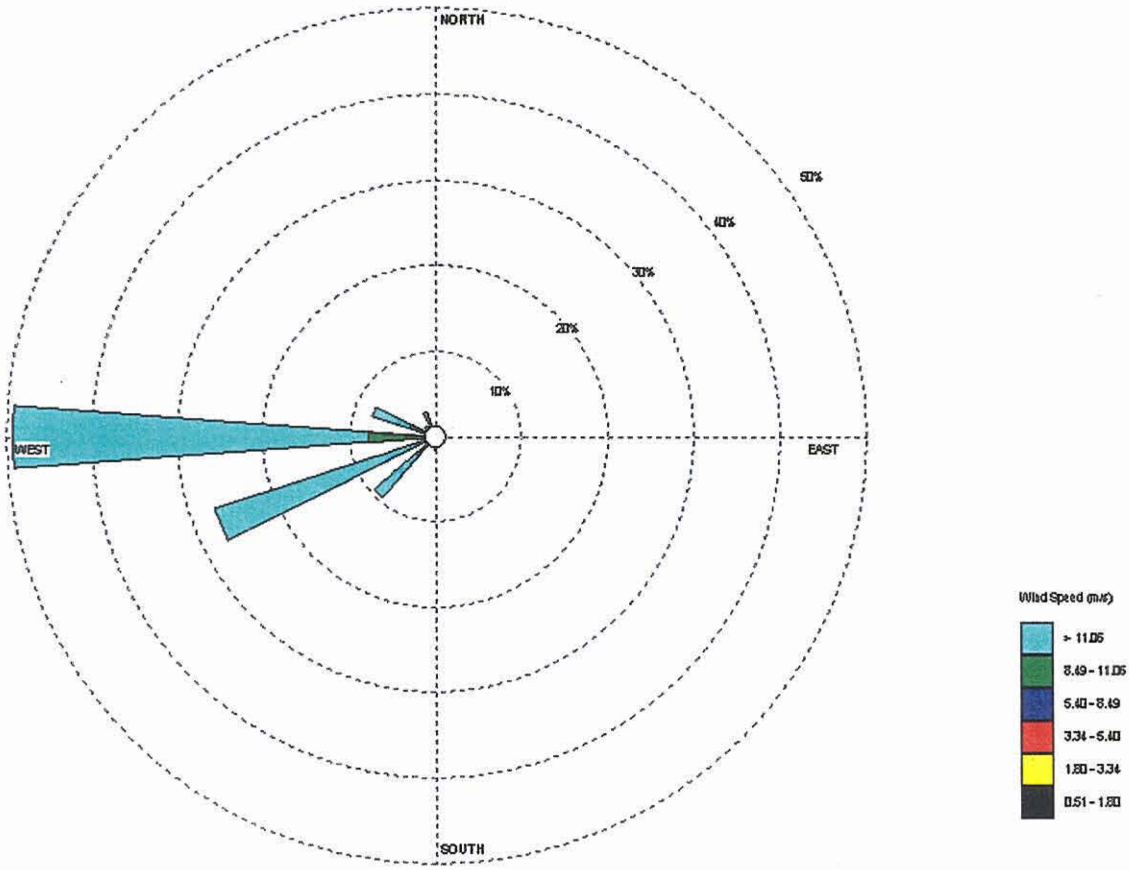

Figure 4.21 December 700 mb Wind Rose, East Area

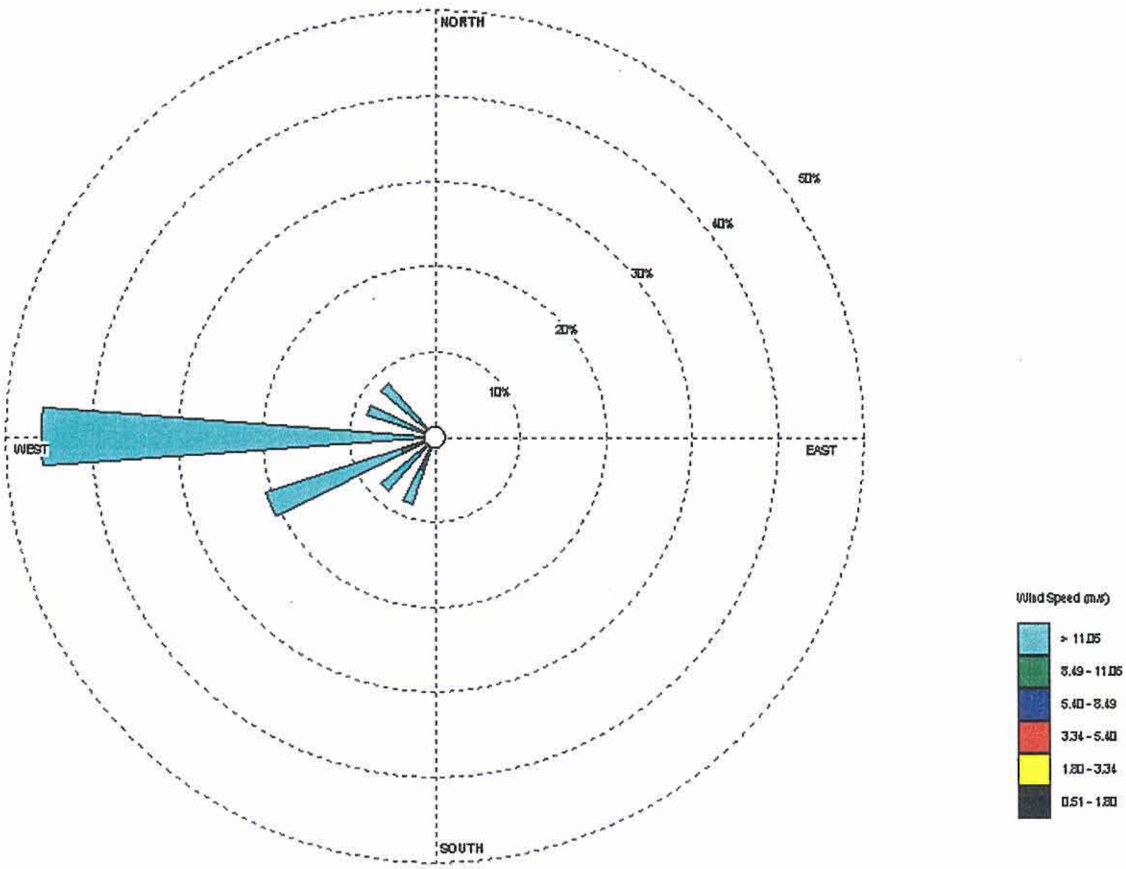

Figure 4.22 January 700 mb Wind Rose, North Area

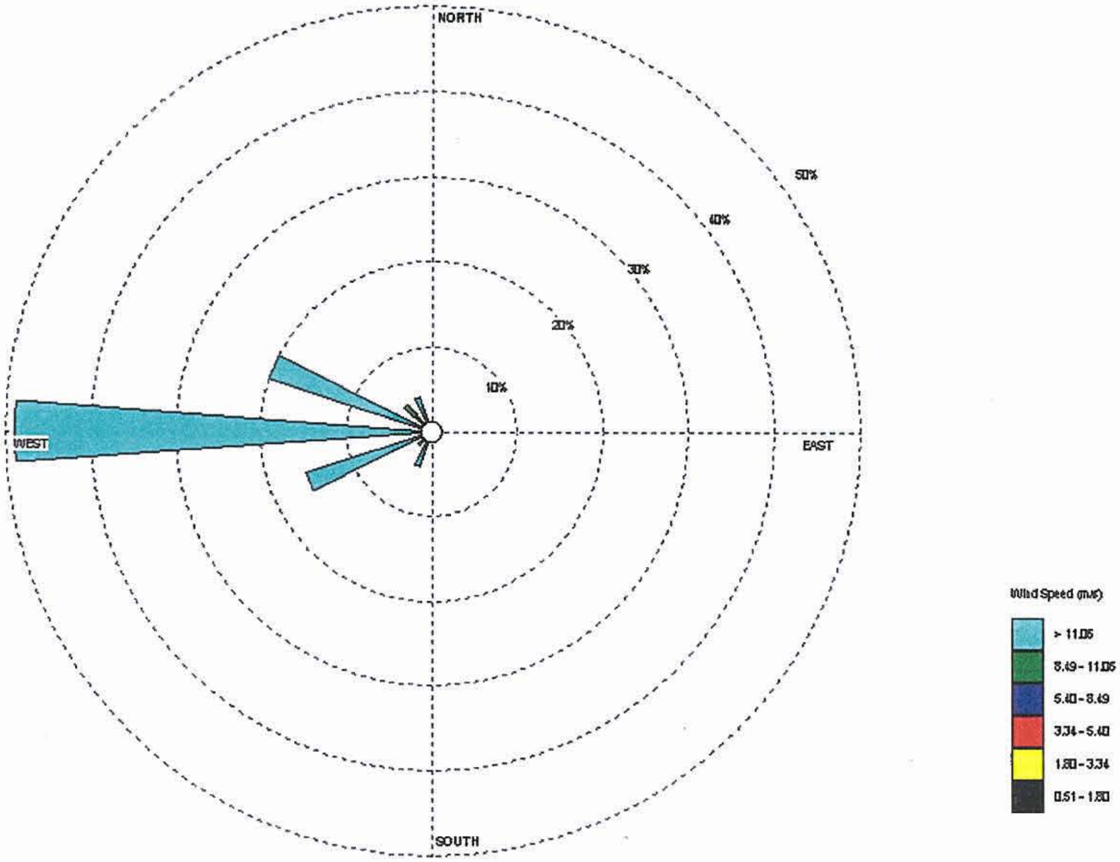

Figure 4.23 January 700 mb Wind Rose, East Area

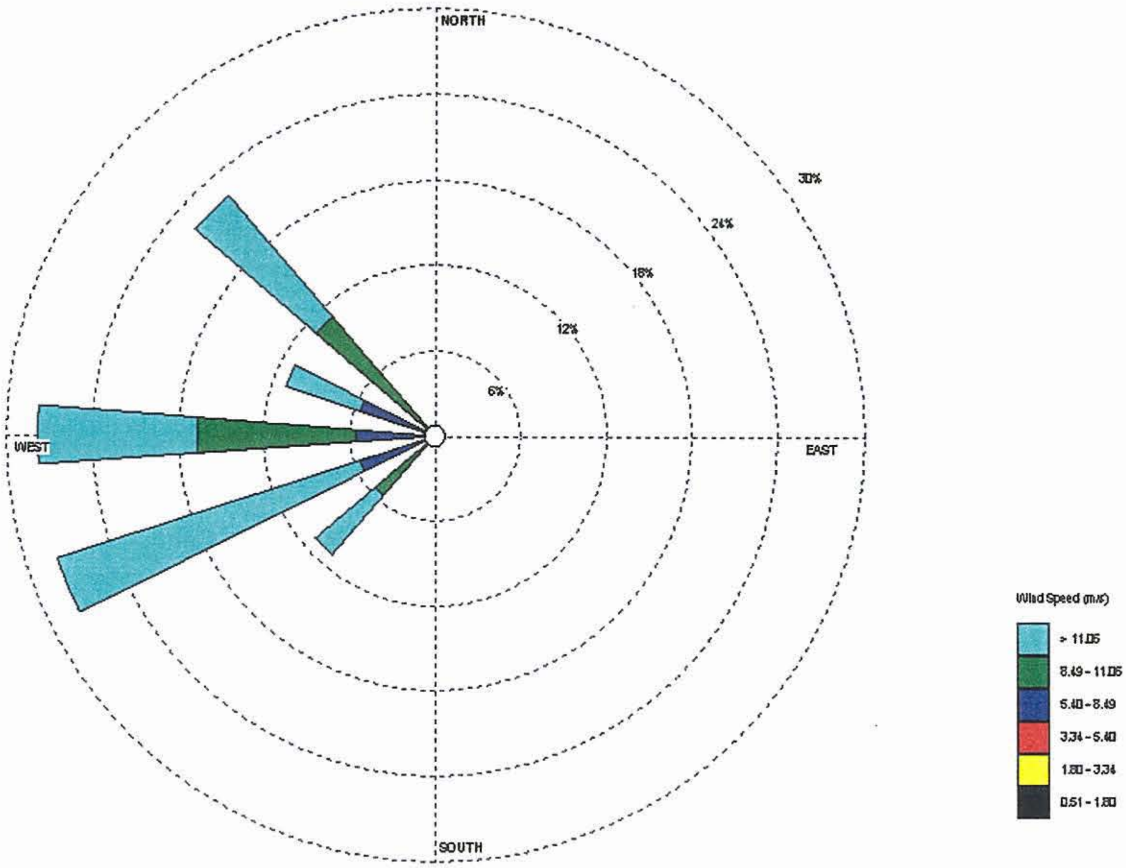

Figure 4.24 February 700 mb Wind Rose, North Area

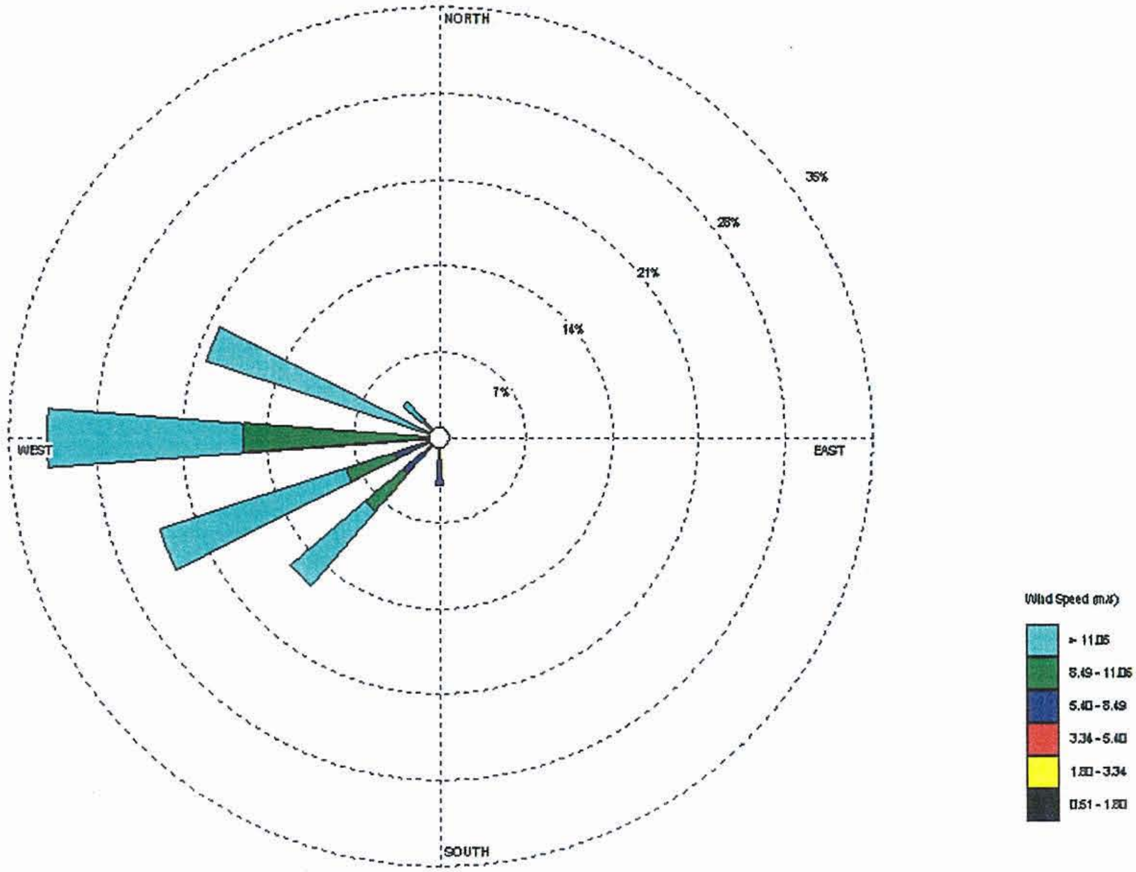

Figure 4.25 February 700 mb Wind Rose, East Area

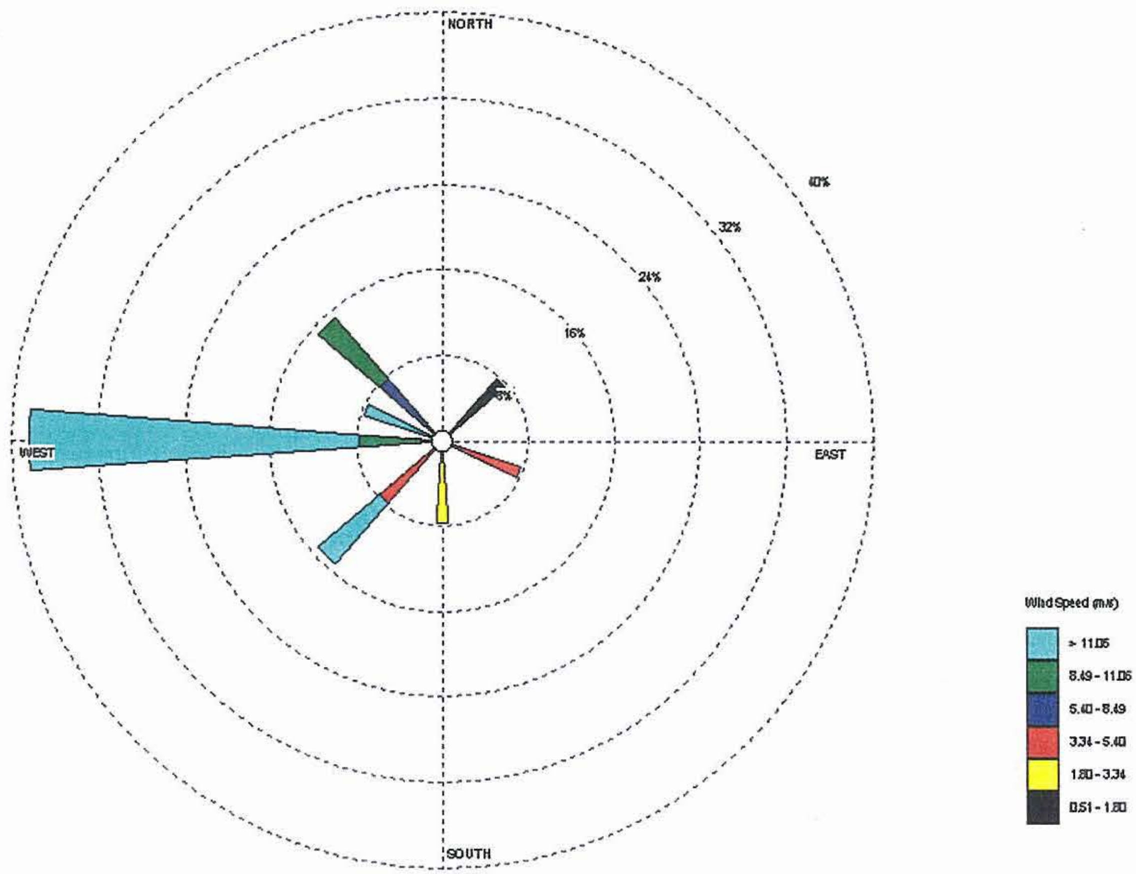

Figure 4.26 March 700 mb Wind Rose, North Area

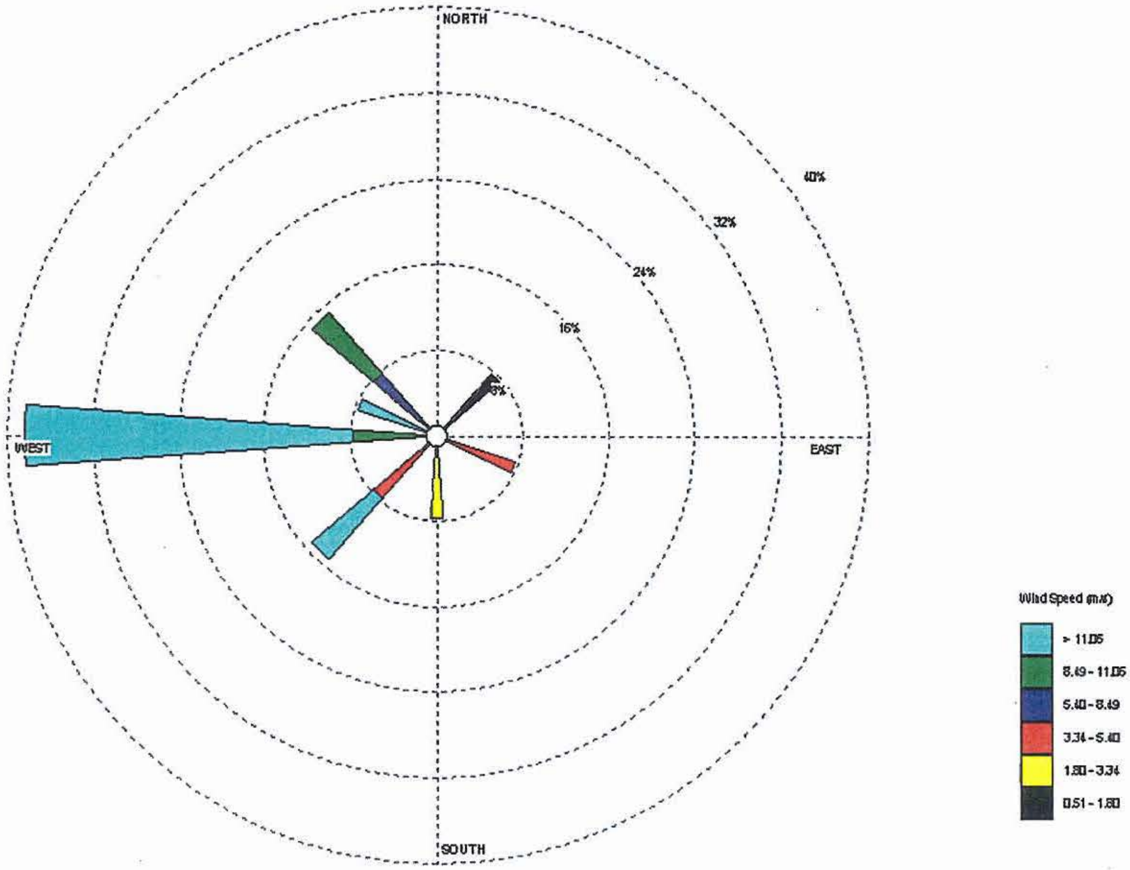

Figure 4.27 March 700 mb Wind Rose, East Area

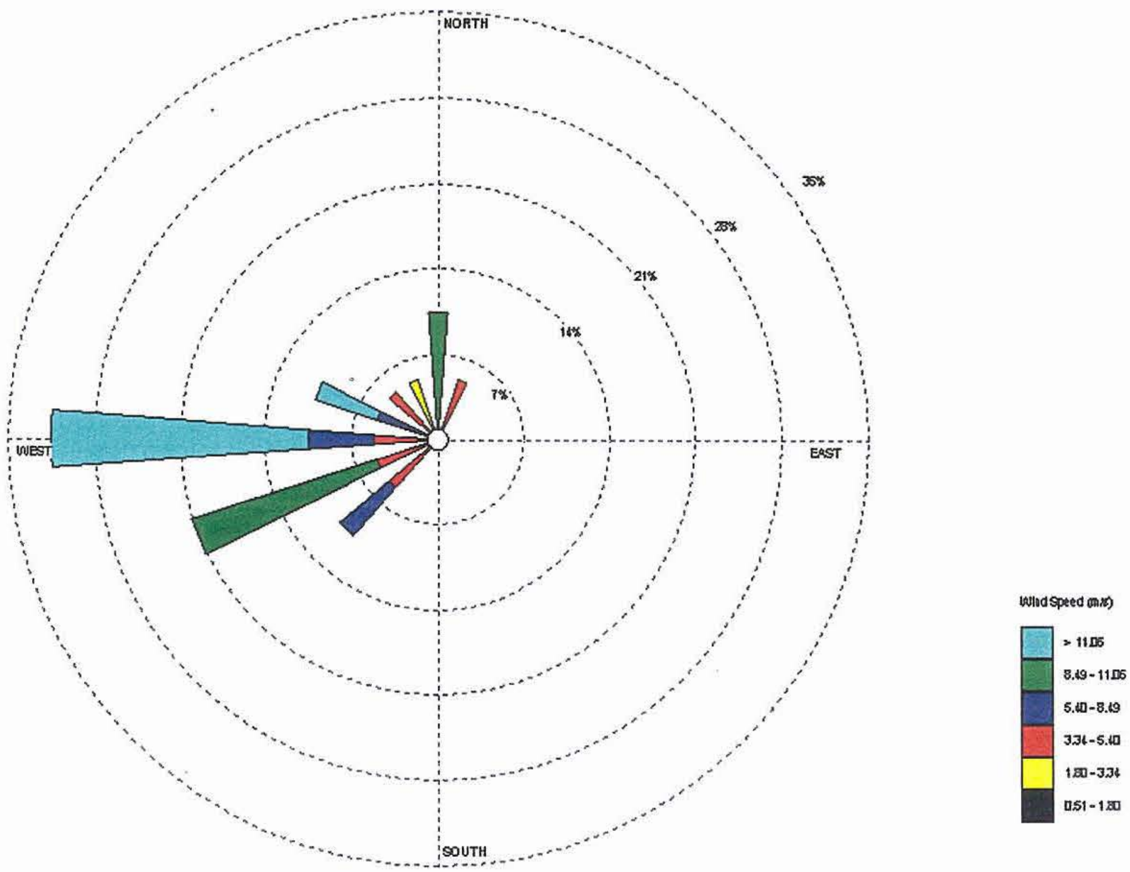

Figure 4.28 April 700 mb Wind Rose, North Area

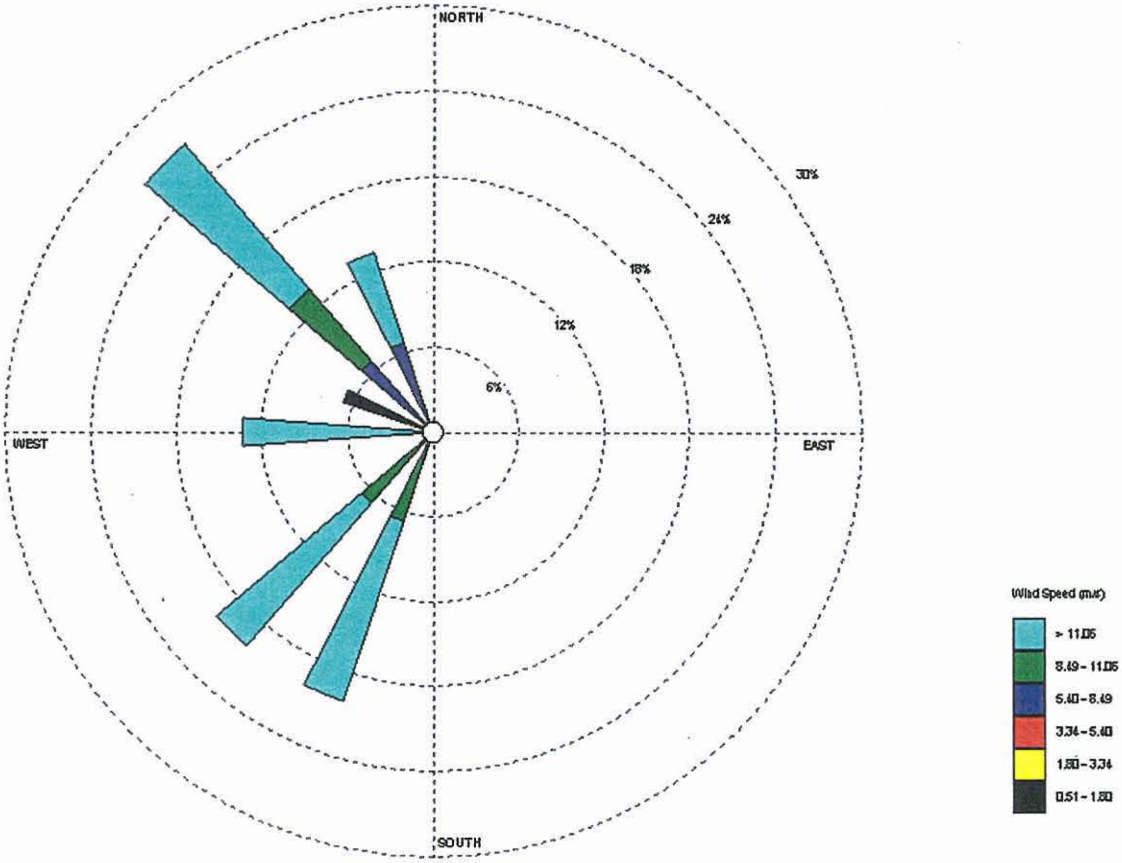

Figure 4.29 April 700 mb Wind Rose, East Area

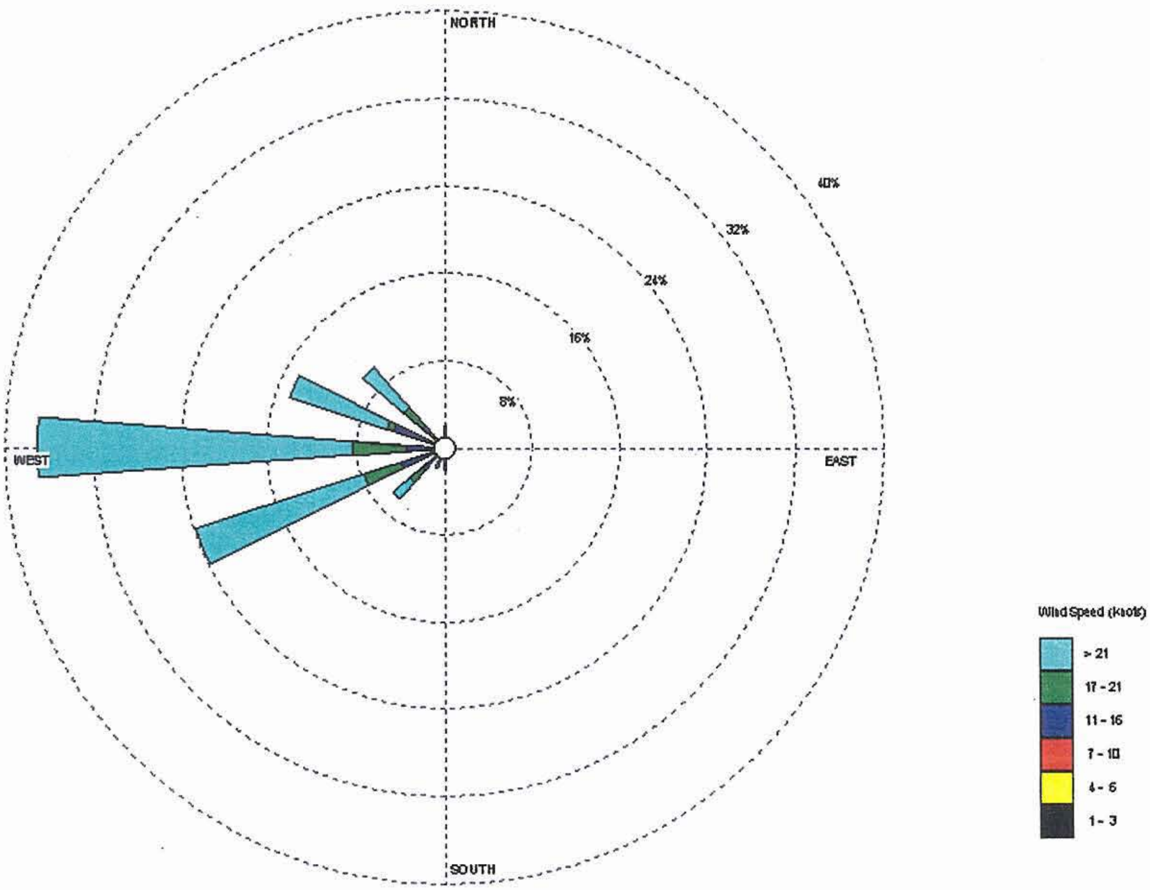

Figure 4.30 October-April 700 mb Wind Rose, North Area

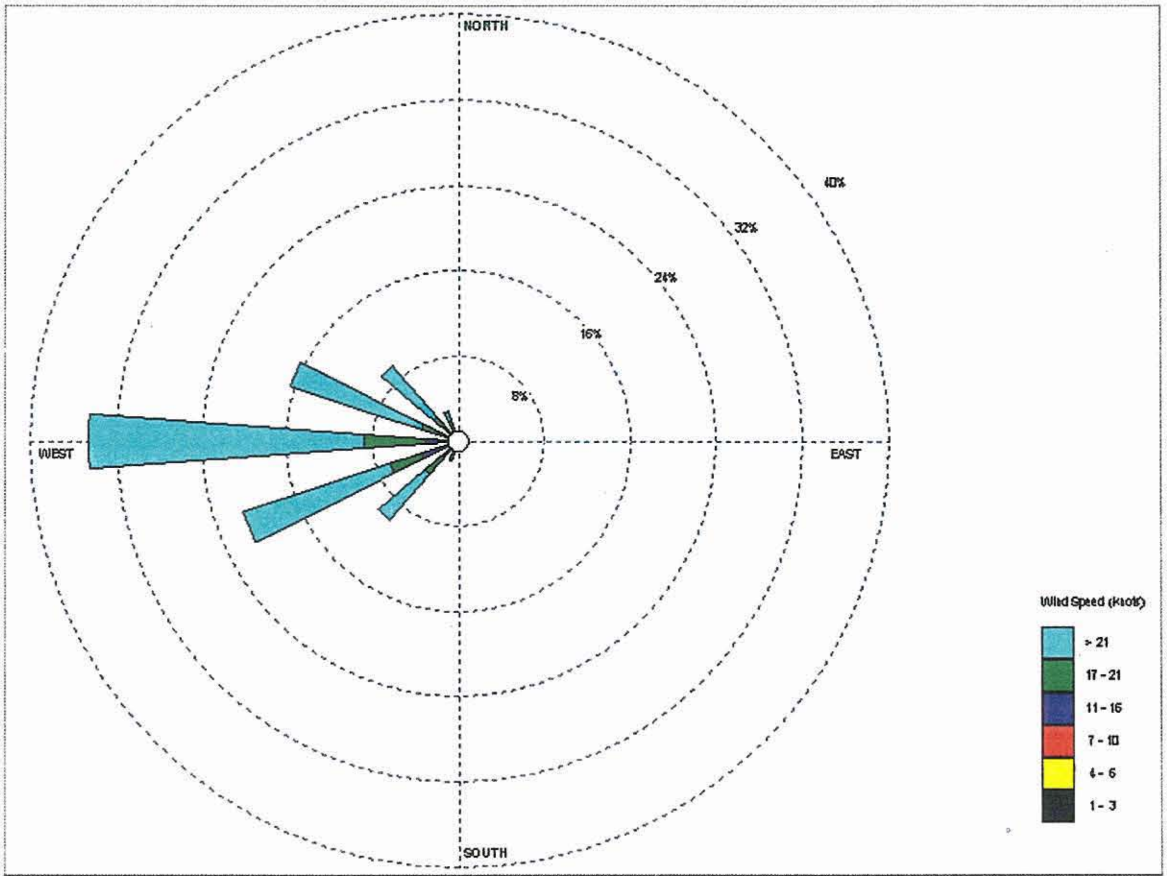

Figure 4.31 October-April 700 mb Wind Rose, East Area

Figures 4.16 through 4.29 indicate a notable consistency from month to month in each of the areas and also between the North and East target areas. Wind direction at the 700-mb level during precipitation events in both areas is predominately from the west and predominately greater than 21 knots. Some deviation from this general pattern is seen during the months of October, February and April when wind directions are more variable. Events with winds from the southwest and northwest are more common during these months in both areas.

4.2.2.3 700 mb Temperatures

A plot of the average 700-mb temperatures during the six-hour precipitation events by month was prepared for the North and East areas (Figures 4.32 And 4.33). We use temperatures at this level in helping decide whether a specific storm period is considered seedable using ground-based generators. Our concept is that the 700-mb level is typically near the height of the target mountain barriers. Seeding materials released from ground generators have been shown to rise up to approximately 1000-2000 feet (300-600 m) above the mountain crest heights. Silver iodide becomes an active ice nucleant at temperatures of about -4 to -5 ^{0}C or colder. These factors indicate that the 700-mb temperature should be approximately -5 ^{0}C or colder in order for seeding to be effective. The seeding material must have the opportunity to form ice crystals upwind of the barrier, which can then grow into snowflakes and fall onto the barrier. Figures 4.32 and 4.33 indicate that 700-mb temperatures did, in general, average –5 ^{0}C or colder for the six-hour precipitation events in both areas. The month of October was on the marginal (warm) side in both areas and the month of April marginally on the warm side in the East area. Figures 4.34 And 4.35 provide plots of the mean height of the -5 ^{0}C isotherm by precipitation intensity (based on 6-hour precipitation amounts). These figures demonstrate that, on average, the -5 ^{0}C isotherm is higher during periods of greater precipitation intensity. The events with mean 6-hour amounts of > 0.40" are not very frequent, however, in the East area as shown earlier in Figure 4.15, but somewhat more frequent in the north area (Figure 4.14).

We also compared the mean 700-mb temperatures to the precipitation intensity (based on the average 6-hour precipitation accumulation for the north and east areas) as shown in Figures 4.34 and 4.35. These figures indicate that greater precipitation intensities are generally associated with warmer 700 mb temperatures, consistent with the higher –5 ^{0}C levels shown in Figures 4.32 and 4.33. This makes sense meteorologically since warmer air masses can hold more water, which can be converted into more snowfall, under the right conditions, than possible with colder storms.

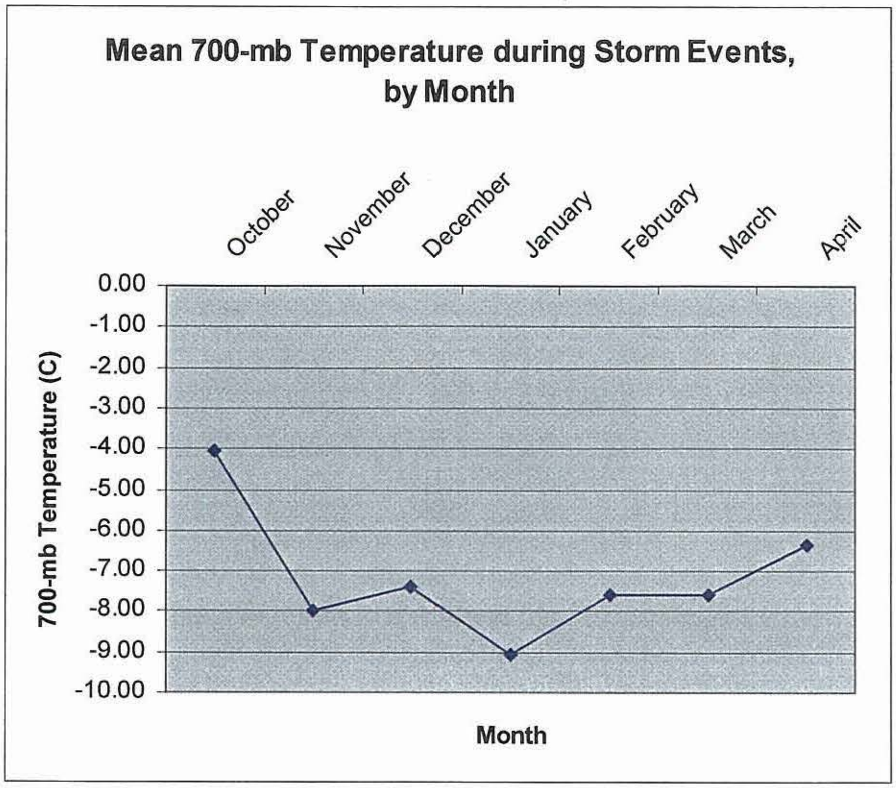

Figure 4.32 Mean 700 mb Temperature by Month, North Area

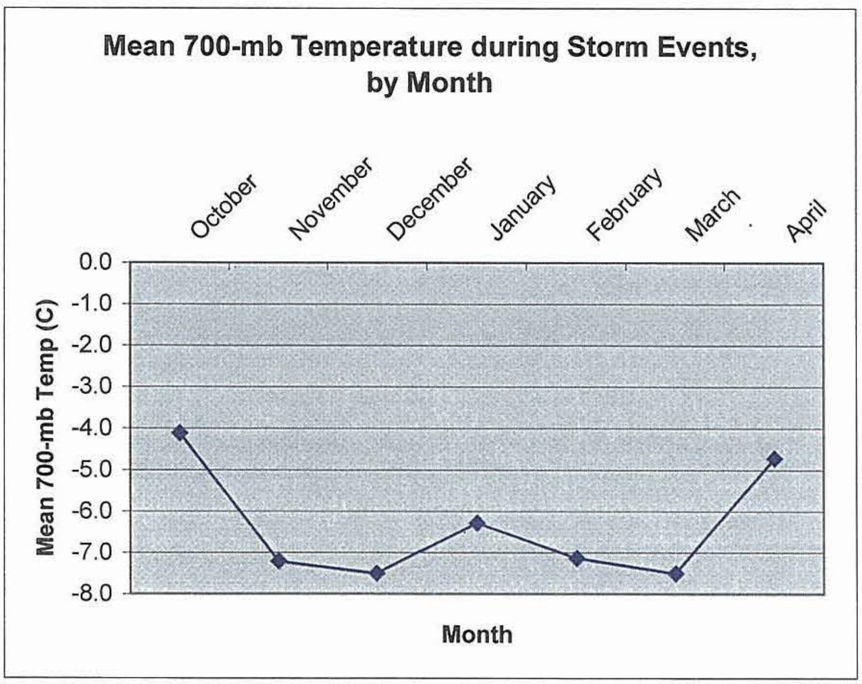

Figure 4.33 Mean 700 mb Temperature by Month, East Area

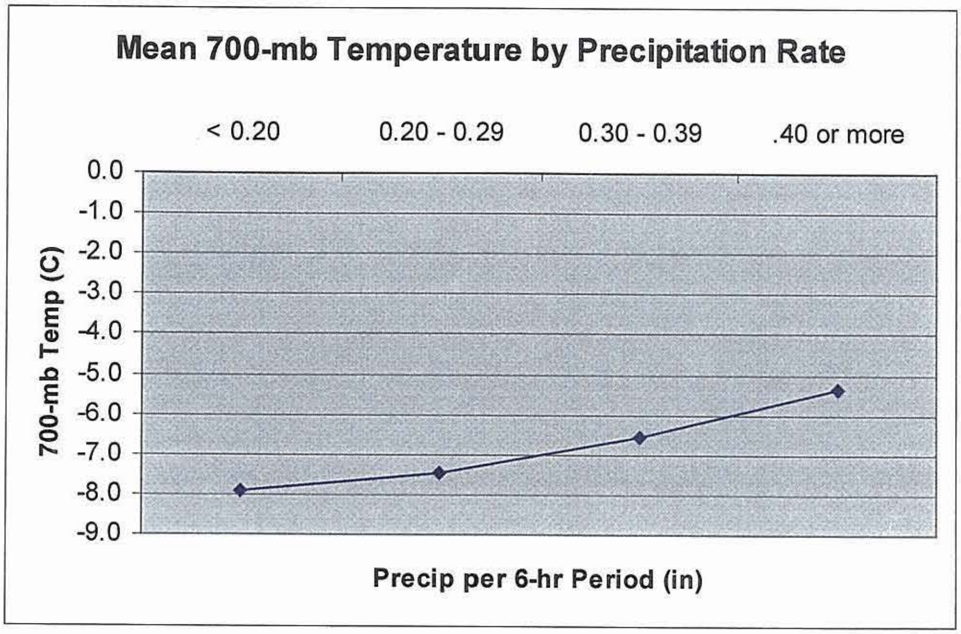

Figure 4.34 Precipitation Rate as a Function of 700 mb Temperature, North Area

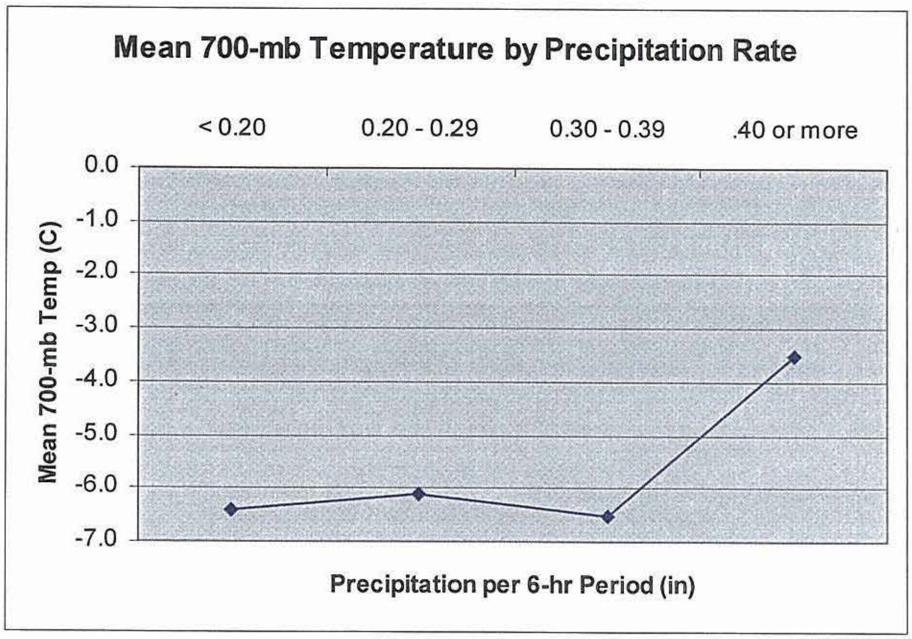

Figure 4.35 Precipitation Rate as a Function of 700 mb Temperature, East Area

4.2.2.4 Low-Level Stability

Another meteorological feature of special interest when considering ground-based cloud seeding is the frequency of occurrence of low-level temperature inversions in the atmosphere that may restrict the vertical transport of seeding materials released from the ground into effective cloud regions. Temperatures in the atmosphere typically decrease with height. An inversion is said to exist if there is a layer in the atmosphere in which the temperatures increases instead of decreases with height. Such inversions are responsible for the trapping of pollutants and formation of smog in mountain-valley areas (the Los Angeles Basin is an extreme example).

We performed an analysis to examine whether this phenomenon would potentially present a problem in seeding from ground generators in the ESRBP. For this analysis, atmospheric stability (between the surface and 700 mb) was determined for precipitating periods based on both the NCEP reanalysis-derived soundings and surface reports. Surface temperature, wind and dewpoint observations were also utilized in conjunction with the sounding profiles to obtain better estimates of low-level stability issues and wind patterns. After examination of the availability and quality of surface data, three sites were utilized. For the eastern portion of the target area, one suitable site was found (Wayan, WYNI1, at 6391' elevation) to represent potential areas for ground-based seeding. For the northern portion, two sites (DUB, Dubois, at 5465' and Three-Mile, THMI1, at 6625') were utilized. These data were obtained through the MesoWest observation network maintained by meteorology staff at the University of Utah.

The availability of data at these three sites helped in making estimations of the presence and depth of any inversion/stability layers that may affect ground-based seeding from sites in the upper Snake River Basin. Low-level stability (which could prevent seeding material from reaching the –5 C level over the target areas) was classified into four categories: Well-mixed or neutral conditions (no stability problems evident which should mean that silver iodide particles released near the surface can be transported over the mountain barriers in the storm winds), slightly stable, moderately stable, and very stable. These categories correspond roughly to situations when less than 2 C of surface heating would be necessary to mix out the atmosphere (slightly stable), 2-4 C (moderately stable), and more than 4 C (very stable). Cases that were well mixed or slightly stable were considered suitable for lower elevation ground-based seeding, while more stable cases would require remote high-elevation or aircraft seeding.

The more-stable situations are cases where lower elevation ground-based seeding would probably not be attempted due to stability considerations. Figure 4.36 and 4.37 provide plots of the frequency of "neutral" stability below 700 mb by month, expressed as the percentage of the time during stormy periods for the North and East areas. Figure 4.36 for the North area indicates that the most favorable category of stability (neutral) averages ranges from ~ 20-80%. In the North area, stability appears to present significant problems during the months of December through March (all neutral less than 50% if the time), which are some of the months with the highest average precipitation occurrences (refer to Table 4-5). In the East area the situation is somewhat better, only two months (October and December) have neutral stability less than 50% of the time.

Actual observations during future storm periods would be highly desirable to document the frequency and depth of low-level inversions. For example, rawinsonde observations (vertical profiles via weather balloons) could be conducted at perhaps 6-hour intervals during storm periods for one winter season to provide this information. These observations should be conducted from a central location in the Snake River Basin (e.g., Rexburg or St. Anthony). This possibility will be discussed in a later section concerned with program recommendations.

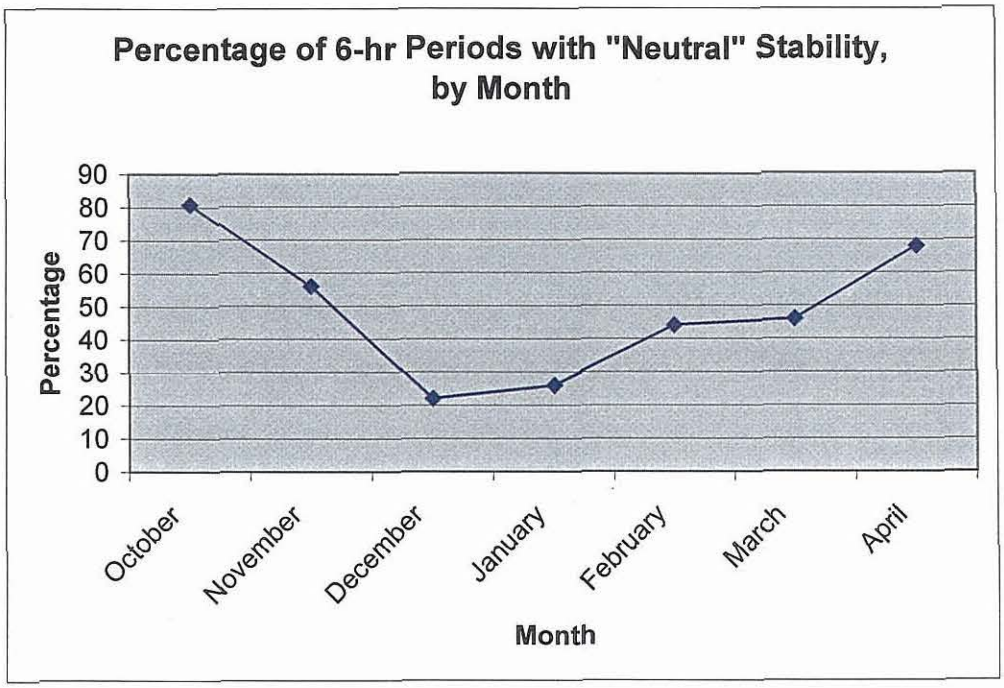

Figure 4.36 Percentage of Six-Hour Storm Events with Neutral Stability by Month, North Area

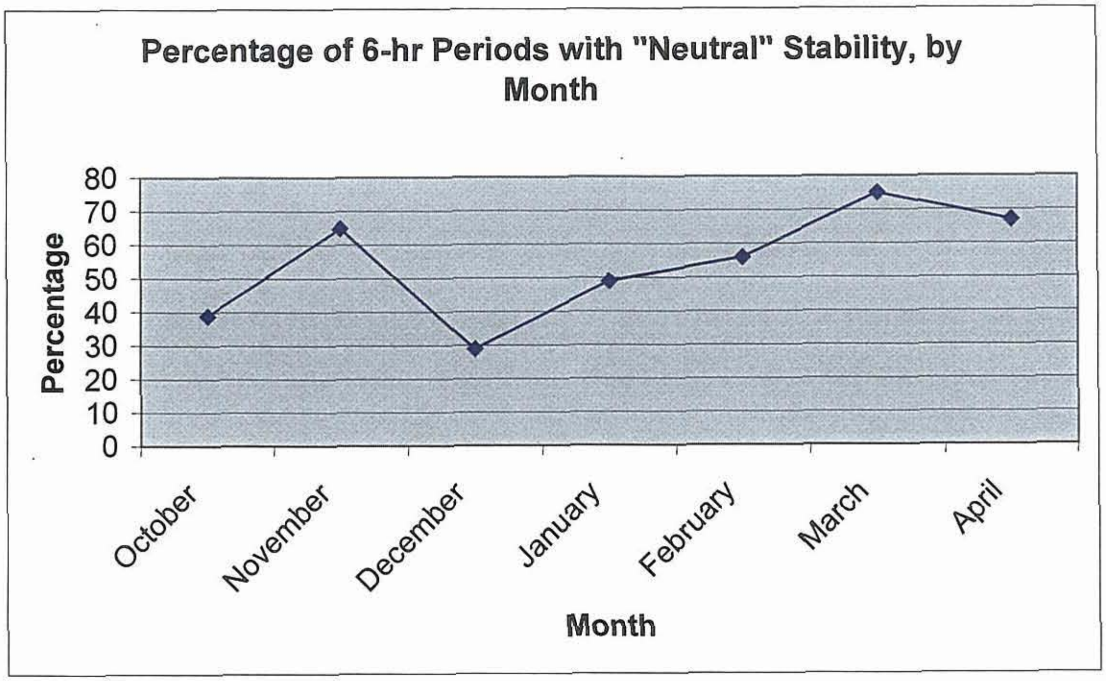

Figure 4.37 Percentage of Six-Hour Storm Events with Neutral Stability by Month, East Area

4.3 Utilization of Climatological Information

The data complied in this section will be used in the development of a preliminary cloud seeding design that is discussed in the following section.

5.0 DEVELOPMENT OF A PRELIMINARY PROGRAM DESIGN (Task 3)

The development of a preliminary program design assumes that the application of cloud seeding to the proposed target areas appears feasible. There are two primary considerations in determining whether a proposed program is feasible: 1) is there a scientific basis supporting the conduct of the proposed program? and 2) if the program appears scientifically feasible, is it economically feasible?

Is the Proposed Program Scientifically Feasible?

NAWC believes that a program can be designed for the ESRBP potential target areas that is scientifically feasible based upon the transferability of the techniques and results obtained in the conduct of previous research programs as described in section 3.0. In addition to these research programs, there are a large number of operational programs that have been conducted in the Intermountain West that provide additional support to the concept that a viable cloud seeding technology exists that can be applied in wintertime orographic (mountainous) programs. The Weather Modification Association's response (Orville, et al, 2004) to a National Research Council report entitled "Critical Issues in Weather Modification Research" contains the following summary:

There is a broad body of evidence in the literature and in company reports describing the results from various operational programs involving winter orographic clouds. Some programs in California have been in existence since the 1950's and 1960's. The Kings River program in southern California has been operational for 48 years and has produced an average 5.5% additional runoff per year (Henderson, 1986, 2003). An operational program run for the past 25 years or so in Utah has published results for 13 and 19 years of operations that indicate 11-15% increases in seasonal precipitation (Griffith, et al, 1991; Griffith, et al, 1997). Add to these results the San Joaquin River program showing at a minimum 8% increase in target area seasonal precipitation using trace chemistry studies of snowpack (McGurty, 1999), the Climax indications of 10 % increases, and the Tasmanian results of 10% increases when storm *cloud top temperatures are in the range of -10 ^{0} C to -12 ^{0} C and the evidence becomes very convincing that cloud seeding conducted under proper conditions increases precipitation in winter orographic situations. These findings and statements are in accord with the American Meteorological Society policy statement on weather modification regarding capabilities of winter orographic cloud seeding (AMS, 1998).*

As a consequence, we propose that the design of the ESRBP be based upon the assumption that winter cloud seeding programs, when properly conducted, are effective. The resulting design will not attempt to "prove" that cloud seeding "works". This work is therefore focused on the development of a **State-of-the-Art operational cloud seeding program.** This approach assumes that the IWRB accepts the fact that there is an existing technology that has been developed over the past 50 plus years that can be applied in orographic winter settings to produce beneficial increases in precipitation of the order of 10%. This is not to say that all facets of cloud seeding, nor natural cloud processes for that matter, are completely understood; they are not. Additional research is needed to advance our understanding in both areas. We do **not** view this program to be of the type that would be research oriented with the primary goal being to advance understanding in this manner. It is our understanding that the interest in this potential program is directed towards the production of additional water at a reasonable cost, not the conduct of a research program that attempts to "prove" that "cloud seeding works." **In a sense, we therefore propose to develop a core program whose goal would be the production of additional water at a reasonable cost via cloud seeding.** Such a core program could serve as a platform for the addition of ancillary measurements by the State or other interested parties including universities or Federal agencies if additional funding sources are available and the IWRB wishes to sponsor such research activities. The National Oceanic and Atmospheric Administration (NOAA) utilized this "piggy-back" research concept in the 1990's under their Atmospheric Modification Program (AMP) (Reinking, 1992). Research components were added to ongoing operational programs in several states, including Nevada, North Dakota and Utah.

Is the Proposed Program Economically Feasible?

Determination of whether the program appears to be economically feasible can be accomplished by compiling estimates of the expected increases (if any) due to cloud seeding and then determining the potential value of such increases. Oftentimes sponsors of winter programs are interested in estimates of additional streamflow that may result from implementation of the cloud seeding programs. Once such estimates are obtained (through relating increases in precipitation to increases in runoff), approximate monetary value of the additional streamflow may be established based upon the perceived value of the water for different end uses (e.g., irrigated agriculture, municipal water supplies, hydroelectric generation). Calculations of the value of the additional water can be compared to the cost of conducting the program in order to derive a preliminary benefit to cost estimate. These topics will be discussed later in this section.

5.1 Brief Description of the Theory of Cloud Seeding for Precipitation Augmentation

A basic summary of the concept of how cloud seeding is thought to work in wintertime mountainous (orographic) settings is worthwhile at this juncture in order to set the stage for the development of a preliminary design for the proposed program areas. A number of observational and theoretical studies have suggested that there is a cold "temperature window" of opportunity for cloud seeding. Some information contained in a report from the Weather Modification Association (Orville, et al, 2004) is paraphrased in some of the following discussions.

Numerous observations in the atmosphere and in the laboratory have indicated that cloud water droplets can remain unfrozen at temperatures well below freezing. These droplets are said to be in a "supercooled" state. Thus the phrase supercooled liquid water (SLW) has been coined to refer to the presence of such water droplets in a cloud. In fact, pure water droplets in a laboratory setting have been observed to remain unfrozen to a temperature of -38.2^0 F (-39^0 C). Droplets at -40^0 F (-40^0 C) freeze spontaneously through a process known as homogeneous nucleation. In order for water droplets to freeze at temperatures between 30.2^0 F (-1°C) and -38.2^0 F (-39^0 C) they must come in contact with foreign particles to cause them to freeze. These particles are called freezing nuclei. The process is known as heterogeneous nucleation. Such nuclei occur in nature and are composed of tiny soil particles or dead bacteria (e.g., pseudomonas syringe). Numerous observations around the world have indicated that the numbers of naturally occurring freezing nuclei that can cause heterogeneous nucleation to occur are temperature dependent. These nuclei become increasingly active with decreasing temperatures. Once a supercooled water droplet is frozen, creating an ice crystal, it will grow through vapor deposition (and possibly aggregation) from the water droplets surrounding it and, given the right conditions, form a snowflake large enough to fall from the cloud and reach the ground. **Supercooled water droplets are the targets of opportunity in order to increase precipitation through seeding.**

Studies of both orographic and convective clouds have suggested that clouds colder than ~ -13^0 F (-25°C) have sufficiently large concentrations of natural ice crystals such that seeding can either have no effect or possibly even reduce precipitation (Grant and Elliott, 1974; Grant, 1986; Gagin and Neumann, 1981; Gagin et al., 1985). It is possible that seeding such cold clouds could reduce precipitation by creating so many ice crystals that they compete for the fixed supply of water vapor and result in numerous, slowly settling ice crystals which sublimate before reaching the ground. There are also indications that there is a warm temperature limit to seeding effectiveness (Gagin and Neumann, 1981; Grant and Elliott, 1974; Cooper and Lawson, 1984). This is believed to be due to a) the low efficiency of ice crystal production by silver iodide at temperatures greater than 24.8^0 F (-4°C) and b) the slow rates of ice crystal vapor deposition growth at comparatively warm temperatures. Thus, there appears to be a "temperature window" of about 23^0 F (-5°C) to -13^0 F (-25°C) where clouds respond favorably to silver iodide seeding (i.e., exhibit seedability). Dry ice (frozen carbon dioxide) seeding via aircraft extends this temperature window to temperatures just below 32^0 F (0°C), but the slow rates of ice crystal vapor deposition growth are a factor at this warm end of the temperature spectrum.

Orographic clouds in the mountainous western states are associated with passing storm systems. Wind flow over a mountain barrier causes the orographic lift to produce or enhance the cloud. Other types of clouds associated with frontal boundaries, convergence bands, and convective instability are also present during these storm systems, thus the orographic cloud scenario is often complicated by the dynamics of the storm system (changing winds, temperatures, and moisture). *In situ* and remote observations of SLW in orographic clouds (e.g., Reynolds, 1988) have indicated significant periods of the occurrence of SLW with passing winter storms. These studies have indicated that the preferred location for the formation of zones of SLW is over the windward slopes of the mountain barriers at relatively low elevations (typically only reaching to approximately or slightly above the height of the mountain barrier). Figure 5.1 provides a stylized depiction of this SLW zone associated with a mountain barrier. NAWC developed this figure based upon the results from a number of winter research programs that have used microwave radiometers and aircraft to document the presence of

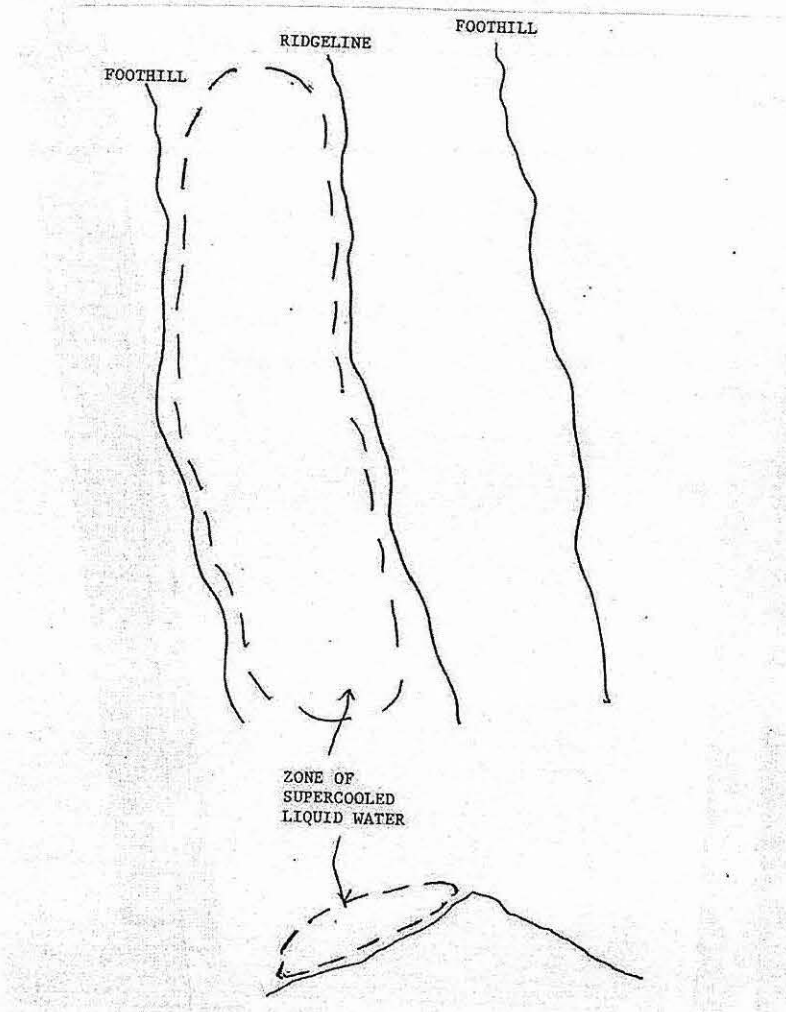

Figure 5.1 Depiction of Supercooled Liquid Water Zone

the SLW. Super, 1990, reporting on measurements of SLW observed in winter research programs in the western U.S. states, "There is remarkable similarity among research results from the various mountain ranges. In general, SLW is available during at least portions of many storms. It is usually concentrated in the lower layers and especially in shallow clouds with warm tops". Another series of quotes from Super, 1990 are as follows: "The tendency for greatest SLW content near the windward slopes of a barrier is clearly shown by Hobbs (1975) from a composite of 22 aircraft missions over the Cascade Mountains, and by Hill (1986) based upon data from 57 vibrating wire sondes released over the Wasatch Mountains of Utah. Holroyd and Super (1984) examined data from many aircraft passes over the flat-topped Grand Mesa of Colorado and showed that SLW was concentrated over the windward slope and barrier top, with higher water contents nearer the surface." Research conducted in the Sierra Nevada Mountains of California as summarized by Reynolds (1988) indicate that shallow orographic clouds are considered the best candidates for winter snowpack augmentation, similar to the findings found in the above references.

The basic consideration in the development of the design of a winter orographic cloud seeding program is to develop a seeding methodology that will tap this reservoir of SLW to convert cloud water droplets into snowflakes that otherwise would be lost through evaporation over the downwind side of the barrier. In other words, we wish to improve the efficiency of the natural storm system in terms of producing precipitation that reaches the ground.

If SLW clouds upwind and over mountain barriers are routinely "seeded" to produce appropriate concentrations of ice crystals, exceeding 1 to 10 per liter of cloudy air, snowfall increases can be anticipated in the presence or absence of natural snowfall. It has been repeatedly demonstrated with physical observations that sufficiently high concentrations of seeding agent and effective of SLW at warmer cloud temperatures will produce snowfall when natural snowfall rates are negligible. Seeded snowfall rates are usually light, on the order of .04"/hr (1 mm/hr) or less of water equivalent, consistent with median natural snowfall rates in the Intermountain West (Super and Holroyd, 1997).

5.2 Preliminary Design Components

There are a number of factors to be considered in the development of a design for a cloud seeding program. The American Society of Civil Engineers published a Standard entitled "Standard Practice for the Design and Operation of Precipitation Enhancement Programs" in 2004 (ASCE, 2004). This Standard lists the following as factors that should be considered:

1) Definition of program scope
2) Seeding agent selection
3) Targeting and delivery methods
4) Meteorological data collection and instrumentation
5) Selection and siting of equipment
6) Legal issues
7) Environmental concerns.

The RFP also asks for estimates of seeding effects, which we would add as item 8 in the list shown above. Items 1-5 and 8 will be discussed in this section. Items 6 and 7 are discussed in Section 8.0.

With this brief explanation as background we will now consider the six topics mentioned in the above.

5.3 Program Scope

Definition of the scope of the program needs to include a statement of the goal or goals of the proposed program and definition of the program areas. This is an important step. Is a basic operational program desired? Is an operational program with the addition of a number of research type components desired? The answer to the first two questions may be defined by a third question; what is the desired level of proof to establish that the cloud seeding program is working? Are the sponsors of the program willing to employ randomization (a statistical design approach) of the treatment to quantify the effects of seeding? What is considered to be a favorable benefit/cost ratio for the program to proceed? One approach that could be considered is the development of a basic core program that can reasonably be expected to produce some level of increase with optional additions to the program that are prioritized to accomplish the goals of the program. The priority of these additions would be evaluated according to an assessment of the additional cost versus the estimated increase in benefit (i.e., produce more water on the ground; better demonstrate the effectiveness of the seeding, etc.) Other considerations can help refine the generic goals mentioned in the above.

NAWC proposes the following goal for the ESRBP: **The stated goal of the program is to increase winter snow pack in the target areas to provide additional spring and summer streamflow and recharge underground aquifers at a favorable benefit/cost ratio without the creation of any significant negative environmental impacts.**

NAWC has proposed that the target areas for the program include portions of mountain ranges in eastern Idaho that contribute significant surface streamflow to the Snake River. Furthermore these areas are defined as being at or above an elevation of 6,500 feet MSL. Figure 5.2 provides a map of these proposed areas. There are two rather different areas in Figure 5.2. One area is located along the south slopes of the Centennial Mountains and the Lion Head and Henrys Lake Mountains in northeastern Idaho. We have denoted this area the North Area. The other area encompasses all or portions of the Big Hole Range, the Snake Range, the Grays Lake Mountains, and the Aspen Range in eastern Idaho. We have denoted this area the East Area. Figures 5.3 and 5.4 provide maps of the North and East areas (locations of snow course and SNOTEL sites are included on these figures).

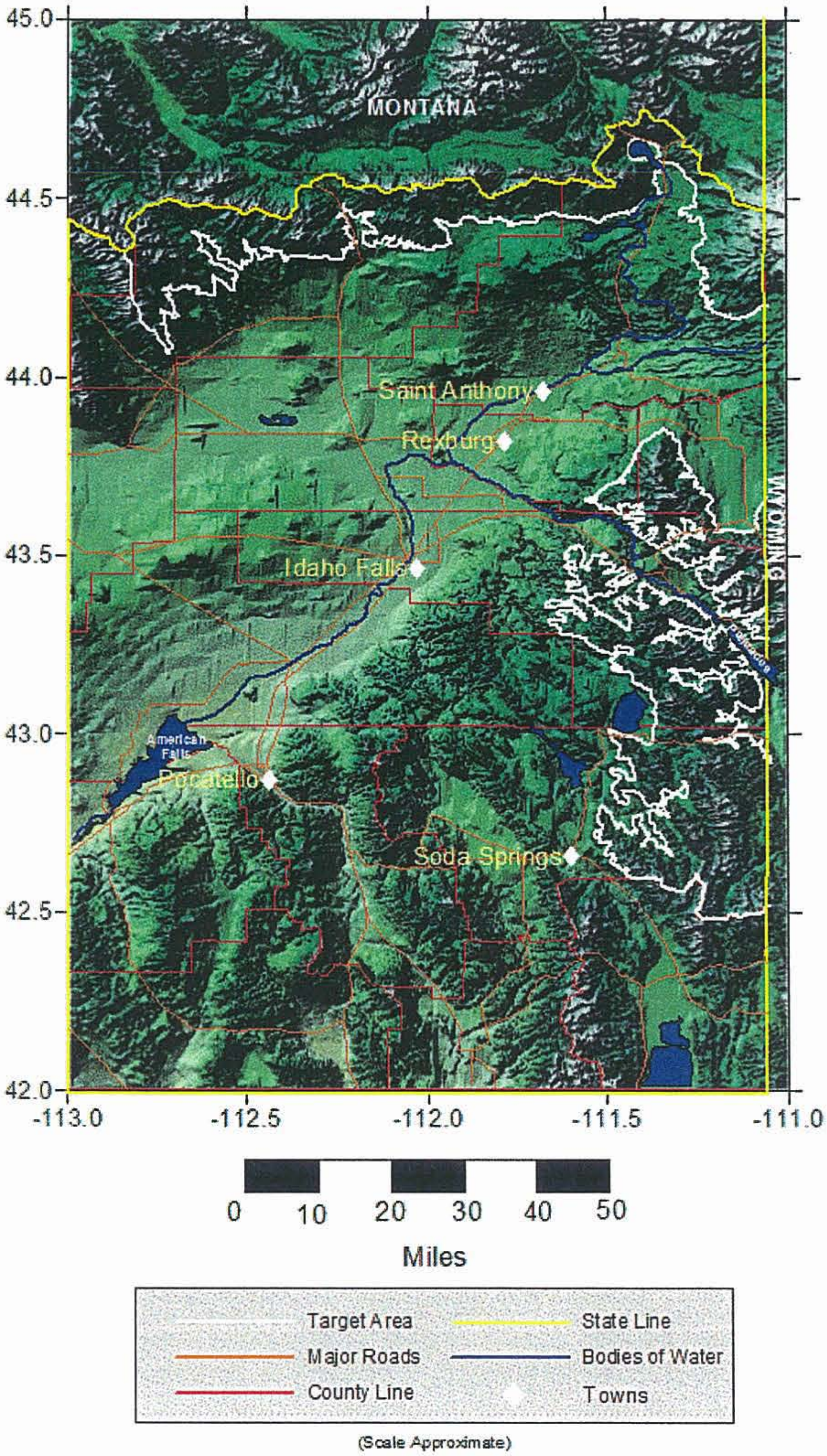

Figure 5.2 Proposed Target Areas

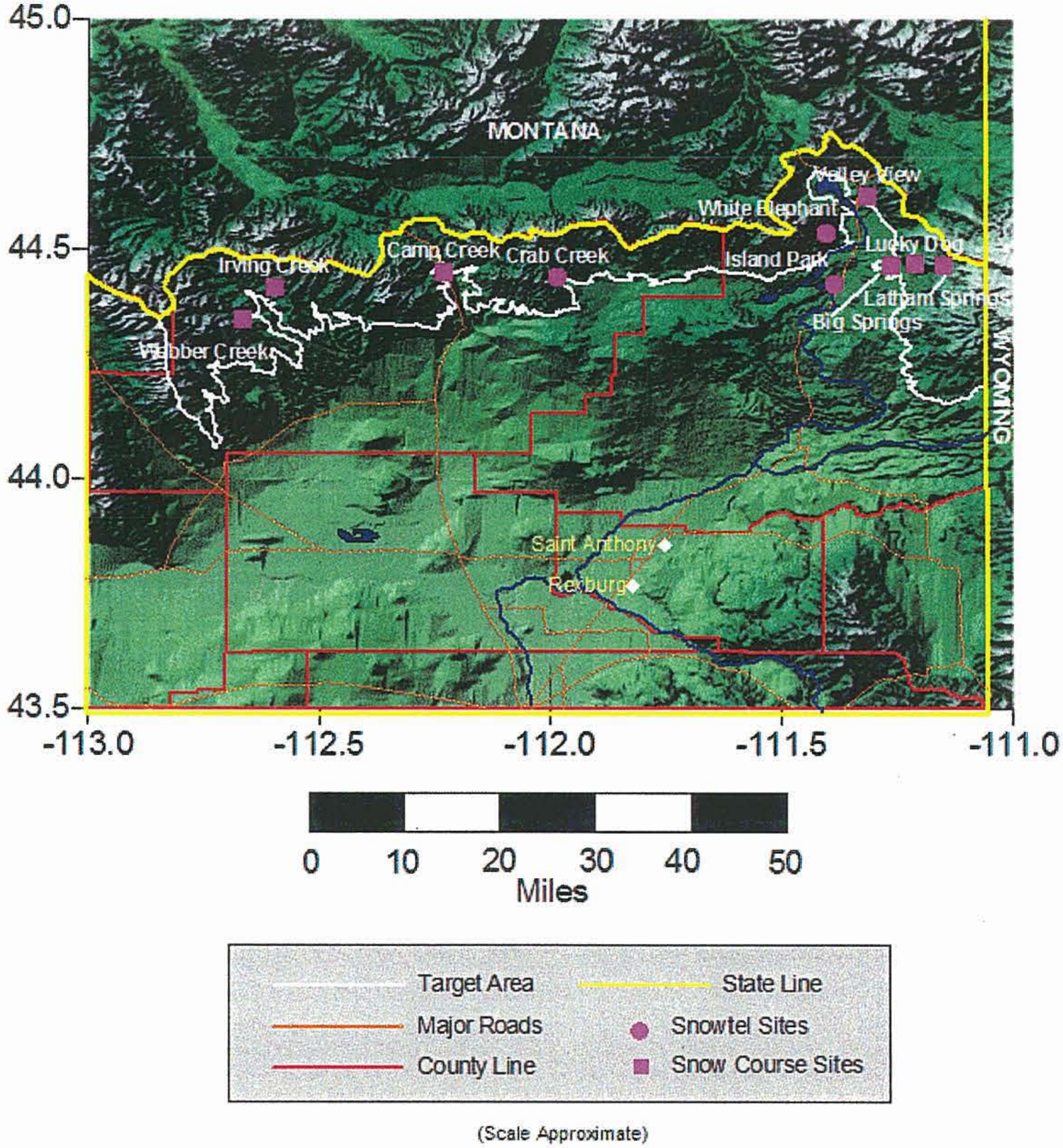

Figure 5.3 Proposed North Target Area
(locations of snow course and SNOTEL sites also provided)

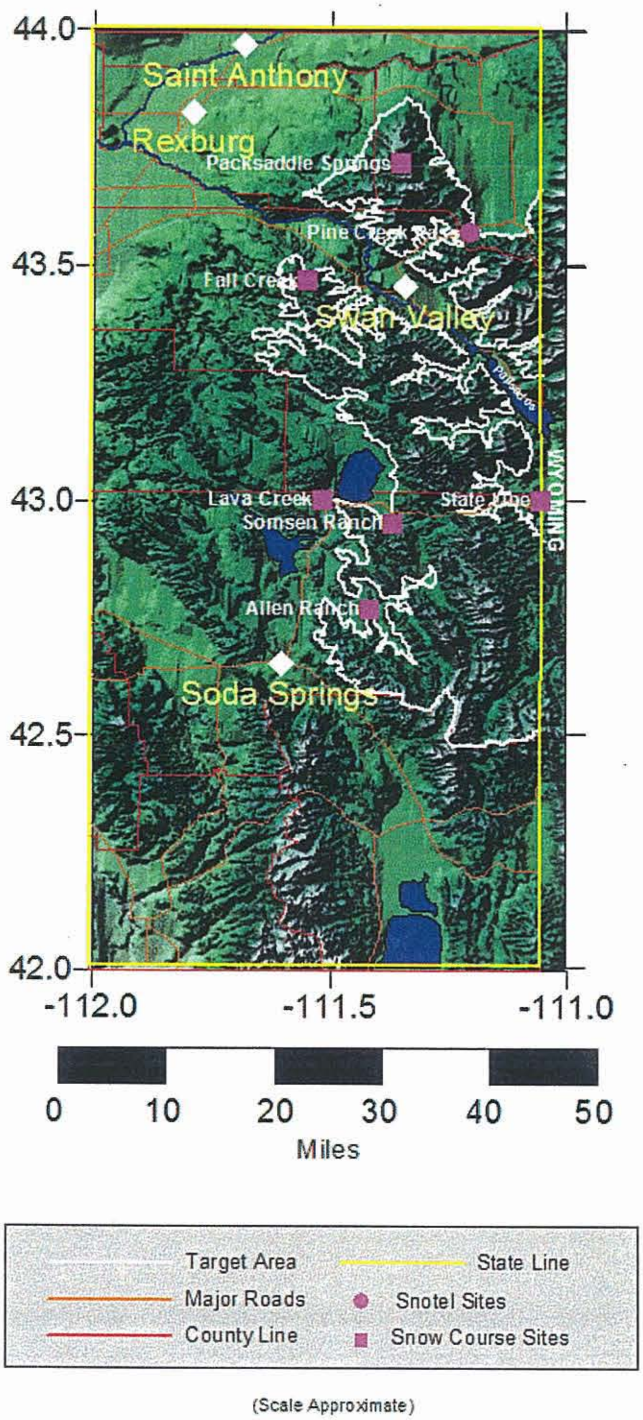

Figure 5.4 Proposed East Target Area
(locations of snow course and SNOTEL sites also provided)

5.4 Seeding Agent Selection

The ASCE/EWRI Standard Practice for the Design and Operation of Precipitation Enhancement Programs (ASCE 2004) contains a summary of the different types of cloud seeding agents. That summary is as follows.

The materials placed within the targeted clouds are known as seeding agents. While glaciogenic agents intended to increase ice formation are the most common, others having hygroscopic properties are being used with increasing frequency. The full effects of this latter class of seeding agents are only beginning to be explored.

Precipitation enhancement involves intervening in the microphysical and/or dynamic development of convective cells and stratiform clouds to improve the efficiency of the precipitation processes. The most widely employed method consists of introducing glaciogenic agents, materials which have the capacity to generate additional cloud ice. When added to the natural ice (if any) within the supercooled cloud region, the collective cloud ice population may alter the cloud sufficiently to result in additional rain or snow.

In nature there are many substances which are capable of acting as glaciogenic agents. Not all these substances, however, form ice crystals with the same facility, since their efficiency in this respect is a function of their composition. For example, each substance has a crystallization temperature threshold, which is the temperature at which it begins to cause the formation of ice crystals. In general, it may be said that a substance's ability to act as an ice nucleating agent is higher to the extent that its threshold value approaches the range from 0 to –4°C. The discovery of silver iodide (AgI) as an extremely efficient ice nucleating agent, with a threshold near -5°C, made by Vonnegut (1947), was therefore a major contribution to weather modification activities.

In addition to this widely-used method, there is another which uses a quite different approach (Dennis and Koscielski 1972; Mather et al. 1997). This approach, called hygroscopic seeding, aims to speed the development of large cloud droplets and rain drops through coalescence in the warmer (lower altitude) portions of the cloud. Such accelerated rain development may result in added rain at the ground. Numerical modeling of hygroscopic seeding also indicates that ice processes are enhanced in the seeded clouds.

<u>Silver Iodide</u>

Silver iodide, in combination with various other chemicals, most often salts, has been used as a glaciogenic agent for half a century. In spite of its relatively high cost, it remains a favorite, especially in formulations which result in ice nuclei (IN) with hygroscopic tendencies.

Silver iodide has utility as an ice nucleant because it has the three properties required for field application. These are: (1) it is a nucleant, regardless of mechanism, (2) it is relatively insoluble at $<10^{-9}$ g per gram of water, so that the particles can nucleate ice before they dissolve, and (3) it is stable enough at high temperatures to permit vaporization and re-condensation to *form large numbers of functional nuclei per gram of AgI burned (see Finnegan 1998). Thus, the ice crystallization temperature threshold for AgI is about -5°C, significantly warmer than the threshold for most naturally-occurring IN, which commonly have thresholds closer to -15°C. The chemical formulations of AgI seeding agents may be modified further, so that the resulting IN function at even warmer temperatures (DeMott 1991, Garvey 1975).*

In many cases, AgI is released by a generator that vaporizes an acetone-silver iodide solution containing 1-2% AgI and produces aerosols with particles of 0.1 to 0.01 μm diameter. AgI is insoluble in acetone; commonly used solubilizing agents include ammonium iodide (NH_4I), and any of the alkali iodides. Additional oxidizers and additives commonly include ammonium perchlorate (NH_4ClO_4), sodium perchlorate ($NaClO_4$), and paradichlorobenzene ($C_6H_4Cl_2$). The relative amounts of such additives and oxidizers modulate the yield, nucleation mechanism, and ice crystal production rates.

Some of the substances used in AgI mixtures are oxidants, and may oxidize (rust) and corrode the metal parts of some IN-generating equipment. Solutions may be obtained pre-mixed, or can be mixed in the field. Care must be taken too that the AgI is thoroughly dissolved, because if it is not, the un-dissolved reagent can block flow in the generator, resulting in generator failures. Once produced, some AgI aerosols may lose some of their glaciogenic capacity with time. Exposure to sunlight, and UV light in particular, may accelerate the deactivation process for some aerosols, while others have shown limited degradation with exposure to sunlight (Super et al. 1975).

As may be imagined from the foregoing, it is of great importance to arrive at a formula for the preparation of silver iodide complexes which provides maximum efficiency, producing the greatest possible number of active IN per unit mass of AgI. Numerous studies have been carried out at Colorado State University using isothermal cloud chambers to analyze the efficiency of different AgI mixtures, and many different formulae have been proposed (e.g. DeMott et al. 1995, Finnegan et al. 1994, Pham Van Dihn 1973, Rilling et al. 1984). Ice nucleus generators may be ground-based, or carried on aircraft, usually at or near the wing tips.

The generation of AgI aerosols can also be accomplished by burning specialized pyrotechnics. In many cases, a mixture containing silver iodate ($AgIO_3$) to diminish the tendency of AgI to break down into its component silver and iodine molecules (Ag and I_2) has been used. Powdered aluminum and magnesium, and some kind of organic agglutinant are also often added to the mixture (Dennis 1980). In recent years, advances in nucleation physics have resulted in a number of more effective pyrotechnic formulations which produce nuclei that, in addition to having ice nucleation thresholds near -4°C, are also somewhat hygroscopic. The resulting nuclei are not only effective as IN, but they also attract water molecules. This results in particles that in high relative humidities (near saturation) quickly form droplets of their own, which then freeze shortly after becoming supercooled. This condensation-freezing nucleation process generally functions faster than that achieved using simple AgI. Laboratory testing has shown that AgI by itself functions primarily by the contact *nucleation process, which is more dependent upon cloud droplet concentration, and consequently, a much slower process (DeMott 1991). Speed in nucleation is very desirable in applications such as hail suppression where quick glaciation of modestly-supercooled cloud turrets is required.*

Dry Ice

The direct creation of cloud ice particles by dispensing dry ice (CO_2) pellets into the cloud is another glaciogenic seeding technique which modifies the natural ice formation process by rapidly transforming nearby vapor and cloud droplets into ice (Schaefer 1946, Holroyd et al. 1978, Vonnegut 1981).

Compared with silver iodide complexes, this system has an advantage in that it makes use of a natural substance (frozen carbon dioxide, CO_2, which sublimes at -78°C at 1,000 hPa). However, effective delivery of the CO_2 requires the use of aircraft. The CO_2 is also difficult to store, as sublimation (and therefore loss) is continuous. It is uncommon for dry ice to be the only seeding agent used in a program; it is sometimes used in conjunction with AgI seeding.

Other Ice Nucleants

Certain proteins derived from a naturally-occurring bacterium, pseudomonas syringae, fall within the description of nucleating proteins, because of their ability to induce the formation of ice crystals in seeding applications. Many other organic substances have this property; among these metaldehyde and 1.5-dihydroxynaphthalene, which have contact freezing temperatures of -3°C and -6°C respectively. Their efficiency in generating ice crystals is very similar to that of dry ice (Kahan et al. 1995).

Hygroscopic Agents

Numerous precipitation enhancement programs have been using AgI complexes as their primary nucleating agent since the 1950s. Nevertheless, the injection of hygroscopic agents which may alter the initial cloud droplet spectra or create raindrop embryos immediately may be an efficient method for treating warm-based continental cumulus clouds, in which the vertical distance from cloud base to the freezing level can be as much as several kilometers. Ludlam (1958) and Appleman (1958) described the concepts involved in hygroscopic seeding with salt particles by dropping large numbers of salt particles into cumulus clouds. Salt seeding was used experimentally in the North Dakota Pilot Program, a combination hail suppression and rainfall enhancement program, in 1972. In this experiment and others conducted in South Dakota, finely ground salt particles were released near the bases of moderate sized cumulus clouds to create raindrop embryos around the salt particles. Experiments carried out in South Africa in the early 1990s underlined the potential importance of seeding with hygroscopic agents. Mather strongly recommends the use of hygroscopic agents to combine hail suppression with precipitation enhancement activities (Mather 1991; Mather and Terblanche, 1994).

Hygroscopic agents deliquesce (that is, become liquid by absorbing moisture from the air) at relative humidities significantly less than 100%. Mather

(1991) has made use of flares containing primarily potassium perchlorate , which when burned produces potassium chloride (KCl) particles of about 1 μm diameter. These flares were burned near the base of cumulus clouds in an attempt to alter the cloud droplet spectra. The hygroscopic flares weigh about one kilogram. Although there are many naturally-occurring hygroscopic substances, KCl particles have an advantage of only requiring a relative humidity on the order of 70-80% to deliquesce, and readily act efficiently as CCN.

Program planners should bear in mind that the hygroscopic flare method is relatively new and is not yet used as widely as the AgI complexes, but has shown considerable promise (Cooper et al. 1997, Mather et al. 1996, 1997). A program in southern France is experimenting with hail suppression based on the new hygroscopic flare technique at the time of writing; other experiments are being conducted in Mexico for rain enhancement (Bruintjes et al. 1999).

In addition to the possible seeding agents mentioned in the above ASCE reference, there is one other category of possible seeding agents that needs consideration for application in winter cloud seeding programs; this category is liquefied compressed gases. One example of such an agent is liquid propane. The following description is reproduced from Manual #81 prepared by the American Society of Civil Engineers (Kahan, et al, 1995).

Liquid propane is a freezing agent much like dry ice. It produces almost the same number of crystals per gram as does CO_2 (Kumai 1982). It cannot be dispensed from aircraft because it is a flammable substance. However, it can be dispensed from the ground if released at elevations which are frequently within supercooled clouds. The United States Air Force has used liquid propane dispensed from ground-based sites to clear supercooled fog at military airports for over thirty years.

Propane seeding was tested as a cloud seeding agent on a winter research program conducted in California for winter snowpack enhancement through the development of a remotely operated ground-based dispenser (Reynolds 1991, 1992). Liquid propane seeding experiments were also conducted on the Utah/NOAA Atmospheric Modification Program (Super, 1999). A recent randomized research experiment was conducted on the central Wasatch Plateau of Utah testing this agents' possible utility in winter cloud seeding programs (Super and Heimbach, 2005). This paper does indicate seeding increases due to a randomized treatment of storm periods with liquid propane but the area of coverage appeared to be quite small, being on the order of 3-4 km x 3-4 km from a single release point.

NAWC's discussion and recommendations concerning seeding agents to be used on the ESRBP are provided in Section 5.6.

5.5 Targeting and Delivery Methods

The ASCE/EWRI Standard Practice for the Design and Operation of Precipitation Enhancement Programs (ASCE 2004) contains a summary on targeting and delivery methods (seeding mode) associated with cloud seeding programs. The introductory portion of this summary is as follows.

> *The most critical portion of any cloud seeding program is the proper delivery of cloud seeding material to the appropriate portion of the cloud. Concentrations of the cloud seeding agent must be adequate to modify a sufficient volume of cloud to significantly affect the precipitation process in the desired manner. To date this has been, and continues to be the most critical element in the development and implementation of precipitation enhancement technology.*
>
> *A number of alternatives exist concerning cloud seeding delivery systems. A basic division exists between these alternatives consisting of ground based or aerial generating systems. Most systems currently in use are designed to dispense silver iodide nuclei, particles of dry ice, or hygroscopic particles. The choice of the delivery system (or systems) should be made on the basis of the program design, which should establish the best system for the specific requirements and the topographic configuration of a given program.*

The following section contains specifics on possible seeding modes and targeting issues as related to the ESRBP preliminary design.

5.6 Seeding Modes

The specification of the seeding mode(s) and seeding agent(s) for the ESRBP preliminary design presents a challenge. In reality there is no one right answer. A number of factors need to be considered to arrive at a reasonable recommendation including effectiveness of the seeding material, cost of the seeding material and delivery mode, reliability of the seeding mode, ability to fly aircraft in the appropriate regions or the ability to locate ground dispensing equipment at preferred locations, ability to disperse the seeding material in the appropriate concentrations somewhat uniformly and continually into the supercooled cloud regions, areas likely to be affected by seeding, and lack of any negative environmental consequences associated with the recommended seeding agents. From this description of factors there is an obvious overlap between seeding modes and the ability to effectively target the seeding material into appropriate cloud regions.

5.6.1 Ground Based Silver Iodide Seeding

Silver Iodide ground based seeding systems are the oldest and most widely used type of seeding mode for winter storms in the western United States. The most common seeding generator burns a solution of acetone in which a certain percentage by weight (usually 2-3%) of silver iodide has been dissolved. Generators can be located at residences upwind of the intended target areas and operated by these residents as specified by the program meteorologist. Figure 5.5 provides a photograph of a typical manually-operated unit. Such locations are often in valley or foothill locations. Remotely controlled silver iodide generators are frequently used at higher elevation unmanned locations. Figure 5.6 provides a photograph of a remotely controlled solution-burning

Figure 5.5 Manually Operated, Ground Based Silver Iodide Generator

Figure 5.6 Remotely Controlled, Ground Based Silver Iodide Generator

generator. Ground-based generators normally disperse from 0.4 – 1.6 ounces (10- 40 grams) of silver iodide per generator per hour of operation. Normal consumption rates with these solution-burning generators are on the order of 0.1 – 0.2 gallons (0.4- 0.8 l) of seeding solution per hour of operation. The effectiveness of this type of generator has been established through the conduct of tests at the Colorado State University Cloud Simulation Laboratory. Figure 5.7 provides the results of tests performed on one of NAWC's manually operated generators. **This figure indicates that approximately 8×10^{14} ice crystals can be produced from a single gram of silver iodide at a temperature of $+14^0$ F (-10C).** This figure also demonstrates that silver iodide becomes increasingly effective with decreasing temperatures. Measurements of naturally occurring ice nuclei (typically soil particles or certain kinds of bacteria) demonstrate this same tendency.

Another method of dispensing silver iodide from ground-based sites is via flares impregnated with seeding material. This approach is used primarily in regions where discrete cloud structures with significant seeding potential can be seeded beneficially via high seeding material dosage rates during their passage over an area. Such seeding sites are commonly remotely operated via computerized control systems. An example is shown in Figure 5.8.

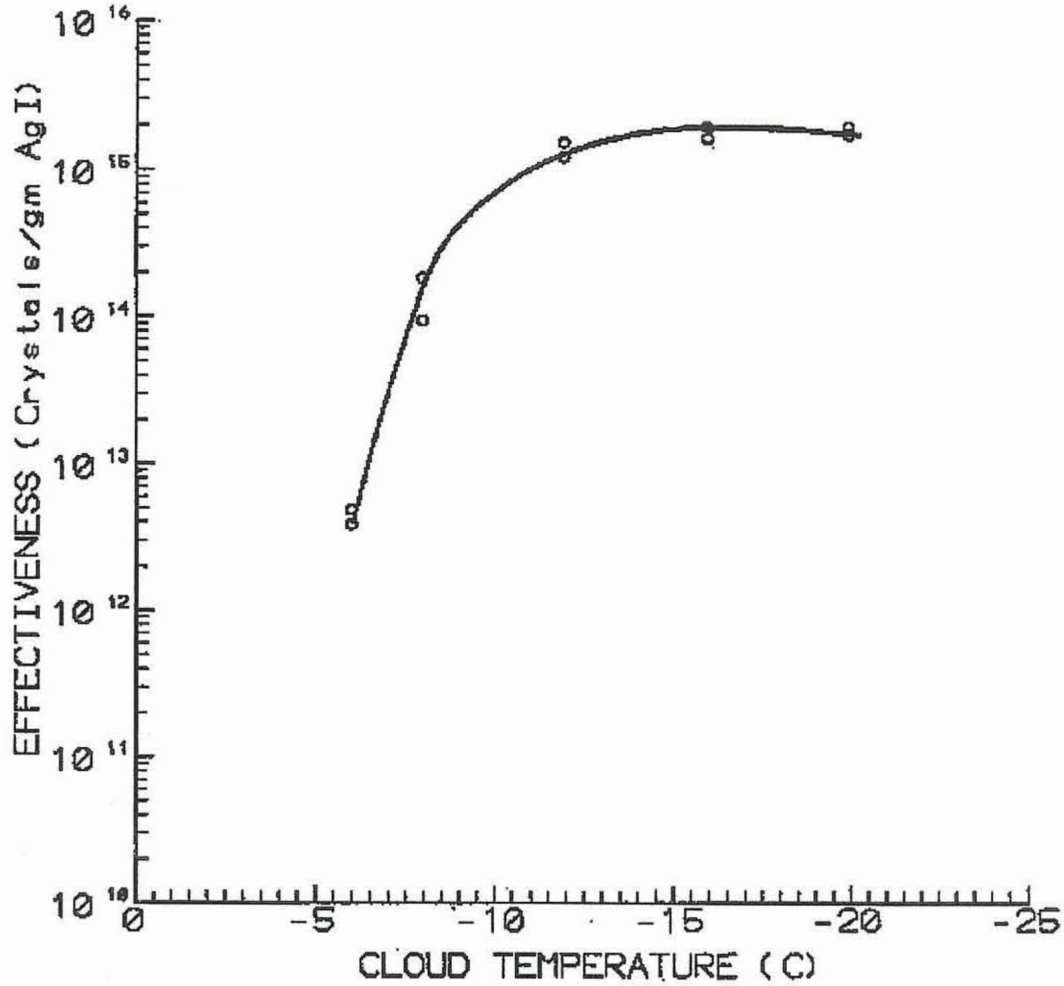

Figure 5.7 Results of Colorado State University Tests of the Effectiveness of a NAWC Manually Operated Ground Based Generator

Figure 5.8 Ground-Based Seeding Flare Site

5.6.2 Airborne Silver Iodide Seeding

Seeding with silver iodide using aircraft is the second most common mode of seeding in existing operational winter cloud seeding programs in the United States. In fact, ground generators and aircraft seeding using silver iodide as the seeding agent is a frequently utilized combination-seeding mode. Aircraft seeding to dispense silver iodide is normally accomplished by one of two methods. Flares (similar to highway flares) that have been impregnated with silver iodide can be carried in racks mounted on the trailing edges of the wings. Flares of this type burn in place, i.e., they remain in the wing-mounted racks as they are ignited and burn. Figure 5.9 provides a photograph of a typical installation. Each flare may contain on the order of 1.4 – 7.0 ounces (40 to 200g) of seeding material. The burn duration of these flares is ~ 1 – 5 minutes so the average rate of release is ~ 0.4 – 4.0 ounces (10 – 100 g) of seeding material per minute. Some of these flares have been tested at the Colorado State University Cloud Simulation Laboratory to determine their efficiency. Table 5-1 provides data from a test performed on a flare manufactured by Ice Crystal Engineering (ICE), Inc. of Fargo, North Dakota. This flare exhibited activity up to temperatures as warm as 24.8^0 F (-4^{0}C). This is a very desirable feature that will be discussed in a later section. The flare formulation also acted very quickly in forming ice crystals, apparently through a condensation/freezing mechanism (in most applications this is also a desirable characteristic).

The other commonly used means of dispensing silver iodide from aircraft is accomplished using acetone/silver iodide generators mounted under each wing tip. These generators hold approximately 8 gallons of a mixture of acetone and silver iodide. This mixture is ignited in the tail cone section of the generator, producing the desired silver iodide particles.

Table 5-1

CSU Cloud Chamber Test Results for Ice Crystal Engineering Flare

Pyro type	Temp (°C)	LWC (g m^{-3})	Raw Yield (g^{-1} AgI)	Corr. Yield (g^{-1} AgI)	Raw Yield (g^{-1} pyro)	Corr. Yield (g^{-1} pyro)	Yield (per pyro)
ICE	-3.8	1.5	$3.72x10^{11}$	$3.87x10^{11}$	$4.01x10^{10}$	$4.18x10^{10}$	$6.27x10^{12}$
	-4.0	1.5	$9.42x10^{11}$	$9.63x10^{11}$	$1.02x10^{11}$	$1.04x10^{11}$	$1.56x10^{13}$
	-4.2	1.5	$1.66x10^{12}$	$1.70x10^{12}$	$1.80x10^{11}$	$1.84x10^{11}$	$2.76x10^{13}$
	-4.3	1.5	$2.15x10^{12}$	$2.21x10^{12}$	$2.32x10^{11}$	$2.39x10^{11}$	$3.53x10^{13}$
	-6.1	1.5	$6.01x10^{13}$	$6.13x10^{13}$	$6.49x10^{12}$	$6.62x10^{12}$	$9.93x10^{14}$
	-6.3	1.5	$5.44x10^{13}$	$5.56x10^{13}$	$5.87x10^{12}$	$6.00x10^{12}$	$9.00x10^{14}$
	-6.4	1.5	$6.22x10^{13}$	$6.34x10^{13}$	$6.72x10^{12}$	$6.85x10^{12}$	$1.03x10^{15}$
	-10.5	1.5	$2.81x10^{14}$	$2.85x10^{14}$	$3.03x10^{13}$	$3.07x10^{13}$	$4.61x10^{15}$
	-10.5	1.5	$2.34x10^{14}$	$2.37x10^{14}$	$2.87x10^{13}$	$2.91x10^{13}$	$4.37x10^{15}$
	-4.2	0.5	$1.41x10^{12}$	$1.45x10^{12}$	$1.53x10^{11}$	$1.57x10^{11}$	$2.36x10^{13}$
	-6.0	0.5	$7.42x10^{13}$	$7.73x10^{13}$	$8.01x10^{12}$	$8.34x10^{12}$	$1.25x10^{15}$
	-10.5	0.5	$2.38x10^{14}$	$2.41x10^{14}$	$2.91x10^{13}$	$2.96x10^{13}$	$4.44x10^{15}$

Figure 5.9 Aircraft with Seeding Flare Racks

Typical consumption rates of the solution are on the order of 2 gallons per hour per generator, which results in a release rate of approximately 4.2 – 6.3 ounces (120-180 grams) of silver iodide per hour. Figure 5.10 provides a photograph of a typical installation. Work performed by Dr. Finnegan of DRI (Finnegan and Pitter, 1988) indicated that the silver iodide particles produced by these generators also act very quickly if the generator is operated in clouds, due to a transient super-saturation condition resulting from the combustion of acetone producing water in an already saturated environment. Normally airborne generators are operated in-cloud on winter programs. Figure 5.11 provides the results of the tests conducted at the Colorado State University Cloud Simulation Laboratory on a generator manufactured by AeroSystems, Inc. of Longmont, Colorado. These tests indicate that this generator is very effective.

A third means of dispensing silver iodide from aircraft consists of racks mounted on the bottoms of aircraft fuselages (see Figure 5.12). These racks are then loaded with flares that can be fired vertically downward. The payloads of seeding material in these "ejectable" flares fall away from the aircraft, traveling about 2000 to 6000 feet (610 – 1830m) vertically before being completely consumed through combustion. This seeding mode is frequently used in seeding isolated towering cumulus clouds via "on top" cloud penetration seeding on summer programs, but is seldom used on winter programs due to the expense involved in seeding large areas in a nearly continuous fashion.

5.6.3 Airborne Seeding with Dry Ice

A less commonly used mode of seeding winter storms is airborne seeding using dry ice (this particular seeding mode is more commonly used to disperse cold fogs at airports to allow aircraft to land and takeoff by improving runway visibilities). Oftentimes dry ice pellets with diameters of 0.2 – 0.4" (0.6 – 1cm) and lengths of 0.4 - 1" (1 – 2.5cm) in length are carried onboard aircraft in hopper/dispensing systems and are dispensed through the floor of baggage compartments or extra passenger seat locations on modified cloud seeding aircraft. These pellets will fall about 3300-6600 feet (1-2km) before they completely sublimate. Typical release rates are from one pound to a few pounds of dry ice per mile of flight path. Dry ice is an effective ice nucleant, producing 2×10^{11} to 8×10^{11} ice crystals per gram of dry ice dispensed. Its effectiveness is relatively independent of temperature in the range of $30^0 – 12^0$ F (-1^0C to -11^0C) (Holyroyd, et al, 1978). Figure 5.13 provides a photograph of a dry ice dispenser mounted in a seeding aircraft.

5.6.4 Ground Based Propane Seeding

Some investigators have suggested that the use of liquid propane as a seeding agent should be considered since it theoretically could produce ice crystals near the freezing level, while silver iodide does not begin to become effective until temperatures of $23 – 25^0$ F (-4 or -5^0C) are reached. Some research (e.g., Super, 1999) has indicated that there are periods near the crests of mountains in the west that experience significant periods of supercooled liquid water at temperatures in the $32^0 – 23^0$ F (0 to -4^0C) range in

Figure 5.10 Aircraft with Silver Iodide/Acetone Generators

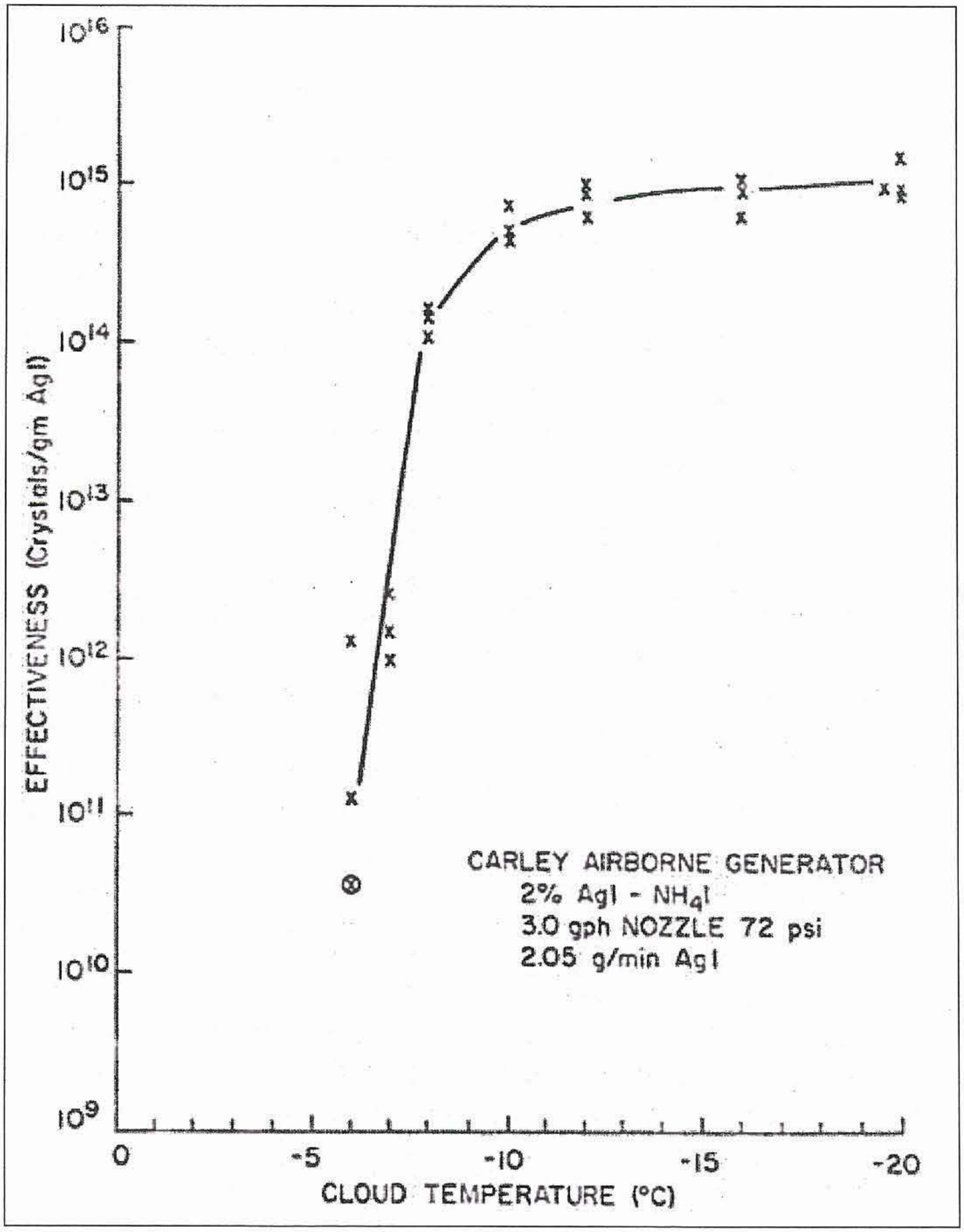

Figure 5.11 CSU Cloud Chamber Tests of AeroSystems Generator

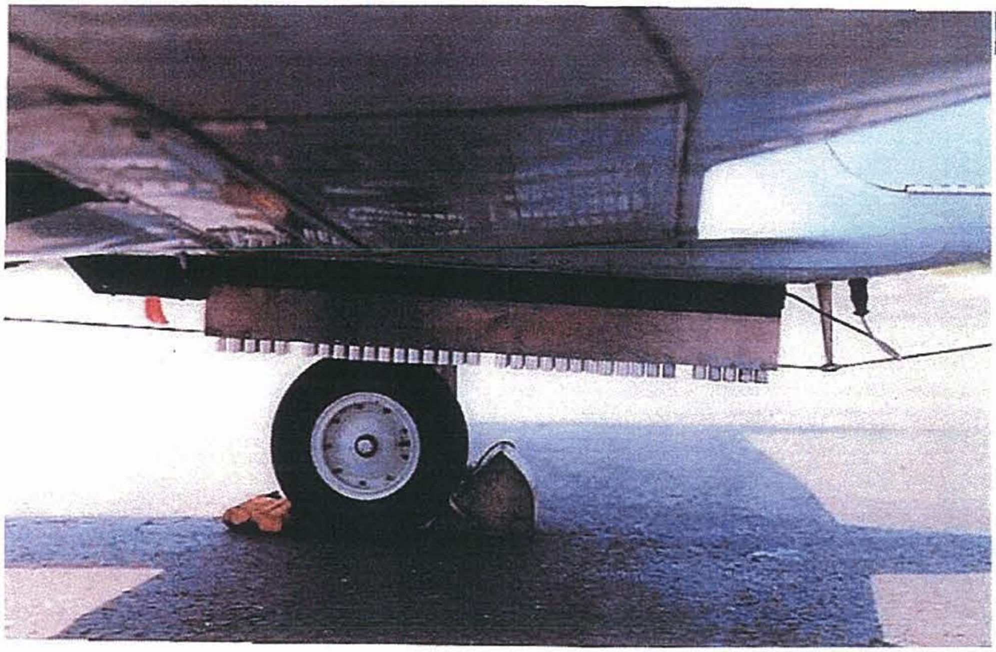

Figure 5.12 Aircraft Belly Mount, Droppable Silver Iodide Seeding Flare Rack

Figure 5.13 Dry Ice Dispenser Mounted in a Seeding Aircraft

which liquid propane seeding may be effective while silver iodide would not be. There has only been one research-oriented program that used liquid propane as the seeding agent that was designed to produce an effect over a sizable target area (Reynolds, 1994). The program was terminated after three winter seasons of seeding with no indication of any positive seeding effects. Recent research conducted in Utah (Super and Heimbach, 2005) did demonstrate positive seeding effects using this technique, but apparently only over a very small area. It is NAWC's position that positive results are needed from a research program conducted over a sizable area before this technique is considered for use on operational winter cloud seeding programs. A statement in ASCE Manual 81 supports this position. This statement is "Future experimentation needs to be conducted to demonstrate that this technique can increase precipitation over a fixed target area for a significant period of time (e.g., a winter season)." NAWC, for the reasons stated herein, does not recommend the use of liquid propane as a seeding agent on the ESRBP.

5.6.5 General Discussion on the Considerations that Govern the Specification of a Seeding Mode(s)

The goal of a wintertime orographic cloud seeding program is to convert supercooled liquid water droplets (SLW) upwind of and over the mountain barrier(s) into ice crystals in a timely fashion, such that they have time to grow into snowflakes and fall within the intended target area. From the discussions contained in Section 5.5 we believe that the primary area of opportunity is over the upwind slopes of the mountain barrier extending to heights of perhaps 1600 – 3300 feet (500- 1000 m) above the crest of the mountain barrier. Figure 5.1 contains a stylized schematic depiction of this zone of opportunity. It appears that this zone of SLW is frequently present in winter storms, although it does appear that SLW concentration and extent fluctuate with storm conditions. For example, if there are deep clouds upwind and over the barrier there may be enough natural nucleation occurring in the colder portions of these clouds such that the natural precipitation processes are efficient in removing any lower level SLW. Under these conditions precipitation rates may be substantial but there is little, if any, opportunity for seeding to increase snowfall rates. It appears that shallower cloud systems and those that contain embedded convection[1] are more likely to have significant periods with the lower level SLW profile as depicted in Figure 5.1.

There are a number of considerations that impact the ability to fill this zone of opportunity in a timely fashion with seeding materials in sufficiently high concentrations to produce a positive effect of seeding in the target area. Several of these considerations are time related. For example, how long does it take to transport silver iodide nuclei from ground generators into this zone of SLW at cold enough temperatures for the silver iodide to nucleate cloud droplets forming ice crystals? Then how long does it take for these ice crystals to grow into snowflakes that are large enough to fall to the ground? This transport, nucleation, growth, and fallout scenario is directly impacted by the wind speeds that are encountered at different stages in this scenario. Stronger wind speeds will mean that the effects of cloud seeding (if any) will occur at increased distances from the release

[1] Embedded convection – convective cells, embedded in a stratiform cloud deck, that promote upward vertical motion.

point. The seeding agent used is also related to these timing issues. If one possible ground based seeding agent threshold is 23^0 F (-5^0C) and another is 28.4^0 F (-2^0C), it will take longer for the agent active at 23^0 F (-5^0C) to reach its nucleation level than the one that begins to nucleate at 28.4^0 F (-2^0C). Cloud chamber tests also indicate that some seeding agents act very quickly through a condensation/freezing mechanism, while others act more slowly though a contact freezing mechanism. These differences can impact where the effects of seeding occur from a given ground release point.

One of the other considerations is how can we fill a majority of this SLW zone in a satisfactory way. In other words, how well does the seeding plumes merge or overlap horizontally to fill this volume? Consideration of this question in combination with the expected lower level wind flows that will be encountered upwind and over the target area will lead to the development of the proposed spacing and location of ground generators. A network of generators will typically be needed to be able to effectively seed under a variety of different wind directions. Not all such generators will be used to seed at the same time, but differing combinations of generators will be used to correctly target the seeding material with changing wind directions. In a similar manner, aircraft seeding tracks need to allow flexibility to account for these changing conditions.

5.6.6 Advantages and Disadvantages of Ground Based Generators

There are advantages and disadvantages associated with manually operated and remotely controlled ground based seeding devices (typically ground based silver iodide generators). Some research (e.g., Super, 1999) has suggested that there may be low-level atmospheric temperature inversions[2] during winter storm periods that may trap the silver iodide particles released from valley or foothill based ground generators. NAWC has found that such inversions certainly do occur, but the strength, height and frequency of such inversions vary considerably from one area to another. An earlier NAWC feasibility/design study (North American Weather Consultants, 2002) conducted for the Uintah Basin in northeastern Utah documented that low-level atmospheric inversions were a fairly frequent phenomenon in that region during the wintertime.

There were two types of inversions identified: 1) ones that were based near the surface, and 2) ones that were elevated. The height of the tops of the surface based inversions averaged 1340 feet (0.4 km) above ground level, or at an elevation of 6290 feet MSL (1.9 km). The tops of the elevated inversions were also relatively low, being on the order of 2600 feet (792 m) above ground level or at an elevation of ~7570 feet MSL (2.3 km). In order to address the concerns about the possible trapping of silver iodide released from valley locations, NAWC recommended that seeding sites for that project be located above the average top height of the elevated inversions (i.e., at or above ~ 7,600 feet in elevation). This would potentially avoid trapping of the silver iodide seeding material in at least half of the occurrences with elevated inversions, and a large majority of those cases with surface based inversions. The clients accepted this data analysis-based approach, and suitable sites were found which could utilize manually operated units (similar to Figure 5.5). These manually operated units are far less

[2] Departure from the usual decrease in temperature with height to an increase in temperature with height.

expensive to fabricate, install and maintain than remotely controlled units. In central Utah, a case study that utilized tracer data to document the likely plume transport of seeding material found that seeding material released beneath a low-level inversion from a valley site between two mountain ranges was transported over the second barrier (Heimbach, et al, 1997). The explanation given by the authors was that apparently a gravity wave[3] was responsible for the transport of the seeding material through the inversion.

Research work conducted in Utah, summarized by Super (1999), suggested that transport from valley generators was limited and that concentrations of silver iodide were too low when transport did occur. There are least two problems associated with these conclusions: 1) some flights conducted to determine if valley released seeding materials were being transported over the crest were conducted under Visual Flight Rule (VFR) conditions in order to allow the aircraft to fly at low altitudes over the barrier, and 2) concentrations of seeding material were primarily inferred from counts recorded on a device known as an NCAR counter. In regards to the first point, it is NAWC's position that atmospheric conditions are different during active storm periods than they are in pre-frontal VFR conditions. The presence of lower level inversions (indicated to occur ~37% of the time based upon valley rawinsonde observations) may not be a problem anyway if there is no supercooled liquid water associated with such occurrences. It is unknown whether supercooled water existed in these cases, since no stratifications of the data were presented using these criteria. Interestingly, this paper does indicate successful transport of valley-released silver iodide to the crest line in 90% of seven different relatively wet cases with supercooled liquid water present. The explanation given was that at most times when supercooled liquid water was present in amounts of 0.002 inches (0.05 mm) or more (i.e. the better cases), weak embedded convection was also present, which likely assisted vertical transport of the valley released silver iodide. Regarding the second point, it is our opinion that counts of ice nuclei observed on an NCAR counter at -4^0 F (-20^0 C) provide qualitative not quantitative numbers. This position is supported by the fact that the actual counts observed by the NCAR counters are often multiplied by 10 to account for possible accumulation of ice crystals on the sidewalls of the device. Further, the crystal growth times in NCAR counters are only on the order of approximately three minutes. We know from cloud chamber tests conducted at Colorado State University that activation of silver iodide particles may take as long as 15-20 minutes. This is another likely source of undercounting of the silver iodide nuclei that may be present.

Finally, there have been evaluations of the operational programs being conducted in Utah using lower elevation silver iodide generators that indicate that this (ground generator) type of cloud seeding is effective (Griffith, et al, 1991) and indications of effectiveness from an operational program being conducted in Eastern Idaho also using lower elevation, manually operated generators (more detail on this program and its apparent effectiveness is provided in Section 12 of this report). There are no doubt winter periods in Utah and in other western mountain ranges when seeding from low level generators will be ineffective. Whether the addition of higher-elevation remotely

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[3] Oscillations over or downwind of mountain barriers resulting in a repeating pattern of upward and downward motions typically organized in waves.

controlled generators to seed more effectively under these conditions is warranted must be examined in light of the additional costs and logistical complications involved versus the perceived increment in additional precipitation that may be produced by using such systems.

Going back to the timing discussions found in section 5.5, a case can be made that it is better to locate the generators upwind of the mountain barriers (usually at lower elevations) since this may allow seeding material reaching effective levels well upwind of the crest. In this scenario, longer growth times are available for the ice crystals to reach snowflake sizes and to fall on the barrier. Placing remotely-controlled generators near the crest lines of these barriers (as has been done on research programs such as the Bridger Range and Utah NOAA programs) may result in only very small snow flakes being formed on the upwind side of the barrier (due to the short times for growth), which may not contribute significantly to the overall water balance on the upwind side of the barriers. Any positive effects are more likely to occur on the downwind side of the barriers. Generation of significant effects in downwind areas, however, will be hampered by descending air motions on the lee side of the barriers, which may result in poor growth of the snowflakes due to lack of significant SLW and warming temperatures, factors which may actually result in sublimation (a phase change going directly from solid to vapor) of some of the snowflakes (in this scenario, the water content contained in the artificially generated snowflakes may never reach the ground). In fact, the Bridger Range experiment was designed for seeding over a first barrier to produce effects over a secondary downwind barrier located approximately 8 miles downwind. The experiment was successful in accomplishing this goal, but these results are only transferable to locations that have dual barriers or perhaps multiple barriers located at similar distances downwind from the first barrier. In these situations, downslope descending flow may not develop (or not develop very strongly) since the second barrier provides orographic uplift to the air mass.

To generalize, seeding the relatively narrow mountain barriers typical of the Intermountain West with remotely controlled generators located well up the windward side of these barriers will probably only produce appreciable positive effects near the crest and on the immediate downwind slopes of these barriers. In other words, little or no seeding effect would be expected on the upwind slopes of these barriers. Unfortunately, higher amounts of precipitation normally occur on the upwind slopes of such barriers, so a major opportunity to provide significant amounts of additional water may be limited. To illustrate, a 10% increase on a 25" (63.5 cm) base is 2.50" (6.4 cm), whereas a 10% increase on a 15" (38 cm) base amount would be 1.5" (3.8 cm). In addition, if seeding can be accomplished from generators located further upwind of the barriers, some of these effects would be expected to affect the downwind slopes of the mountain barrier as well.

Releases further upwind also allow more time for the seeding plumes to spread horizontally, perhaps even overlap, thus potentially affecting larger areas. Finally, recall where we expect the seeding potential to be, according to Figure 5.1; the potential is expected on the upwind side of the barriers. Remotely controlled generators located near the crest would be missing a large majority of the SLW, which would be located further upwind of those generators. These features are demonstrated in a schematic fashion in Figure 5.14. Mountain barriers which are wider than those typically found in the Intermountain West offer a better potential for the location of remotely controlled generators at mid-elevation ranges, which still have the potential of impacting more of the SLW zone and also have the advantage of being far enough from the barrier crest to allow snowflakes to grow in favorable growth regions and fall on a portion of the upwind side of the barrier. An excellent example of such a situation is the Sierra Nevada in California where a number of long term programs have effectively employed remotely controlled ground generators. Interestingly, some of these programs also employ lower elevation, manually operated units.

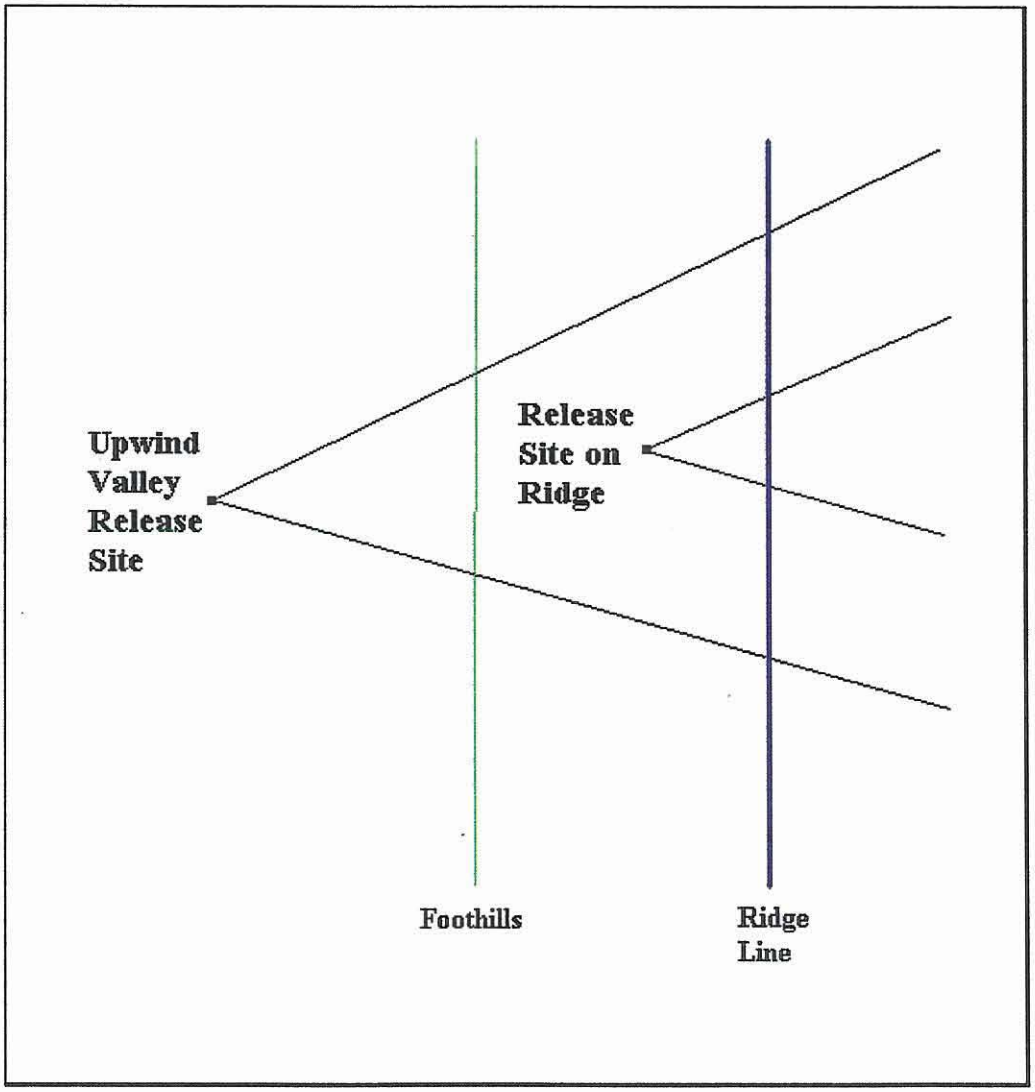


Figure 5.14 Illustration of Seeding Plume Spread (black lines) from an Upwind Valley Site and a Site Near the Ridge Line

Other advantages of ground generator systems (compared to aerial seeding) include lower cost of operation and the ability to operate continuously for extended periods. Ground generators also can be operated to affect mountainous target areas during winter storms under shallow orographic cloud conditions that are impractical or unsafe to seed using aircraft. These conditions can occur for extended durations in winter storms and frequently offer favorable seeding situations.

Disadvantages of ground-based seeding include greater targeting uncertainty; since assumptions have to be made regarding the combined horizontal and vertical transport of seeding material as well as in nuclei activation, ice crystal growth, and fallout time. The high cloud seeding rates possible with aircraft at effective cloud seeding heights (i.e., colder than about 24.8^0 F (-4°C)) are probably not possible using a ground generator system. Another possible disadvantage is that use permits from federal agencies (e.g., U.S. Forest Service) are frequently required in order to site remotely controlled generators on federal lands. Requests for use permits on federal lands may trigger the need to perform an environmental assessment for the program. Also, maintenance of remotely controlled generators in isolated locations often requires costly, regularly scheduled maintenance trips involving over-snow vehicles or helicopters.

Most of the above comments dealing with remotely controlled silver iodide generators would also apply to seeding using releases of liquefied propane, especially since these systems must be in-cloud at temperatures <0C to have any effect. This operating characteristic forces installations at higher elevations, which results in concerns regarding the nucleation and growth time issues discussed elsewhere in this section. The main advantage of seeding with propane is that it will create ice crystals at warmer temperatures than silver iodide (threshold temperatures of perhaps 30.2^0 F (-1^0 C) instead of 24.8^0 F (-4^0 C). As Super (1999) points out, supercooled liquid water may occur rather frequently in the temperature range of $30.2 - 24.8^0$ F (-1 to -4^0 C) during portions of winter storms in the Intermountain West where silver iodide seeding would be ineffective. It should be noted again, however, that the growth rates of ice crystals are relatively slow in this temperature range compared to growth rates at 17.6^0 F (-8^0 C).

Propane dispensers must be located at locations where the temperatures are below $+32^0$ F (0^0 C) and releases must be made in cloud. These conditions dictate that the dispensers be located well up the windward side of the relatively narrow mountain barriers typical of those found in the Intermountain West, thereby invoking some of the disadvantages of such locations mentioned earlier. Seeding effects are only produced in a small cone (perhaps 12" (30cm) in diameter and 36" (91cm) in length) of supercooled air that results from the venting of the liquid propane. Seeding effects are instantaneous through homogeneous freezing of the supercooled water droplets. There are, however, no downwind effects. By comparison, silver iodide particles can be released in upwind valleys at temperatures above freezing and then proceed to nucleate supercooled liquid droplets several miles downwind. This feature offers the opportunity to potentially treat much larger areas from a single silver iodide generator than from a single propane dispenser.

5.6.7 Advantages and Disadvantages of Airborne Seeding

Seeding winter clouds with silver iodide from aircraft offers some attractive features. Theoretically, an aircraft may be flown at flight levels at which silver iodide will activate immediately (~ 23^0 F, -5^0C and colder) without the requirement for the silver iodide to rise from a ground source to these levels. Aircraft may also be flown at locations selected to effectively target the intended target area(s). Aerial systems also offer advantages in terms of the ability to deliver higher seeding rates into given volumes of cloud, and the ability to seed stable atmospheric situations that may not be effectively treated using ground-based systems.

Disadvantages of aerial seeding include higher costs (much greater than ground generator operations). It also is difficult to maintain an effective amount of cloud seeding material feeding into clouds affecting a target area over long periods of time and of perhaps substantial size (i.e., multiple aircraft may be required). In addition, there are potential hazards of flying in icing conditions or extreme turbulence, and there are possible flight restrictions near major airports and within Military Operations Areas (MOAs). The Federal Aviation Administration also restricts minimum altitudes that may be flown in a specific area under Instrument Flight Rule (IFR) conditions (e.g., cloud obscured conditions). The general restriction is that the aircraft may not fly less than 2,000 feet (610 m) above the highest terrain located 5 nautical miles (9.25 km) either side of the proposed flight path. This last item has proven to present a problem in an attempt to use aircraft to seed in some winter orographic programs, e.g., a program conducted by Idaho Power on the Payette River Drainage in Idaho (Riley and Chavez, 2004).

There are two concerns which are interrelated: 1) can an aircraft be flown at low enough altitudes to effectively target the low-level SLW which seldom extends above the crest of the mountain barrier, and 2) can it be done safely? The answer to the questions will depend upon the topography upwind of the intended target area and the height of the freezing level during storm periods. For example, if there is a second mountain barrier upwind of the target barrier and it is 10 miles (16 km) between the mountain ranges with a narrow valley between, then the aircraft could fly no lower than 2,000 feet (610 m) above the crest height of the barriers, which would mean it would be flying above the top of the seedable SLW layer. In other words seeding would be ineffective. If the spacing between barriers is greater, with an intervening valley, then the aircraft may be able to fly along the axis of the valley at low enough altitudes to effectively target the SLW layer over the downwind barrier. The ability to conduct effective targeting in this scenario is confounded by the tendency of the air parcels flowing over mountain barriers to rise over the mountain barrier in stable to neutral stability situations. This could mean that the seeding material could still rise above some or all of the SLW, again resulting in ineffective targeting. This scenario is depicted schematically in Figure 5.15.

A further complication arises if the freezing level is within about 2000' (610 m) above the valley floor. In these conditions, if the aircraft encounters icing (which is likely), it cannot descend to temperatures warmer than freezing to melt off the ice while airborne. High performance aircraft, which can be a costly approach, may be necessary to overcome this potential problem out of concern for the safety of the aircraft crew. Even so, it may be difficult to maneuver the aircraft within the valley in order to make 180 °

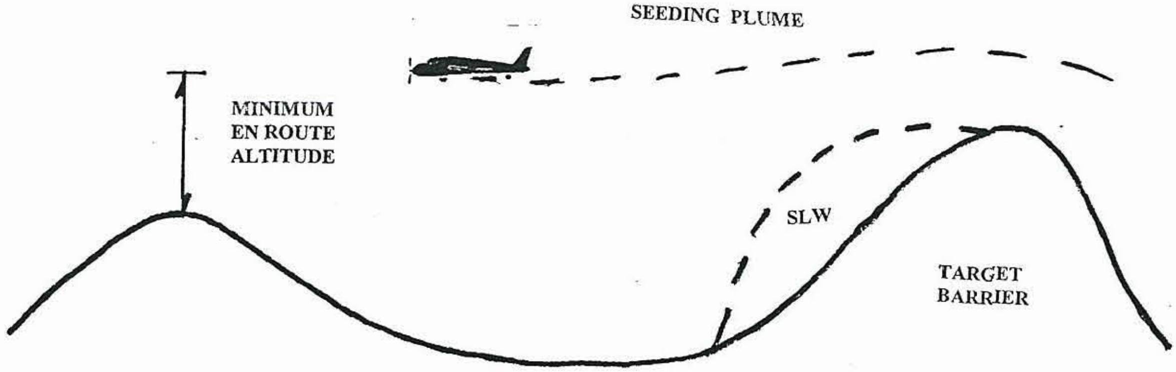


Figure 5.15 Schematic of Aircraft Seeding Upwind of a Mountain Barrier

turns in order to remain upwind of the target areas. The aircraft will typically be flying under IFR flight rules (in cloud) so the pilot cannot necessarily see the underlying terrain to make these maneuvers. The mountain barriers in the Intermountain West are typically rather narrow and there often are relatively close upwind barriers (i.e., separated by rather narrow mountain valleys). These situations may force the aircraft to fly at higher altitudes (to maintain terrain clearance) that may result in seeding plumes being generated above the SLW zone. Figure 5.15 illustrates this problem.

Aircraft seeding in winter storms is quite common in the Sierra Nevada of California. Primary factors in this area is that the upwind San Joaquin Valley (west of the Sierra) is quite wide and that the height of the freezing level in winter storms in this area is typically significantly above the valley floor. As a consequence, seeding aircraft can fly at about the 23^0 F (-5^0 C level), an effective flight level for silver iodide seeding due to the activation threshold of silver iodide being ~ 24.8^0 F (-4^0C), and readily descend to altitudes warmer than freezing to shed any ice build up without the requirement to land. Lower performance aircraft can be safely operated in this environment. The seeding is also likely to be effective since the aircraft may be flown at low enough altitudes that the seeding material will encounter the SLW pool well upwind of the barrier in time for the growth and fallout of augmented precipitation on the upwind side of the barrier. Physical studies of the silver plus tracer content of snow samples taken from one of the long-term target areas in the Sierra Nevada confirm that silver released from aircraft is found in a significant portion of these snow samples (McGurty, 1999).

5.6.8 Seeding with Rockets

The topic of seeding rockets was recently addressed in the second edition of Manual 81 published by the American Society of Civil Engineers (ASCE, 2006). The following is a quote from that publication:

> *Ground-based rockets and artillery shells loaded with silver iodide or some other seeding agent have been used extensively in several of the former Soviet Bloc countries and China on hail suppression programs. The projectiles are launched with directions from radar and targeted for the supercooled tops of the growing cloud elements. While these methods appear to offer the advantages of both ground and airborne delivery systems in some countries, they are costly and unacceptable for use in regions where there are numerous private or commercial aircraft operations.*

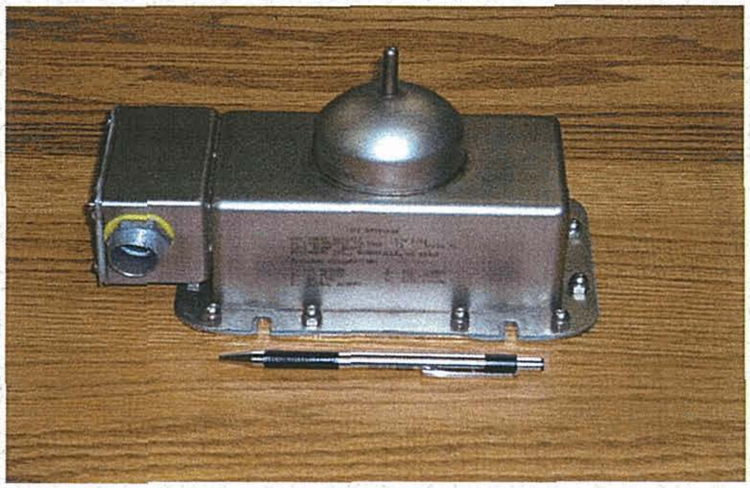
5.6.9 Summary

All of the information contained in sections 5.4, 5.5 and 5.6 was combined with specific considerations (e.g., topography, climatology) associated with the proposed target areas, to identify the recommended seeding agents and seeding modes which are provided in section 5.9.

5.7 Meteorological Data Collection and Instrumentation

Specialized types of equipment, data collection and instrumentation will be needed to conduct the cloud seeding program(s). The various types of equipment or observations will include seeding devices, means of communication, information and observations used in real-time to make seeding decisions and observations used after the fact in evaluations of the effectiveness of the seeding programs. Possible observational systems that will be considered include: microwave radiometers, icing rate meters, rawinsondes, program dedicated weather radars, cloud physics aircraft, and program specific precipitation gages. **There are three primary uses of or justifications for the addition of meteorological measurements or instrumentation: 1) such additions will assist in better targeting of the seeding material, 2) such additions will provide better real-time recognition of seeding opportunities, and 3) such additions will provide the means to help evaluate the effectiveness of the seeding operations.**

NAWC proposes that a phased data collection approach be adopted in the performance of this program. The goal will be to make critical observations early in the history of the program, which may later be discontinued or replaced with more basic measurement or prediction approaches. For example, one of the primary concerns regarding the conduct of a winter orographic cloud seeding program in a new area is the frequency, magnitude and location of supercooled liquid water upwind and over the barriers in question. We propose that a ground based icing rate meter be operated in each of the target areas (Figure 5.16 provides a photo of one of these units). Data from these icing rate meters provide point observations of supercooled liquid water. NAWC has previously used an icing rate meter installed at a mountain top location located east of Salt Lake City, Utah to study icing events at that location (Solak, et al, 2005), with interesting and useful results.



Ice Detector

Figure 5.16 Icing Rate Meter

A microwave radiometer could provide vertically integrated samples of the water content of the atmosphere from the surface to the top of the atmosphere but these radiometers are more costly than the icing rate meters. A microwave radiometer could be operated for one or two winters in association with ground based icing rate meters to determine how the degree of correlation between the two observational techniques. Figure 5.17 provides a photo of a portable microwave unit.

We also propose that program specific rawinsonde (weather balloon) observations be taken during storm periods during the first winter season of the program. Predicted soundings based upon some of the operational National Weather Service atmospheric models (e.g., NAM (ETA), GFS) would be obtained at 6- or 12-hour intervals for coordinates at or near the rawinsonde release site. The predicted soundings could then be compared with the actual sounding information to determine if the predicted soundings are providing information that is sufficiently accurate for direction of cloud seeding operations. If so, the program specific soundings could be discontinued in future seasons of operation.

Figure 5.17 Example of a Portable Microwave Radiometer

The need for program communications will be partially dependent upon the type of seeding methodology or methodologies that are adopted. For example, if both higher elevation remotely controlled generators and seeding aircraft were utilized, there would be a need for radio, cell phone or satellite links to the remotely controlled generators. Means of communication between the pilot of the seeding aircraft and the program meteorologist would also be needed (e.g., radio). Both situations may entail some form of licensing by the Federal Communications Commission.

A variety of public information and observations will be useful in the real-time decision making on these programs. Weather observations (surface and upper-air), weather forecasts, weather warnings, prognostic charts, satellite photos (both visible and infrared), NEXRAD radar displays and predicted or observed streamflow will all be utilized. Such information is readily obtained through the internet from a variety of web sites and is therefore available to the programs at no cost. Providers of this type of information include, for example, the National Weather Service (NWS) and the Natural Resources Conservation Service (NRCS).

The need for other additional program specific observations has been considered in other studies. For example, should additional precipitation gauges be installed in the potential target areas? One might think that installing additional precipitation gages in the cloud seeding target areas would provide a better means of evaluating the effects of the cloud seeding. This would be true if the program design called for randomization of the seeding treatment decisions as discussed in Section 7.3. The program design that we are recommending does not call for this randomization technique to be used since the program goals focus on maximizing the precipitation augmentation potential. As a consequence, we do not recommend that any additional program specific gages be installed. The reason that additional gages would not be useful in detecting effects of cloud seeding is that most of the precipitation episodes will be seeded. Consequently, there will not be any useful non-seeded data within the program target area to compare with the seeded data. There will be some non-seeded data but they will have built-in biases. The non-seeded events will be either very weak events with little or no seeding potential or perhaps very strong ones that are considered to have very limited seeding potential or are not seeded because seeding suspension criteria are exceeded.

Weather radars provide very useful information in terms of real-time decision making on operational cloud seeding programs. Radars that are installed specifically to support cloud seeding programs are more commonly used when cloud seeding aircraft are used on a program. This is especially true in the case of summertime programs where echo developments observed by the program meteorologist on the weather radar can be relayed to the pilot of the seeding aircraft. Such information can be useful in both identifying favorable areas for seeding as well as areas to avoid while flying (safety issues). The National Weather Service (NWS), through a modernization effort in the 1990's, installed a network of very sophisticated 10 cm wavelength weather radars throughout the U.S. These sites are known as NEXRAD (Next Generation Radar) installations. Each installation originally cost on the order of $1,000,000. Figure 5.18 provides a photo of a NEXRAD Installation. Figure 5.19 shows the array of these sites across the U.S. There are approximately 160 NEXRAD sites now in service. Each of the radars provides information on precipitation and wind speed and direction within the precipitation echoes. The radars step scans through up to 14 different elevation angles in a 5-minute period and a computer program integrates the stepped scans into a volume scan. Several very sophisticated algorithms then produce a large number of specialized displays and products from each volume scan. The maximum range for the detection of precipitation echoes is ~140 miles from each site. The NWS provides all the necessary support for these systems; operation, calibration, spare parts and maintenance. Because the NEXRAD network is important to NWS forecasting and public safety responsibilities, as well as many hydro meteorological applications and aviation safety, these radars enjoy high priority support and a resultant high degree of reliability.

There are three NEXRAD installations of potential usefulness to the conduct of the ESRBP. These sites are Pocatello, Idaho, Boise, Idaho and Salt Lake City, Utah. The Pocatello, Idaho site (actually located ~ 10 miles north, northwest of Pocatello) would provide good coverage over the intended target areas since these areas would be within ~ 65 miles (~105 km) of the radar site. The NEXRAD radars provide information out to ~144 miles (230 km), but the usefulness of this information declines beyond ~100 miles due to the curvature of the earth. The NEXRAD Boise and Salt Lake City radars will provide information on storms approaching from the west or south, which covers the common directions of storm movement in this area. NEXRAD data are available in near real time at approximately 5-6 minute intervals through a variety of internet web sites.

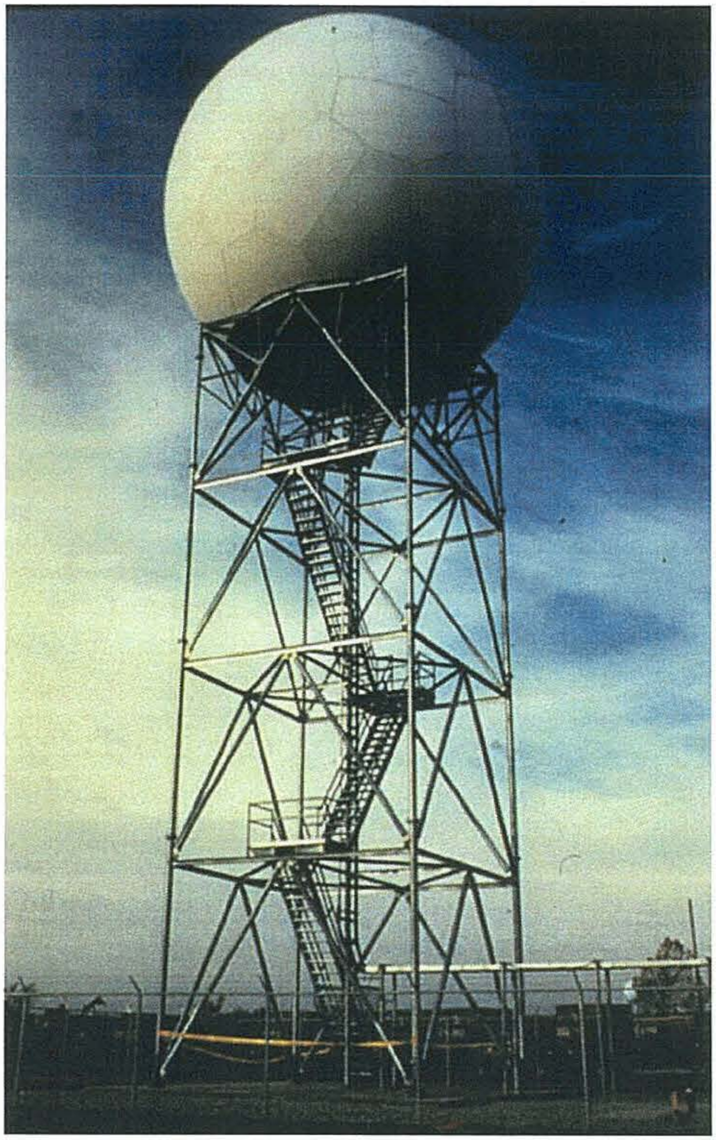


Figure 5.18 Photo of A National Weather Service NEXRAD Radar Installation
(Photo courtesy of the National Oceanic and Atmospheric Administration)

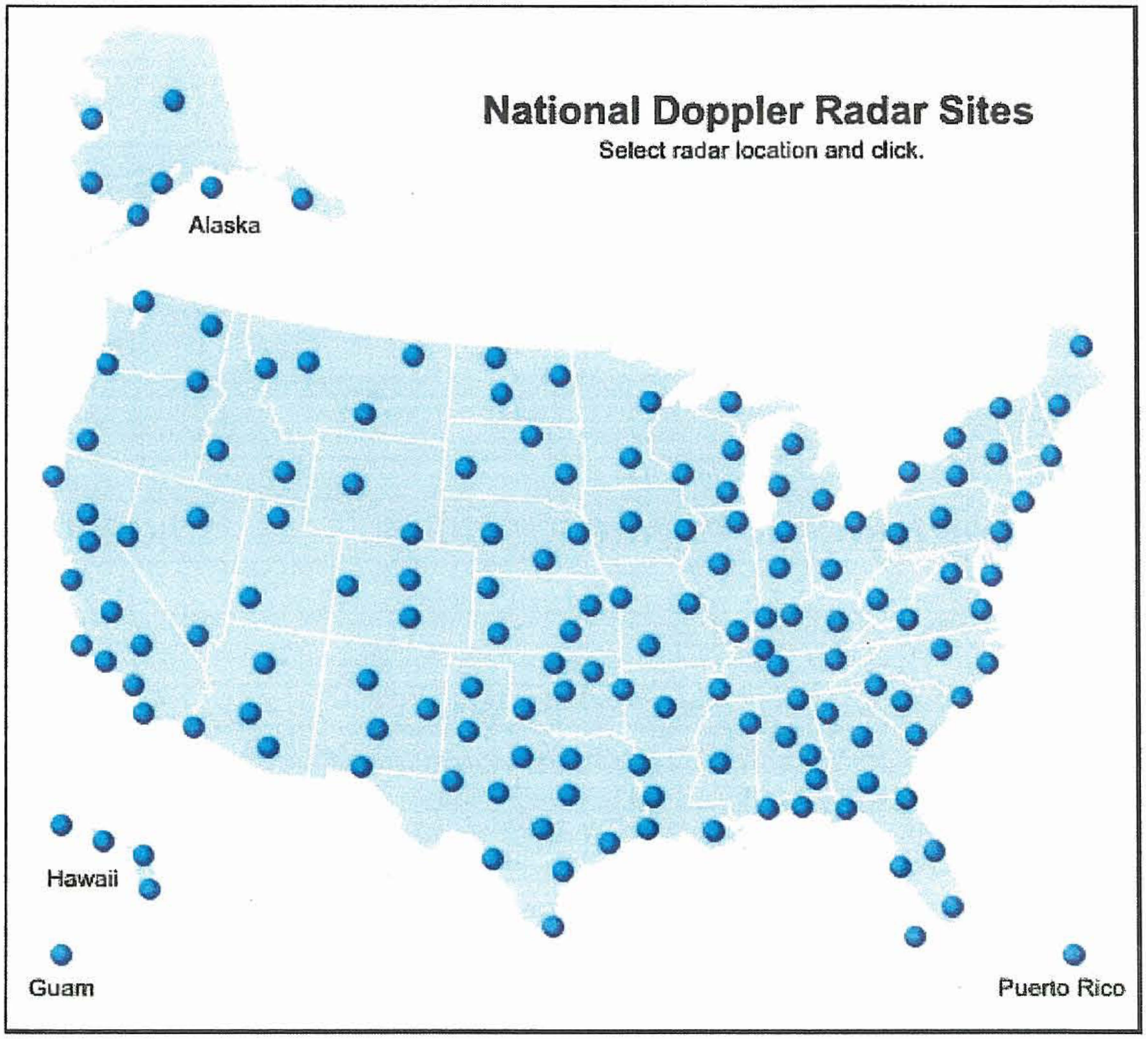


Figure 5.19 National Weather Service NEXRAD radar locations

NAWC has utilized the WeatherTap (commercial, subscription) web site extensively over the past several years to provide radar data for conduct wintertime cloud seeding programs. This web site provides a variety of useful products including: echo intensities (precipitation), echo tops, vertical profiles of wind speed and direction (the very useful VAD displays mentioned earlier) and composite echo displays that integrate radar returns from all of the 14 different elevation scans.

Given that good NEXRAD coverage is available for the proposed project areas, we do not think the additional cost of providing program dedicated weather radar is justified. This recommendation is based not only on a cost consideration but also upon actual experience in which NAWC has successfully used the NEXRAD radar at Vandenberg AFB, California to help direct a winter cloud seeding program for the Santa Barbara County Water Agency and at Hanford, California to help direct seeding operations for a winter cloud seeding program conducted for the Kings River

Conservation District. These programs utilize both ground based seeding equipment and a cloud seeding aircraft.

Since NAWC has indicated that a cloud seeding aircraft may be potentially useful in the conduct of the ESRBP (refer to Section 5.10), it is concluded that the Pocatello, Idaho NEXRAD weather radar would provide sufficient weather radar support to these airborne operations. Computer programs are available that can overlay the aircraft track on the most recent weather radar depiction from the Pocatello site. This combined information can be relayed to the aircraft pilot by the program meteorologist to provide seeding guidance and safety advisories. In addition, systems are also commercially available that can provide surface-based radar depictions for use in-flight by the seeding aircraft aircrew.

Public observations of potential use in post program assessments of seeding effectiveness will include NWS cooperator precipitation measurements, NRCS SNOTEL and snow course measurements and USGS streamflow measurements. Potential means of evaluating these programs will be discussed in section 7.0.

5.8 Personnel and Program Headquarters

The personnel needed to conduct this program and the location of the operations headquarters will be a function of the components of the final design. These needs will primarily be dictated by the seeding mode or modes selected for implementation. If the decision was made to conduct only a ground based seeding program, then the operations headquarters could be removed from the proximity of the target areas. In this scenario a qualified program meteorologist(s) would direct seeding operations and handle the logistics associated with the program. A technician living near the target area could be hired to perform installation, filling and maintenance activities associated with the generator networks. The situation would change if aerial seeding were utilized in conjunction with ground based seeding. In this scenario, an operations headquarters would typically be located at a suitable airport as close as possible to the target areas. A qualified program meteorologist(s) and a pilot or pilots would operate the field program from that facility. A technician(s) living near the target areas would also be needed if ground generators were used. As discussed in section 5.10.3, one possibility that appears to offer the various services that would make an airport suitable for this type of operation is located in Pocatello, Idaho. Should a combined airborne/ground-based seeding program go forward, a visit to this airport facility would be in order to insure that the appropriate types of support services are available.

5.9 Operational Period and Selection and Siting of Equipment

An operational period of November through March is recommended based upon the climatology of the area (refer to Section 4) and the likelihood of generating positive seeding effects during this period. Operations could be continued into the month of April.

NAWC recommends silver iodide as the seeding agent to be used in the conduct of the ESRBP program. We also recommend manually operated, possibly remotely operated, ground based generators and possibly airborne seeding (the use of the latter two seeding modes will be a function of their costs versus program benefits. We do not recommend that a program dedicated weather radar be used on the program, but do recommend that one season of rawinsonde observations be taken. The installation/operation of two ground based icing rate meters is recommended. The addition of a microwave radiometer for one winter season is also a possibility. We do not recommend the addition of any new precipitation gages in support of the program. The recommendations are discussed in the following.

5.9.1 Manually Operated, Ground Based Silver Iodide Generators

It is proposed that a network of ground based, manually operated silver iodide generators be installed for this program. Figure 5.5 provides a photograph of a generator of this type. These generators would be sited at local residences or ranches at which the residents agree to be trained in their operation. These residents would operate the generators as requested by the program meteorologist(s). The ideal sites will be those within the foothill areas on the windward sides of the mountain barriers. **Sites in the mouths of canyons have been shown to be especially favorable locations based upon research conducted in Utah (Super, 1999).** The ideal spacing between generators would be approximately 5 miles (8km), again based upon research conducted in Utah (Griffith, et al, 1992). These generators should burn an acetone/silver iodide mixture that results in the generation of fast acting ice nuclei. Research summarized by Finnegan (1988) documents some possibilities (e.g., acetone, silver iodide, sodium iodide and para-dichlorobenzene). Release rates should be in the 0.4- 0.9 ounces (10-25 grams) of silver iodide per hour range. Based upon the discussion in Section 5.4, fast acting nuclei are desirable in order to generate ice crystals as far upwind of the crest of the barriers as possible, in order to allow time for them to grow into snowflakes and fall onto the barrier.

The results of the climatology work in Section 4.2.3.2 suggest that the favored site locations would be southwest, west and northwest of the East target area and from south through west-northwest for the North target area. Establishing ground seeding sites in Montana to possibly affect the North target area is not recommended due to the stringent Montana cloud seeding permit process. Those cases with west-northwest flow at the 700 mb level in the north area could be of concern regarding targeting considering the restriction on placing ground generators in Montana and perhaps with airborne seeding as well. We compiled a wind rose for the surface observations at Dubois when the cloud top temperatures were > -26C and low-level stability was neutral (considered potentially seedable cases using ground generators as discussed in Section 5.10). This wind rose is provided in Figure 5.20. This figure indicates that the surface wind directions during seedable events are predominately from the south. This is a fortuitous situation since this information when considered in conjunction with the prevailing wind flow at 700 mb (predominately south-west to westerly) indicate that the seeding plumes produced from ground generators under potentially seedable conditions should initially travel north then veer towards the east as the seeding plumes are forced vertically upward to higher levels

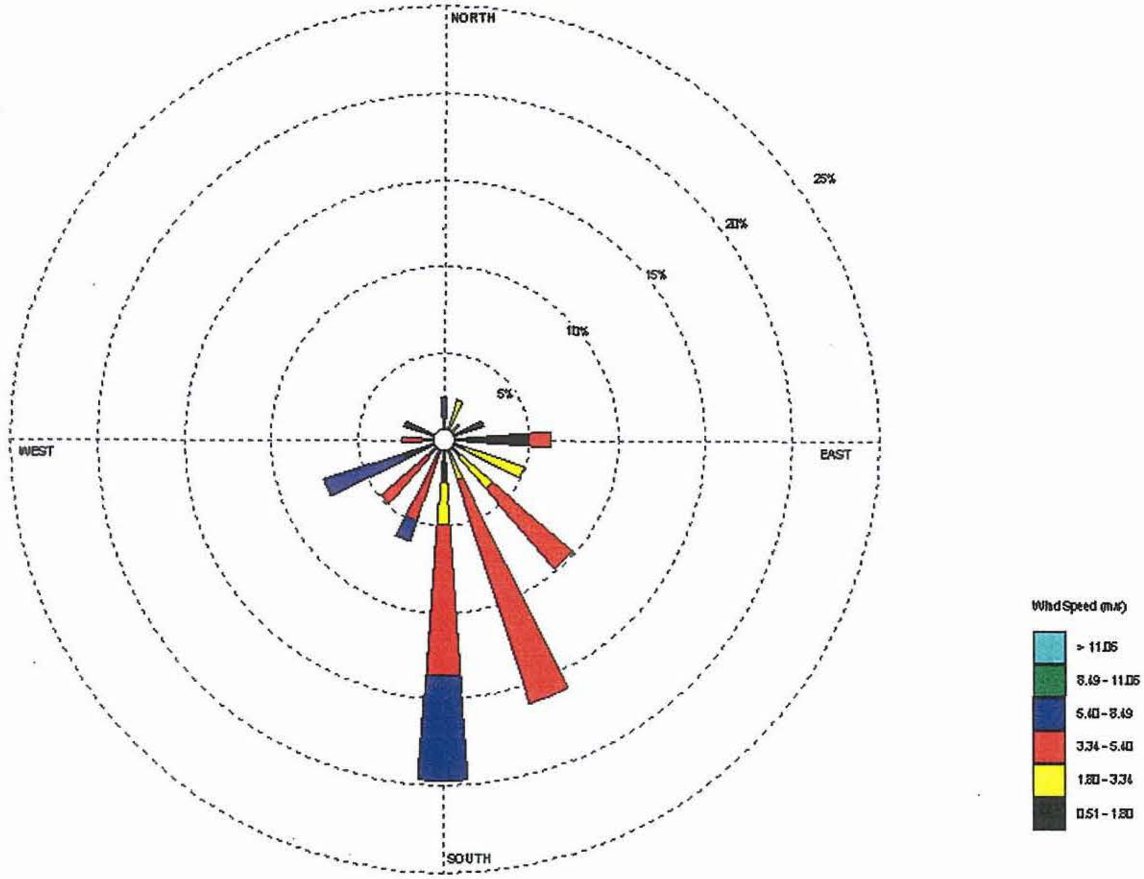


Figure 5.20 Surface Wind Rose for Dubois with Cloud Top Temperatures > -26C and Neutral low-level Stability

in the atmosphere where the westerly winds predominate. If airborne seeding is performed, flight levels would be near the –5 C level. This level will likely average somewhat below the 700 mb level based upon Figure 4.33. It is concluded that the winds at the –5 C level will likely be from the south-west which should generally allow for correct targeting of the majority of the North area using aircraft flight tracks located south of that target area (e.g., flights would be conducted over Idaho).

Figures 5.21 and Figure 5.22 provides some approximate locations for these manual generator sites. Approximately 17 generators would be installed to seed for the north area and 23 for the East area. If the decision is made to proceed with the ESRBP, site surveys will be necessary to locate suitable site locations with local residents willing to contract to operate the manual generators.

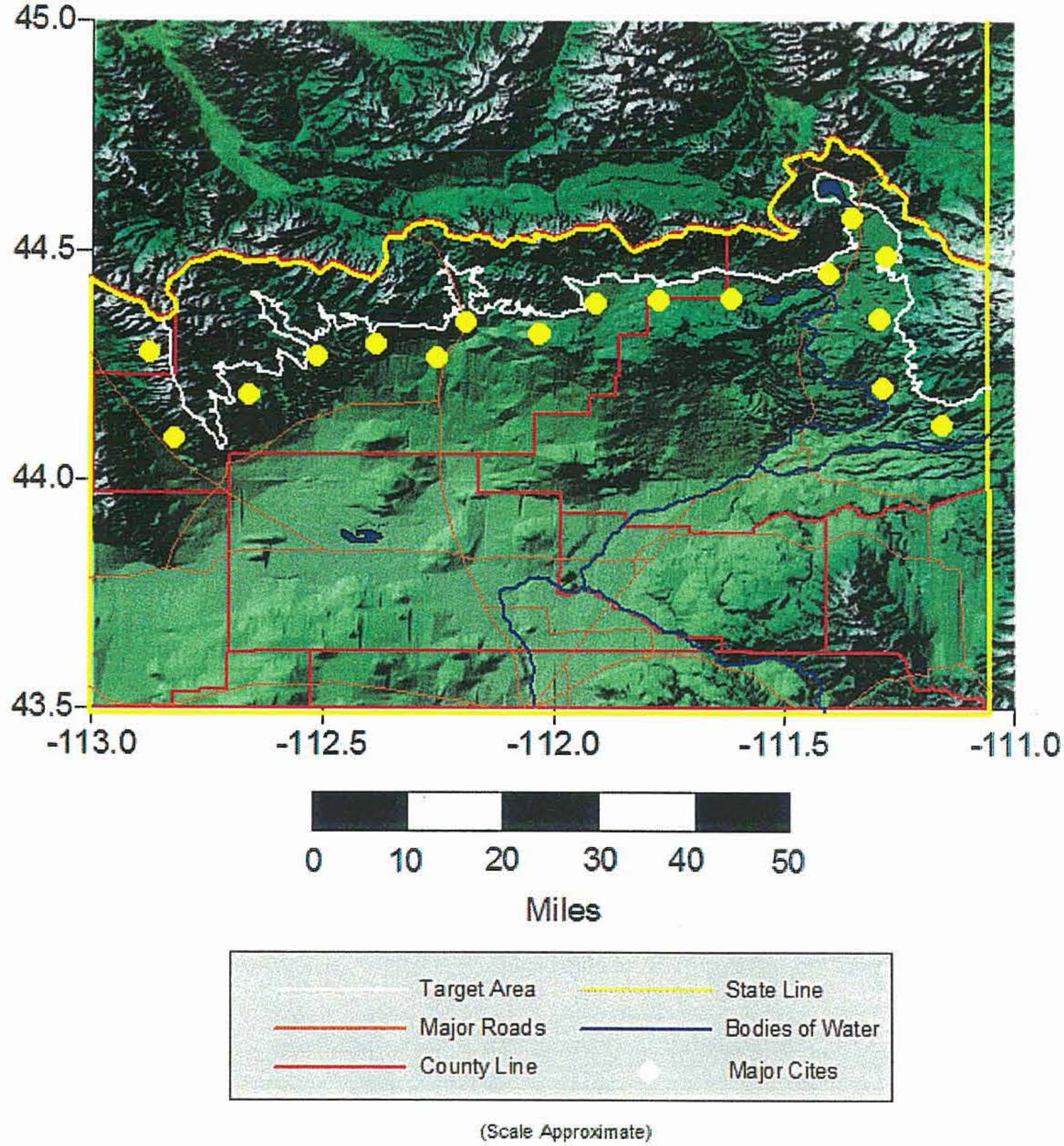


Figure 5.21 Approximate Locations of Manually Operated Ground-Based Generators, North Area

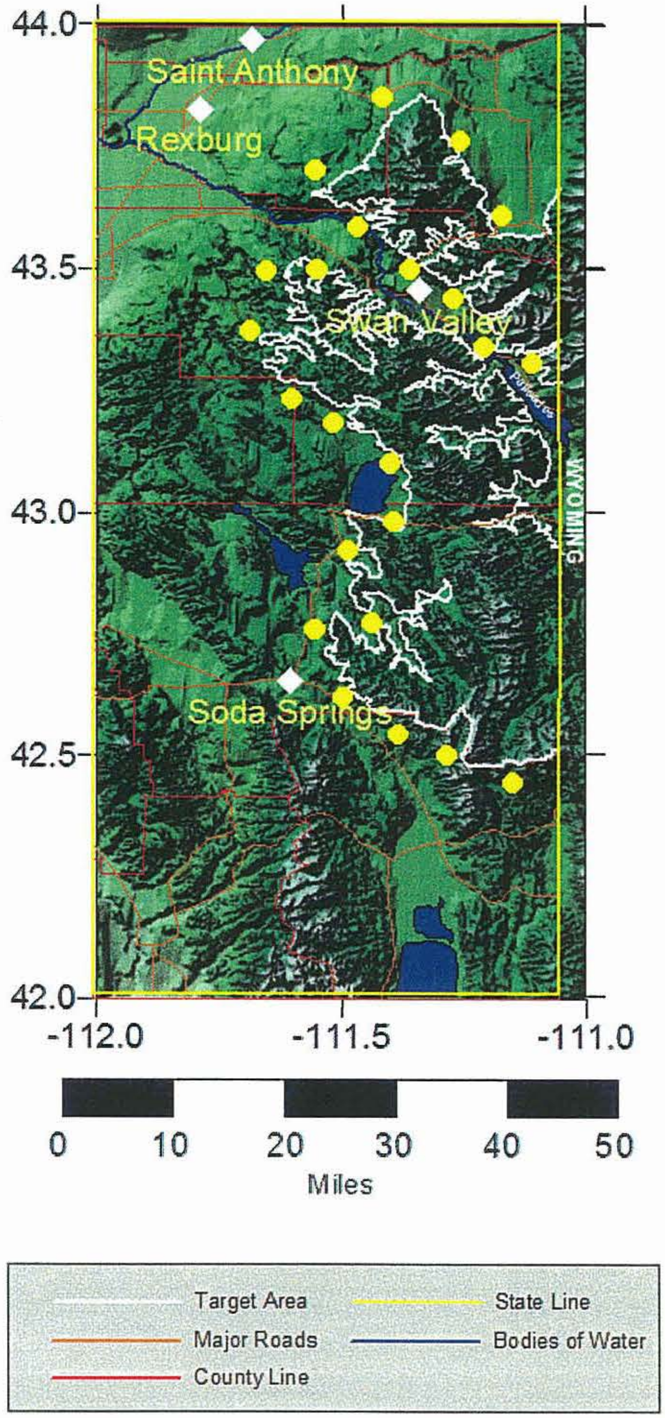


Figure 5.22 Approximate Locations of Manually Operated Ground-Based Generators, East Area

5.9.2 Remotely Controlled, Ground Based Silver Iodide Generators

Section 5.10 contains an assessment of the potential average seasonal increases in precipitation based on the three different cloud seeding modes: 1) manually operated ground generators, 2) remotely operated ground generators and 3) aircraft seeding. This assessment considers cloud top temperatures, low-level atmospheric stability and 700 mb temperatures during storm periods. This analysis only indicates a limited potential of increasing target area precipitation using remotely controlled ground generators (0.7% in the North area and 0.5% in the East area). As a consequence, and given the considerable expense and logistical considerations involved, NAWC does not recommend the use of remotely controlled ground based generators for the ESRBP.

5.9.3 Airborne Silver Iodide Seeding

The terrain upwind (west) of the potential East target area in southeastern Idaho is rather mountainous. There are a couple of mountain ranges such as the Blackfoot Mountains and the Gray's and Webster Ranges in this area. These mountains are not particularly high, however, being on the order of 7500-8000 feet (2.25 – 2.4 Km) with one isolated peak (Henry Peak) south of Wayan at an elevation of 8320 feet (2.55 km). The Outlet Valley, which lies between the Caribou Mountains (part of the target area) and the Blackfoot Mountains, might provide an area (especially in the northern portion) that would provide an area where seeding flights might be conducted at relatively low altitudes. Seeding aircraft flights would need to be conducted 2000 feet (610 m) above the terrain five nautical miles (9.3 km) either side of the flight path. The highest terrain elevation in the likely seeding area is Henry Peak which would mean that flights could generally be conducted down to altitudes of ~10,350 feet (3.15 km) MSL. Lower altitude fixed flight legs may be possible in the Outlet Valley area north of the Henry Peak area. The seeding material released at these altitudes may remain over the zones of supercooled liquid water that are depicted in Figure 5.1 as illustrated in Figure 5.15. If this were to happen routinely, there would be minimal if any increases in precipitation in the intended target areas due to airborne seeding.

The terrain south through south-west (upwind) of the proposed North target area is relatively flat and at relatively low elevations. The area west of this target area contains the Lemhi Range located west of the Beaverhead Mountains (which constitute part of the target area). The Lemhi Range has several peaks in the 10,000+ foot elevation range and one peak at an elevation of 12,197 feet (Diamond Peak). These peaks would mean that seeding flights would probably need to be conducted at altitudes of ~12,000 to 15,000 feet (3.65 – 4.6 km) when the winds at these flight levels are from the west to west-southwest. This again may place the seeding plumes above the SLW zone as depicted in Figure 5.15. Lower flight levels could be flown when the winds at flight levels are more southwest to south.

The seeding impacts would involve the rather complex interactions of several factors: 1) timing of the seeding material coming into contact with supercooled water droplets, 2) the speed at which ice nucleation occurs (a function of the type of seeding agent), 3) the growth rate of the ice crystals (a function of the ambient temperature), and 4) wind direction and especially wind velocities from the flight level down to the surface.

Perhaps the primary reasons that airborne seeding should be considered for the ESRBP program are related to the following two issues:

1. How frequent are low-level atmospheric temperature inversions in the Outlet and adjacent river valleys during active storm periods? Section 5.2.3.4 contains some information on this topic, but it is based primarily upon reanalysis data from NCEP and is lacking any actual sounding profiles. There are, however, surface reporting weather stations in the area that can provide some indirect indications of the presence of low-level inversions (this topic is addressed in Section 5.10). The concern is that low-level inversions could prevent the transport of seeding materials released from the ground into the supercooled liquid droplet regions upwind of the mountain barriers. Aircraft seeding under these conditions may be beneficial, but only if the two concerns noted above are not a factor in these situations.

2. Aircraft seeding may be conducted when the temperatures near crest level are too warm for silver iodide released from the ground to be effective. In other words, the aircraft can be flown at or near the -5^0 C level in these storms, assuming there is liquid water present at these altitudes, thus having the potential for augmenting the natural snow fall in the target areas.

The importance of the first aircraft advantage scenario noted above is difficult to assess without having some actual temperature profile data from one of the valleys (probably the Outlet Valley and/or the area north of Kilgore). This issue, in part, led us to the recommendation that representative rawinsonde data be collected in/near the project area for one winter season as described in section 5.2.3.4.

The second question or issue (suitability of temperature near or just above crest height) was examined using some of the climatological information developed for storm periods as described in Section 5.2. Analysis of 700-mb temperature data, representative of temperatures just above crest levels, showed temperatures warmer than –5 C 20% of the time for all of the threshold precipitation events examined, and about 15% of the time for the November – through March period. These are cases where aircraft may be more suitable for seeding than either type (manual or remote) of ground-based seeding equipment. This is because, under these conditions, orographic lifting alone is unlikely to transport seeding material into effective temperature zones in these cases.

The types of aircraft used in the conduct of cloud seeding programs vary depending upon the seeding modes selected, the time of year and safety considerations. For the ESRBP program, if aircraft seeding is to be conducted, we recommend that turbine engine aircraft (e.g., Cheyenne II's) be used. This recommendation is based primarily on aircraft performance as it relates to safety considerations. As discussed in Section 5.6, if the aircraft were to encounter extreme icing conditions, it could not descend to altitudes warmer than freezing to shed the ice due to the frequency of sub-freezing temperatures to the surface. As a consequence, the seeding aircraft requires ample power to operate safely for adequate durations under such (airframe icing) conditions. Turbocharged, piston engine aircraft may not have sufficient power to operate safely for an extended period under these conditions. The aircraft should be equipped with a basic data collection package that would record: location, altitude, time of seeding equipment operation, temperature and supercooled liquid water content. Some of this information will be useful in both real-time to make seeding decisions as well as in post operations assessments of seeding operations.

Potential bases of operation for the aircraft would include airports at Pocatello, Idaho, Idaho Falls, Idaho and Jackson, Wyoming. The more suitable airports are those that are manned for significant portions of each day (including weekends), have good navigational aids including instrument approach capability, have an adequate length of runway, have lit runways at night, have aircraft maintenance services available, and have 24 hour fueling services available. Airports with control towers offer an additional attraction for basing aircraft operations at these locations. Another consideration is the location of the airport in relation to the normal flight operational areas. All things being equal, the airport closest to the operational area would be preferred since there will be less ferry time involved. NAWC recommends that if this program goes forward and seeding aircraft are utilized, that the contractor who is awarded the work has the flexibility to select the airport from which to base operations.

5.9.4 Supercooled Liquid Water Observations

As mentioned in section 5.7, NAWC recommends that two ground-based icing rate meters and possibly a microwave radiometer be installed for the first operational winter season. It is desirable to locate the radiometer at a location at which the temperature during storm periods is below freezing. Such a location removes the confounding effects of water droplets warmer than freezing being included in the observations, since these droplets are not viable targets for cloud seeding using silver iodide as the recommended seeding agent.

NAWC's experience has been that the simplest location at which a surface based icing rate meter can be installed is one at which other weather parameters of interest (temperature, wind direction and speed and precipitation) are already being measured and recorded. A prime example of such locations is ski areas. A field survey may be needed to identify potentially useful location.

5.10 Estimates of Seeding Effects

The RFP requests "estimates of the additional water that could be provided by the snowpack augmentation program, provided in terms of acre-feet of surface runoff by watershed." There are two steps that need to be accomplished in providing these estimates. The first step is to estimate the impact of cloud seeding on precipitation in the target areas. The second step is to convert these estimated increases in precipitation into estimates of increases in streamflow. The approach used to accomplish the first step is discussed in this section. The approach used to accomplish the second step is discussed in the following section.

Developing quantitative estimates of the effects of seeding presents a challenge, but is a necessary step in order to have any hope of developing reasonable estimates of increases in streamflow. The use of a range of potential increases in precipitation, probably expressed as percentage increases and the resultant additional quantities of precipitation (e.g., 10-15% increases amounting to an extra 1.0 to 1.5", 2.5- 3.8 cm) of precipitation), may offer the best approach. The technique used to develop these quantitative estimates is described in the following section. We feel the best estimates of potential increases from winter snowfall augmentation programs can be derived from previously conducted research programs in similar geographical and climatological settings.

A detailed analysis of storm periods affecting the target area was conducted for a 5-season period (water years 2003-2007) for the October-April season. Precipitation data from several SNOTEL sites were considered, and six-hour time blocks were selected when precipitation was clearly occurring in the target areas. As previously mentioned, the target area was divided into two sections, a North area and an East area. Data from two SNOTEL sites (Pine Creek Pass and Sheep Mountain) were considered for the East area, and from three SNOTEL sites (Crab Creek, White Elephant and Island Park) for the North area (locations of these sites were provided in Figures 5.3 and 5.4. The SNOTEL data ranged from hourly to six-hours in resolution and were obtained from the Natural Resources Conservation Service (NRCS).

There is always a question when performing detailed analyses of meteorological data over rather short time periods (in this case five winter seasons) of whether the results are correct for longer time periods? In other words, are the results representative of the climatology of the area? Table 5-2 provides information on the percent of normal values of April 1st snow water content for a representative SNOTEL site in each of the two potential target areas. This table indicates that four of the five water years were less than normal and one was above normal. The percent of normal amounts were lower for the East area than the North area in three of the four dryer than normal water years. This information indicates that our five-season sample period may underestimate the number of winter storms that impact these areas over the longer term. Consequently, there could be impacts on some of the other results that are provided in the following (e.g., seeding potential estimates) but there is no way to determine the possible magnitude of these effects. The five seasons were selected based upon the availability of NRCS hourly to six-hourly precipitation data combined with the availability of the NCEP reanalysis data.

Table 5-2

April 1 Snowpack Percent of Average for the Five Winter Seasons Selected for Detailed Analyses

Water Year	White Elephant (N)	Pine Creek Pass (E)
2003	66%	78%
2004	92%	74%
2005	91%	74%
2006	127%	129%
2007	66%	69%

The 6-hour periods selected roughly correspond to available National Center for Environmental Prediction (NCEP) reanalysis data, from which vertical sounding profiles were created. These profiles are available for selected points (a grid with 2.5 degree resolution). One of these points was selected for proximity to the East target area. It is located south of Pocatello (42.5 N, 112.5 W,) and another area located in southwestern Montana (45.0 N, 112.5 W) was used to represent conditions in the North target. Figure 5.23 provides the locations of these two points, plus the locations of the three surface meteorological reporting stations used in the stability analyses (discussed in the following paragraph). These soundings were used to derive temperature and wind data at the 500- and 700-mb levels, which are at approximately 18,000 and 9,500 feet MSL. The soundings also provided moisture (dewpoint) values, and some general information on low to mid-level atmospheric stability. Estimates of the -5^0 C isotherm height and estimated cloud-top temperature were developed based on these sounding profiles as well.

Although useful in many respects, the reanalysis sounding profiles provide a rather crude dataset with poor resolution. Even though the sounding profiles contain data for the 850-mb (approximately 5,000 feet MSL or near-surface) level, the low-level data tend to be poor in mountainous regions such as Idaho because of sharp low-level variations in the weather due to terrain, etc. Because of this, surface data (temperature, wind and dewpoint) were also utilized in conjunction with the sounding profiles to obtain better estimates of low-level stability issues and wind patterns. After examination of the availability and quality of surface data, three sites were utilized. For the East area, one suitable site was found (Wayan, WYNI1, at 6391' elevation) to represent potential areas for ground-based seeding. For the North area, two sites (DUB, Dubois, at 5465' and Three-Mile, THMI1, at 6625') were utilized. These data were obtained through the MesoWest observation network maintained by meteorology staff at the University of Utah. The availability of data at these two sites helped in making estimations of the presence and depth of any inversion/stability layers that may affect seeding from ground-based sites in the upper Snake River Basin. Low-level stability (which could prevent seeding material from reaching the -5^0 C level over the target areas) was classified into

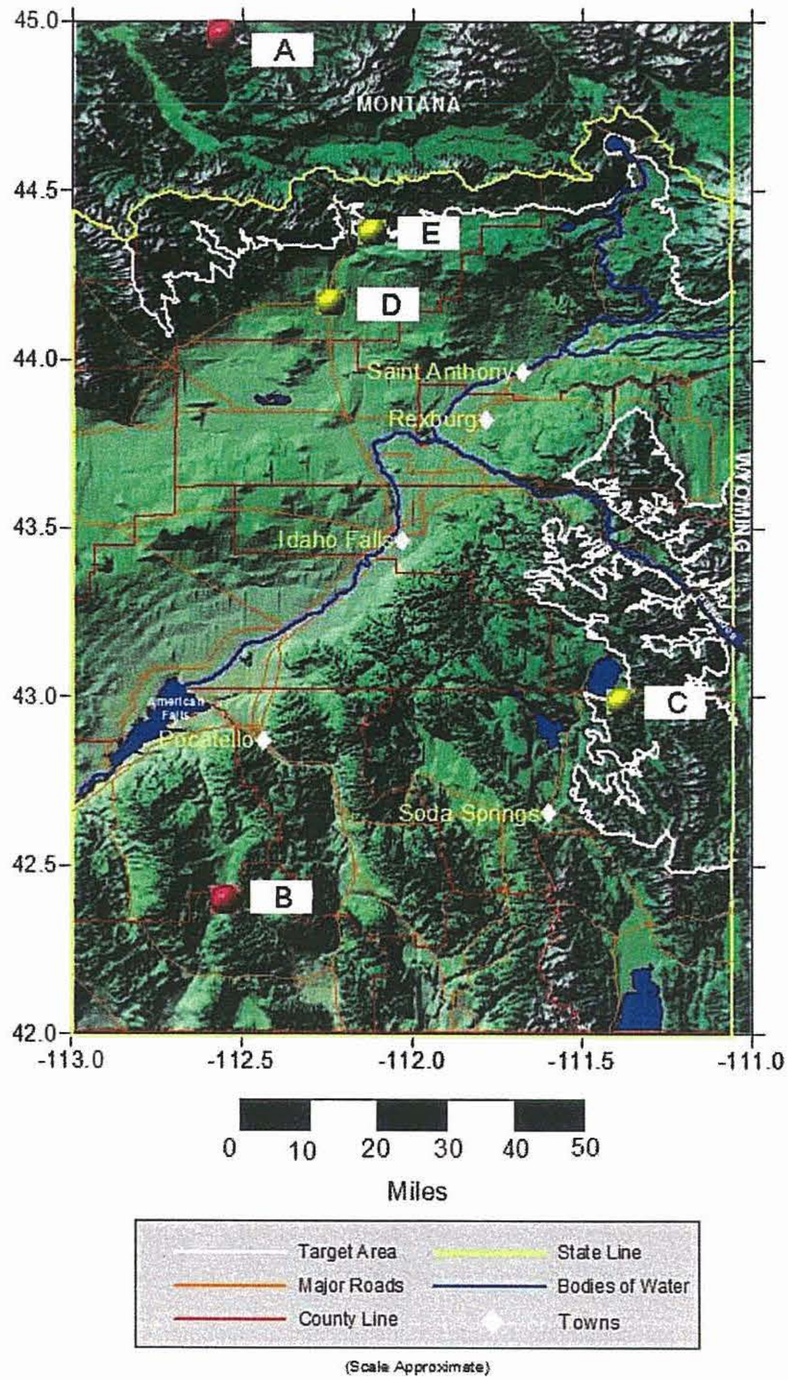


Figure 5.23 Reanalysis sounding points (A and B), and surface observation sites (C-E) used in atmospheric stability analyses.

four categories: well-mixed (no stability problems evident), slightly stable, moderately stable, and very stable. These categories correspond roughly to situation when less than 2^0 C of surface heating would be necessary to mix out the atmosphere (slightly stable), 2-4^0 C (moderately stable), and more than 4^0 C (very stable). Cases that were well-mixed or slightly stable were considered suitable for ground-based seeding, while more stable cases would require remote high-elevation or aircraft seeding.

During the October through April period, there were 170, 6-hour periods identified and analyzed for the North area, and 239 periods for the East area. There was approximately a 40% overlap in these identified time periods for the two proposed target areas, suggesting significant meteorological differences in precipitation patterns and the timing of storms between the two areas. In other words, storm periods with significant precipitation rates appear to only affect both the North and East areas 40% of the time.

We used the results from a well-known, randomized research program conducted in the Climax region of the central Colorado Rocky Mountains in two phases, Climax I (1960-65) and Climax II (1965-70) (Mielke, et al, 1980) to estimate the potential seeding effects in the ESRBP program. These experiments utilized ground-based releases of silver iodide in 24-hour treatment periods. The detailed statistical analyses indicated that precipitation was increased by 25%-41% (depending upon whether a single or double ratio analysis was used) when 500mb (approximately 18,000 feet) temperatures were in the -4^0 to $+12.2^0$ F (-20^0 C to -11^0 C). These results were statistically significant at the .05 level. Other reports on the two Climax programs indicated positive effects of seeding at 500mb temperature ranges of ~ -5.8^0 to -14.8^0 F (-21^0 to -26^0 C). One report (Hess, 1974) indicated approximately 10% increases in this 500mb temperature range. NAWC used this information to derive an estimate of the possible seeding increases in the ESRBP as discussed in the following.

The 500mb analysis of Climax I and II contains a very important assumption: that the 500 mb temperature level approximates the height of the effective cloud tops. The theory is that ice crystals produced near the tops of stratiform winter clouds may descend through the cloud and "seed" it naturally. It has been established that the natural ice nuclei in the atmosphere become increasingly active as the ambient temperatures decrease. As a consequence, clouds that have cold tops are normally naturally efficient in producing snowfall that reaches the ground. In other words, the Climax results suggest that the clouds in this area are efficient once their top temperatures reach -17^0 F (-27^0 C) or colder. Grant and Elliott (1974), when discussing the Climax research programs use of the 500 mb level to approximate cloud top heights, make the statement "Undoubtedly, this pressure height is not representative of cloud top temperatures over many other mountain barriers".

We decided that we should examine this question of whether the 500 mb height represents the cloud tops in the proposed ESRBP target areas. Cloud-top temperatures were used in an alternative analysis to the 500-mb temperature evaluation, in order to try to address the issue more directly. For each 6-hour time block in the five-season detailed analysis, the NCEP reanalysis sounding profile was analyzed to obtain important temperature, moisture, and wind data. An attempt was made to estimate the cloud-top temperature for the cloud layer at or immediately above crest height of the proposed target areas. Higher cloud layers separated by significant dry layer(s) were not considered, as any precipitation would be expected to evaporate during its descent through the dry layer(s), and therefore not seed the lower layer(s). Once these estimates of cloud top heights and temperatures were completed for the five-season period, the results were plotted versus the associated 500 mb temperatures (Figures 5.24 and 5.25). It is obvious from these figures that the 500 mb level is <u>not</u> a good approximation of cloud top temperatures for the ESRBP area. We therefore decided to focus on the use of the cloud top temperature data set to provide alternative estimates of the potential seeding increases in the Upper Snake River Basin. We performed an analysis of the percentage of the six-hour events that had cloud top temperatures in a "seedable range of -5^0 to -25^0 C based upon the Climax I and II results. The lower limit of -25^0 C is similar to indications of seedable conditions in northern Utah (Hill, 1980 b) and northern Colorado (Rauber and Grant, 1986) both of which estimared seedable conditions with cloud top temperatures of -22^0 C or warmer. Figures 5.26 and 5.27 provide plots of this information for the North and East areas. These figures indicate that a seeding potential would exist in only approximately 38% of the cases, due to cold cloud top temperatures; temperatures $< -26^0$ C in the remainder of the cases.

The basic seeding potential during six-hour periods that occurred **from November through March** was calculated using results from Climax I and II studies in Colorado, except that cloud-top temperature was utilized instead of 500-mb temperature (the month of October was excluded due to limited snowpack accumulation during this month and relatively warm temperatures at the 700 mb level). The seeding potential was considered to be +25% when cloud-top temperature was between -5^0 C and -20^0 C, +10% for cloud-top temperatures of -21^0 to -25^0 C, and 0% for cloud-top temperatures of -26^0 C or colder (or warmer than -5^0 C, although no such cases were identified in this analysis). This seeding potential was then sub-divided between different seeding modes or methods, including manual ground-based, remote ground-based, and aircraft seeding. The seeding potential for a given time period was delegated to ground-based seeding if a) the low-level air mass was well-mixed or slightly stable, and b) The 700-mb temperature was –5 C or colder. Similarly, the seeding potential was delegated to remote, high-elevation seeding sites if low-level stability was classified as "moderate" or higher and the 700-mb temperature was -5^0 C or colder. Seeding potential was counted as aircraft-only for cases where the 700-mb temperature was above -5^0 C regardless of stability considerations. These divisions are summarized in the following:

The assumptions made to accomplish this stratification were:

<u>For lower elevation manually operated silver iodide generators</u>

1. The low level atmospheric stability (surface to the 700 mb level) was neutral or slightly stable.
2. The 700 mb temperature was $\leq -5^0$ C, 23^0 F.

<u>For higher elevation remotely operated silver iodide generators</u>

1. The low level atmospheric stability was moderately or very stable
2. The 700 mb temperature was $\leq -5^0$ C, 23^0 F.

<u>For Aircraft silver iodide seeding</u>

1. The 700 mb temperature was $> -5^0$ C, 23^0 F.

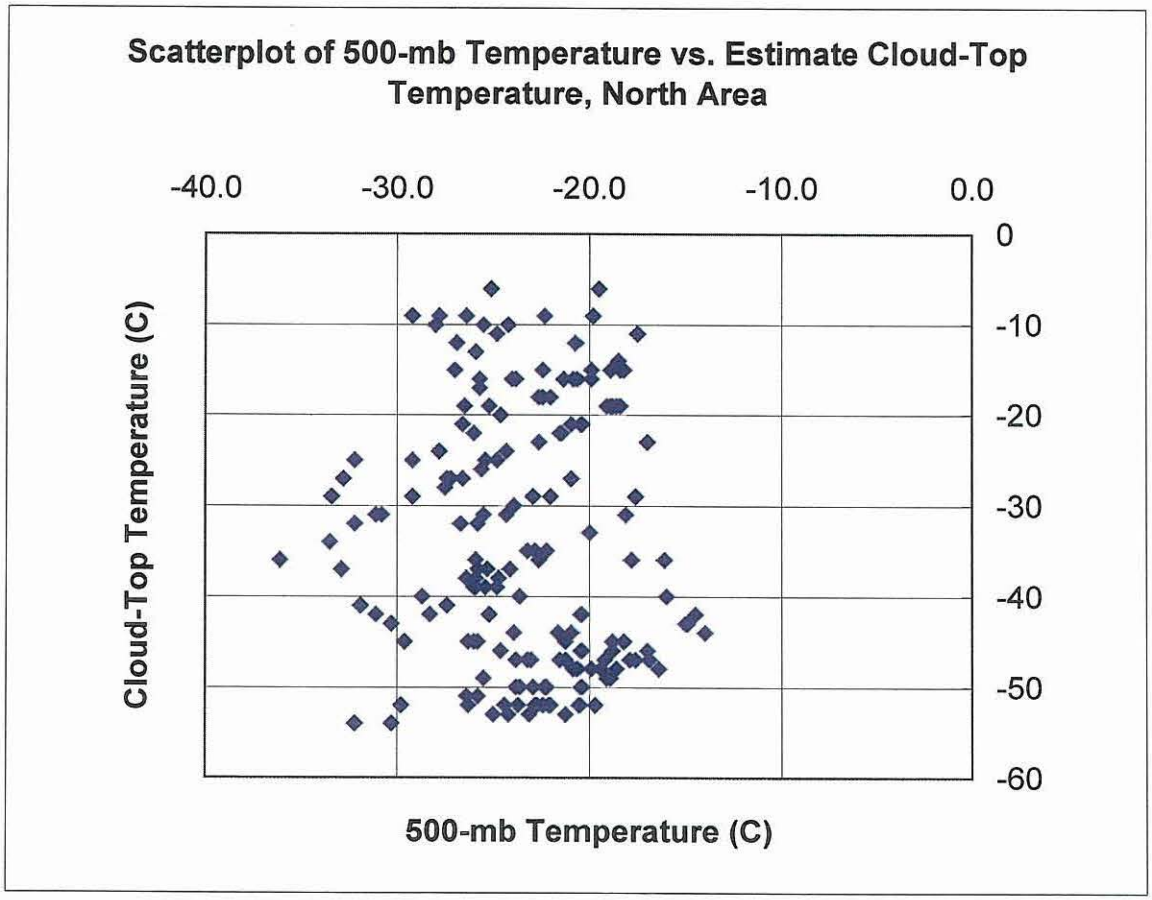


Figure 5.24 Estimated Cloud Top Temperature vs. 500-mb Temperature for Storm Periods, North Area

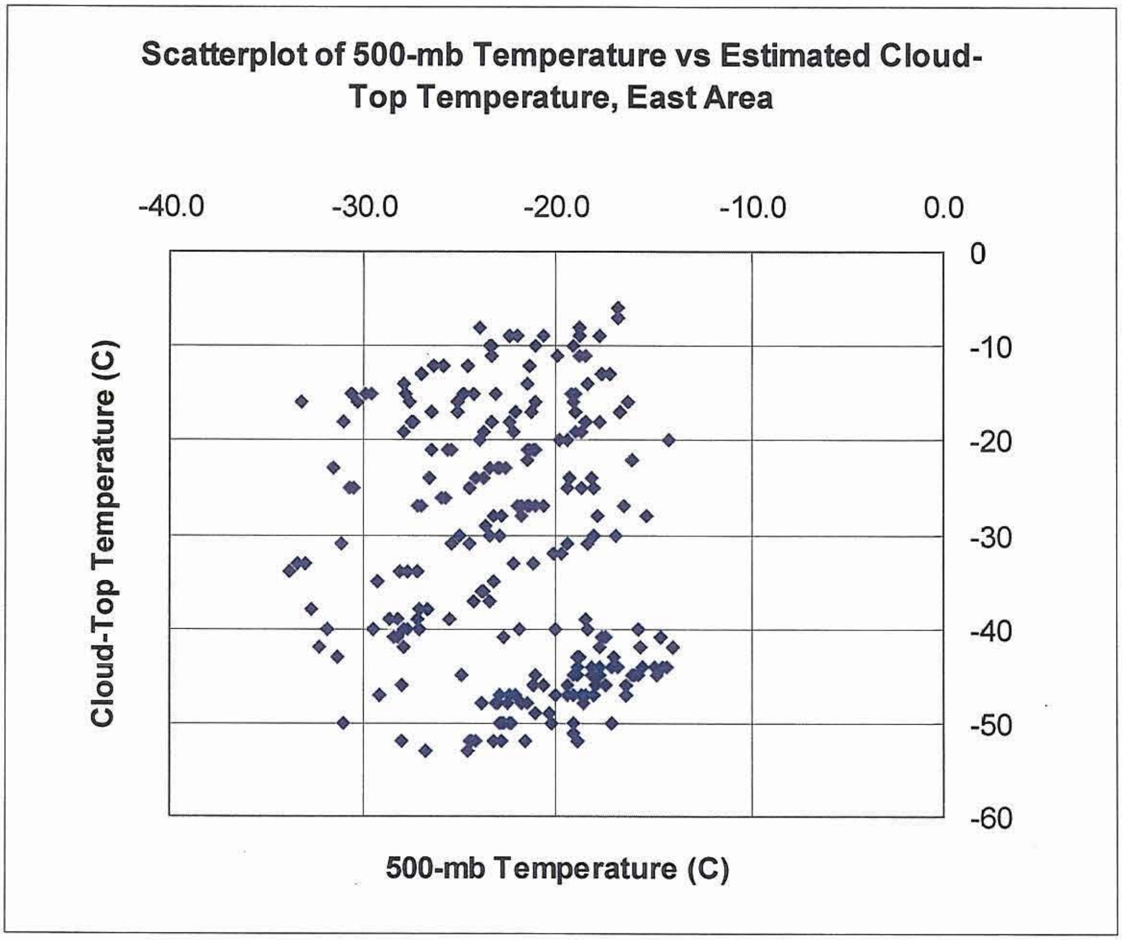


Figure 5.25 Estimated Cloud Top Temperature vs. 500-mb Temperature for Storm Periods, East Area

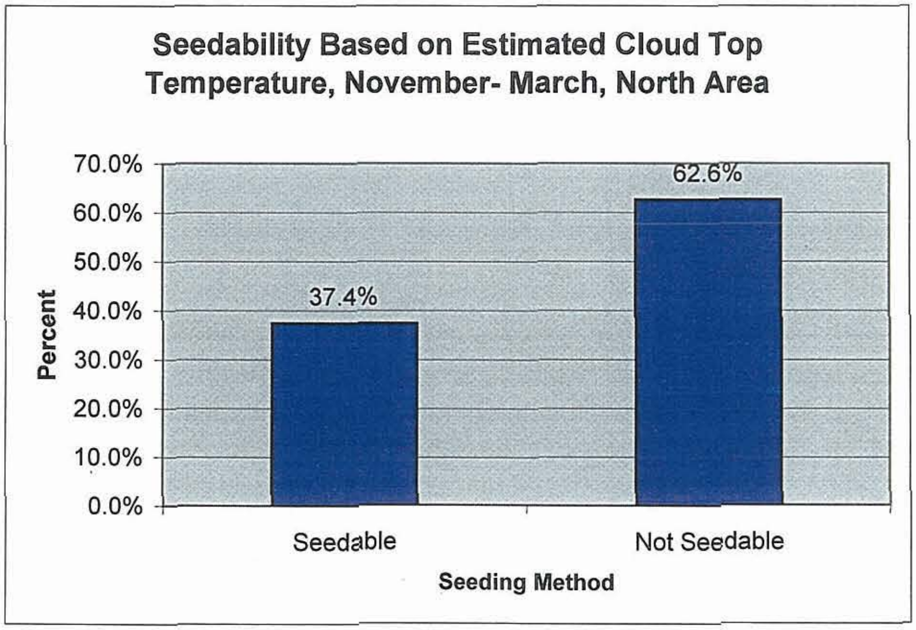


Figure 5.26 Seedability of 6-Hour Periods in Detailed Analysis Based on Estimated Cloud Top Temperature, North Area

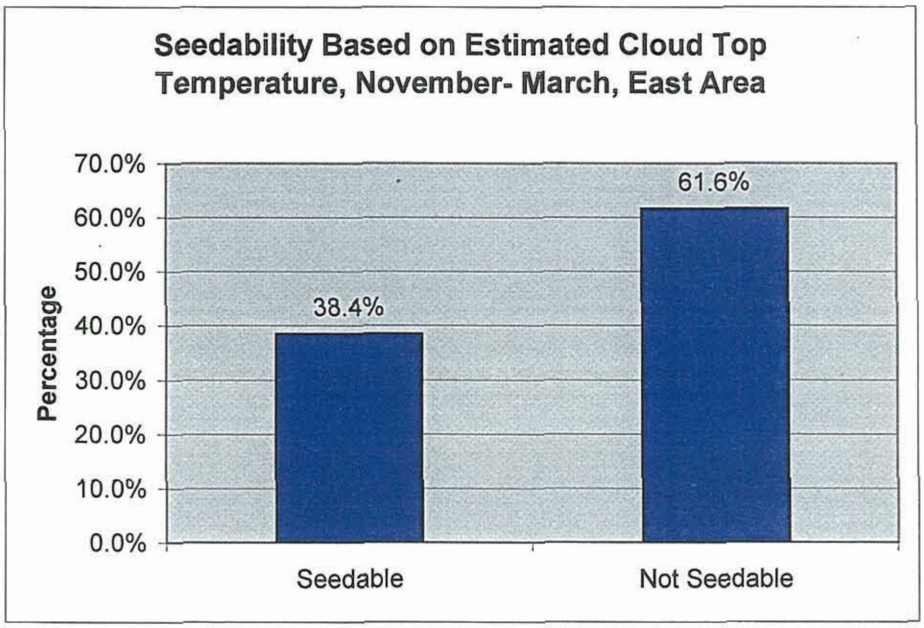


Figure 5.27 Seedability of 6-Hour Periods in Detailed Analysis Based on Estimated Cloud Top Temperature, East Area

High elevation remote generators might be used in conditions classified as seedable using lower elevation, manually operated generators, although some of the concerns like those depicted in Figure 5.14 would still apply. We, however, decided to start with the least expensive (or most economical), yet effective technology first (manually operated generators). Aircraft seeding could be used under most conditions (an example of a situation that might not be seedable with aircraft are very shallow clouds), but our focus for any potential aircraft seeding is in situations that probably could not be effectively seeded using ground generators of either type.

The potential seeding increases from the Climax program (10% or 25%) were applied to the average November – March precipitation measured at the corresponding SNOTEL sites during the appropriate 6-hour period, and then were summed for the entire 5-season data set for each seeding method. Figures 5.28 and 5.29 provide the estimated percentage of the "seedable" cases that would potentially be seedable (based on cloud top temperatures, lower-level atmospheric stability and 700mb temperatures criteria discussed in the above) using the three different seeding modes (manual ground generators, remotely controlled ground generators and aircraft).

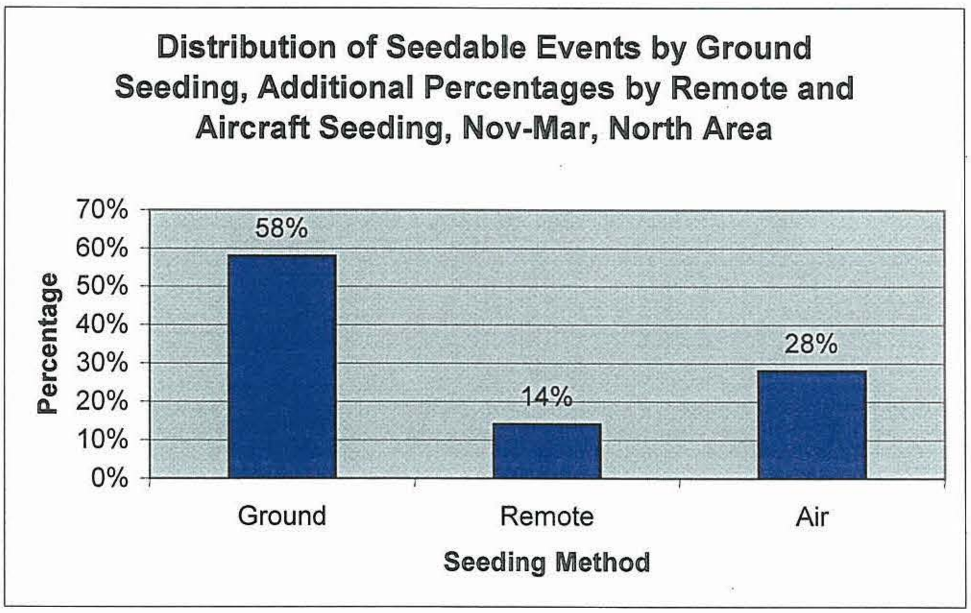


Figure 5.28 Estimates of Percentage Increases for Seedable Cases Partioned by Seeding Mode, North Area

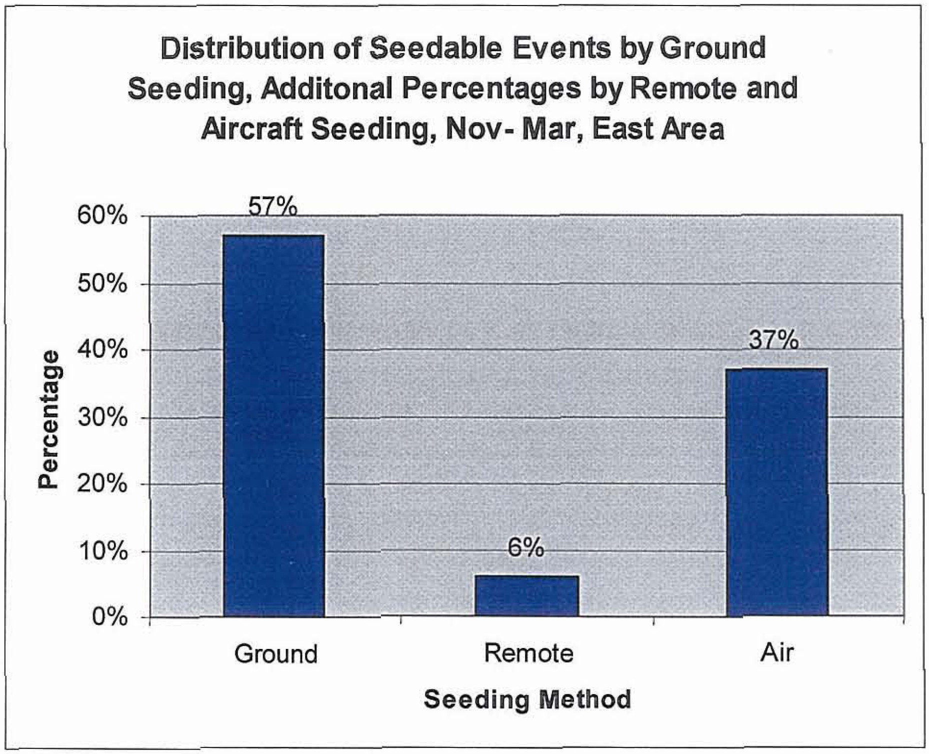


Figure 5.29 Estimates of Percentage Increases for Seedable Cases Partitioned by Seeding Mode, East Area

Figure 5.28, for the North area, provides estimates that 58% of the "seedable" cases would be seedable using manual ground based generators, 14% using remotely controlled ground generators and 28% using airborne seeding. Similar numbers for the East area are 57%, 6%, and 37%. This would imply that the use of remotely controlled ground generators to seed for the North area might be worthwhile, whereas it does not appear very practical for the East area. Aircraft seeding appears potentially feasible in both areas.

Finally, the estimated increases for the November – March period for each method were divided by the total precipitation (for the storm periods under analysis) for each target area to obtain estimated percentages for each seeding mode. Figures 5.30 – 5.31 provide the results. **For the North area the estimated average precipitation increases for November through March precipitation are 3.0 % using manual ground generators, 0.7 % using remotely controlled ground generators and 1.8% using aircraft seeding. Similar information for the East area is: 3.9 %, 0.5 % and 3.2 %. On the basis of this information it is tentatively concluded that:**

- **A program could be run only using manually operated ground based generators to potentially achieve a 3.0 % average increase in the North area and a 3.9 % average increase in the East area. This might be considered as a "core" seeding program which would be the least costly type of operation.**

- **Based upon the percentages of potential increases, it does not appear that the use of remotely controlled, ground-based generators is warranted, at least from a benefit/cost perspective**

- **To optimize seeding effects, a program utilizing both manually operated ground generators (the core program) and a seeding aircraft could potentially achieve a 5.5 % increase in the North area and a 7.6 % increase in the East area. The aircraft could seed in conditions where remotely controlled ground generators might be used, so the remotely controlled estimated increases have been included in the aircraft estimates.**

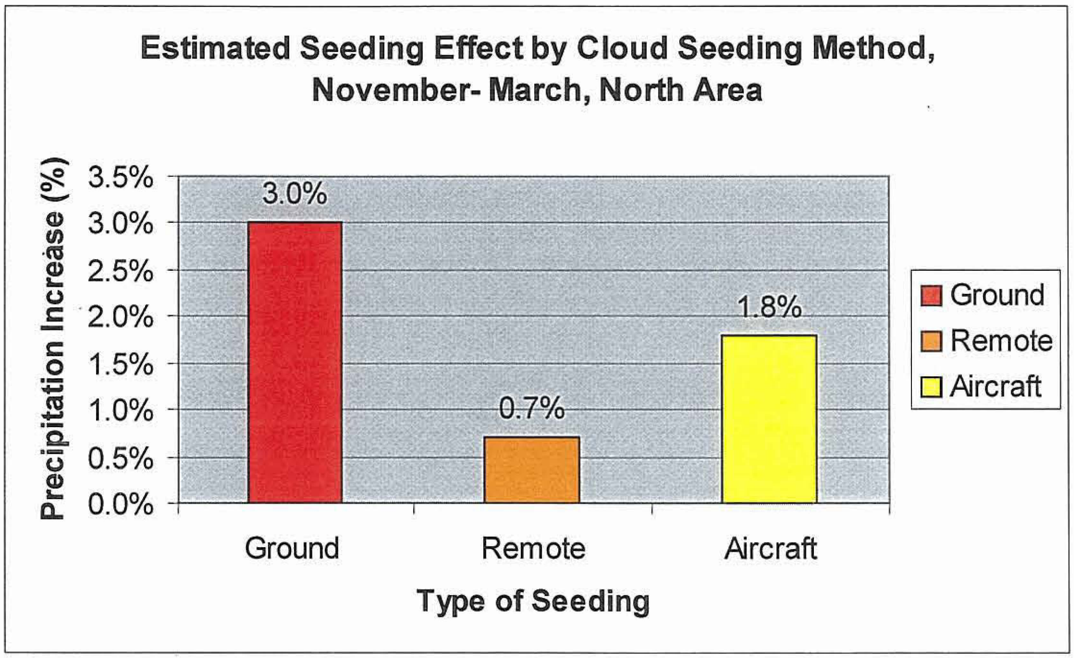


Figure 5.30 Estimates of Percentage Increases in November – March Precipitation for Seedable Cases Partitioned by Seeding Mode, North Area

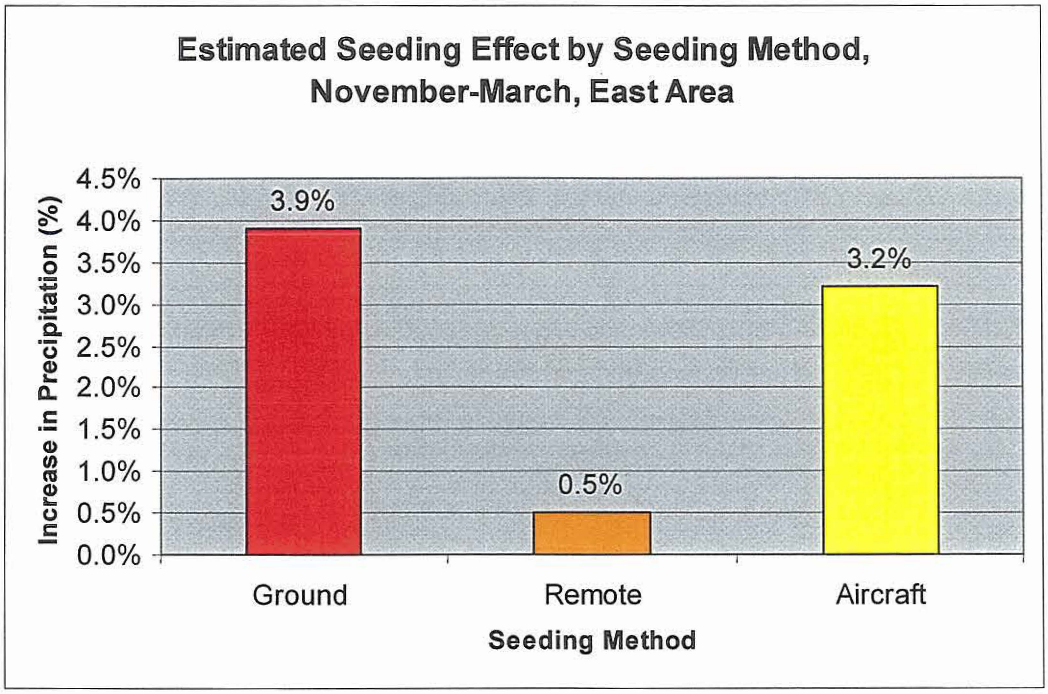


Figure 5.31 Estimates of Percentage Increases in November – March Precipitation for Seedable Cases Portioned by Seeding Mode, East Area

There are caveats built into these estimates of seeding increases according to the different seeding modes. Some of these caveats are as follows:

- Achieving the increases using manually operated, ground based generators assumes that suitable sites can be found at the proper spacing where local residents are willing to operate the equipment, and that these locations will be in the desired areas considering the prevailing wind flows encountered during "seedable" storms. This also assumes that NAWC's estimates of the frequency of low-level inversions during seedable events is reasonably accurate. A recommendation is made in this report that one winter of specialized data collection be conducted in the area to verify this and other conclusions which are based on indirect analyses instead of actual observations of the important parameters regarding the seedability of the natural storms that impact the target areas.

- To achieve the increases indicated for aircraft seeding assumes (in addition to those mentioned earlier concerning the number of aircraft and pilots) that the aircraft can be safely flown low enough often enough so that the seeding plumes impact the regions of supercooled liquid water occurring during the storm periods. The other assumption, if only using one seeding aircraft, is that the seeding plumes will spread and merge together (in the horizontal) before they reach the supercooled liquid water regions. Deshler, 1990 concludes "Achieving fairly continuous coverage along the direction of seed line advection requires seed lines to be no longer than 37 km (23 miles)." A further assumption is that one aircraft could effectively be used to seed both target areas although the provision of two pilots may be required to do so. To address this last assumption, we examined the percent of the time that aerial or ground-based, remote generator seeding opportunities occurred in both target areas at the same time based upon the six hour data set. This analysis indicated that seeding opportunities that are amendable to airborne seeding only would only occur simultaneously in both areas approximately 10 – 15% of the time. Recall we are combining the aerial and remote ground generator opportunities into airborne seeding for benefit/cost reasons.

We decided that the estimates contained in Figures 5.30 and 5.31 could be applied to the longer-term April 1st snow water content averages for all of the SNOTEL target sites in the proposed target area. This step makes at least two assumptions: 1) that the five seasons selected for detailed analysis are representative of the longer period records, and 2) the estimated increases calculated for the 6 hour periods can be extrapolated to estimate seasonal increases in the April 1st water content. The results of the November through March analysis extrapolated into estimates of increases in April 1st snow water contents at snow course or SNOTEL sites, stratified by seeding mode for the North and East areas, are provided in Tables 5-3 and 5-4.

For the North area, the resulting average increases in April 1st snow water content are 0.53" (1.35 cm) via use of lower elevation ground generators, an additional 0.12" (0.30 cm) for remote ground generators, and another 0.32"(0.81 cm) if aircraft are included. The combination of the three seeding modes is predicted to result in an average of 0.97" (2.5 cm) of additional April 1st snow water content.

The resulting average increases in April 1st snow water contents, for the East area, are 0.60" (1.52 cm) for lower elevation ground generators, an additional 0.08" (0.20 cm) for remote ground generators, and another 0.49"(1.25 cm) if aircraft are included. The combination of the three seeding modes is predicted to result in an average of 1.16" (2.95 cm) of additional April 1st snow water content. For reasons stated above, we believe the estimated total increases in the two areas could be achieved with a "core" program using manually operated, ground based generators with the addition of one seeding aircraft. These estimates will be used in later sections in the process of estimating: 1) increases in streamflow from the proposed ESRBP target areas, 2) the value of this additional streamflow, and 3) the costs of implementing the various seeding modes and then comparing those costs to the estimated benefits, resulting in a first approximation of potential benefit/cost ratios.

Table 5-3

Estimated Increases in April 1st Snow Water Content for the North Area based on Estimated November – March Precipitation Increases for Storm Periods using Cloud Top Temperature Estimates

Estimates in April 1 Snow Water Increase (using Nov-Mar percentages):

Site	Apr 1 Snow	Total Increase (5.5%)	Ground (3.0%)	Remote (0.7%)	Air (1.8%)
Big Springs SC	19.3	1.06	0.58	0.14	0.35
Camp Creek SC	9.8	0.54	0.29	0.07	0.18
Crab Creek*	16.4	0.90	0.49	0.11	0.30
Irving Creek SC	5.7	0.31	0.17	0.04	0.10
Island Park*	15.7	0.86	0.47	0.11	0.28
Latham Springs SC	33.0	1.82	0.99	0.23	0.59
Lucky Dog SC	25.2	1.39	0.76	0.18	0.45
Valley View SC	15.4	0.85	0.46	0.11	0.28
Webber Creek SC	5.9	0.32	0.18	0.04	0.11
White Elephant*	29.2	1.61	0.88	0.20	0.53
Mean	**17.6**	**0.97**	**0.53**	**0.12**	**0.32**

* SNOTEL site

Table 5-4

Estimated Increases in April 1st Snow Water Content for the East Area based on Estimated November – March Precipitation Increases for Storm Periods using Cloud Top Temperature Estimates

Estimates in April 1 Snow Water Increase (using Nov-Mar percentages):

Site	Apr 1 Snow	Total Incr (7.6%)	Ground (3.9%)	Remote (0.5%)	Aircraft (3.2%)
Allen Ranch	10.5	0.80	0.41	0.05	0.34
Fall Creek	7.3	0.55	0.28	0.04	0.23
Lava Creek	15.7	1.19	0.61	0.08	0.50
Packsaddle Spring	29.3	2.23	1.14	0.15	0.94
Pine Creek Pass*	16.0	1.22	0.62	0.08	0.51
Somsen Ranch	13.4	1.02	0.52	0.07	0.43
State Line	15.0	1.14	0.59	0.08	0.48
Mean	**15.3**	**1.16**	**0.60**	**0.08**	**0.49**

* SNOTEL site

Since snowmelt is a consideration during the month of April, NAWC performed an analysis similar to that above, using precipitation data from the target SNOTEL sites for the month of April. This analysis indicated that increases in April precipitation for the three seeding modes in both the North and East areas would be approximately 0.10" for ground generators, 0.03" for remote generators and 0.05" for aircraft seeding. The seeding costs and estimates of seeding potential for the month of April could be added to the November through March estimates to determine the potential advantages of extending the seeding program and each seeding mode through the month of April.

The estimated average seasonal increases are in general agreement with evaluations that NAWC has performed on several of our seeding projects conducted in or near the vicinity of the proposed ESRBP program. The results from some of these programs are summarized in Table 5-5. All of these programs have utilized only the lower elevation, silver iodide ground-based seeding mode. The estimated average results from operational programs that have been conducted by other groups in the proposed target areas (using manually operated, ground-based generators), as discussed in Section 12.0, range from 2-10%. If the results from these operational programs conducted are reasonably accurate and applicable to the proposed target areas, then the indicated estimates from the analyses shown in the current feasibility study for the ESRBP area are perhaps a little on the conservative side. This may be partially due to the fact that the four of the five seasons selected for detailed analyses were below normal in terms of precipitation (refer to Table 5-2).

This range of potential seeding increases is supported by a World Meteorological Statement on cloud seeding capabilities. The Policy Statement of the World Meteorological Organization (WMO) on winter orographic clouds states (WMO, 1992):

> *In our present state of knowledge, it is considered that the glaciogenic seeding of clouds or cloud systems either formed, or stimulated in development, by air flowing over mountains offers the best prospects for increasing precipitation in an economically viable manner. These types of clouds attract great interest in modifying them because of their potential in terms of water management, i.e., the possibility of storing water in reservoirs or in the snowpack of higher elevation. Numerous research and operational programs conducted since the beginning of weather modification as a science provide the evidence. Statistical analyses suggest seasonal increases (usually over the winter/spring period) on the order of 10 to 15% in certain program areas.*

Other capability statements from the Weather Modification Association and the American Meteorological Association provide estimates of seeding increases in a similar range (e.g., 10-15%) in winter orographic conditions (Appendix A).

Table 5-5

Indicated Results from Other operational Programs in the ESRBP Region

Program Area	Water Years of Operation	Estimated Increases in Apr.1 Water Content
Smith and Thomas Forks, ID and WY	1954-1970,1979-1982,1989-1990	11%
Eastern Box Elder & Cache Counties, UT	1989-2005	11.5%
Western Box Elder County, UT	1989-1997, 2000-2001, 2004-2005	14%
South Slopes Uinta Mountains, UT	2003-2005	11%

5.11 Estimated Potential Increases in Streamflow

Considerable effort was expended by the Idaho Department of Water Resources Hydrology Section and NAWC in attempts to derive average unregulated streamflow values for the North and East target areas. Unfortunately, there were few historical measurements from these areas of any duration. In addition, most measurement sites had regulations of flow above them, which meant some sort of adjustments would need to be made to develop estimates of natural flows. A further complication was that a number of the measurement sites included flows derived from river basins located in Wyoming. This meant that some scheme would need to be developed to remove the Wyoming contribution to streamflow to estimate the streamflow derived from the North and East areas. Due to these circumstances, it was ultimately decided that a combination of the limited stream gaging information (with some adjustments) would be used along with estimates of streamflow derived for other sub-basins from the size of the drainage and average April 1st snow water contents.

The Idaho Water Resource Board provided NAWC with sizes of the sub-basins above 6,500 feet within the two target areas. Estimates of March through July streamflow increases due to cloud seeding were made for these sub-basins. These sub-basins are those shown on the map in Figure 5.32. Sub-basins 1-3 are located in the North Area. Sub-basins 4-8 are located in the East area.

The average March through July streamflow values were estimated for some sub-basins (3, 4, and 5) by hydrologists of the Idaho Department of Water Resources, based on available historical streamflow records. One of the few historical unregulated stream gage measurements in either of the proposed target areas was identified as the Willow Creek gage (number 13057940) located in the East area (sub-basin 8). The Willow Creek average March through July streamflow was calculated from a 24-year historical period (water years 1978, 1979, and 1986-2007). The streamflow for the remainder of the sub-basins was scaled from the Willow Creek watershed, based on sub-basin size (above 6,500 feet) and average April 1 snowpack.

A linear regression equation was developed for the unregulated Willow Creek drainage, relating increases in April 1st snow water content to increases in streamflow during the March – July period. This period was considered to be most representative of the seasonal runoff from snowmelt. This equation is: Streamflow increase (AF) = 8,510 x (April 1 snowpack (inches)) – 60,336 AF.

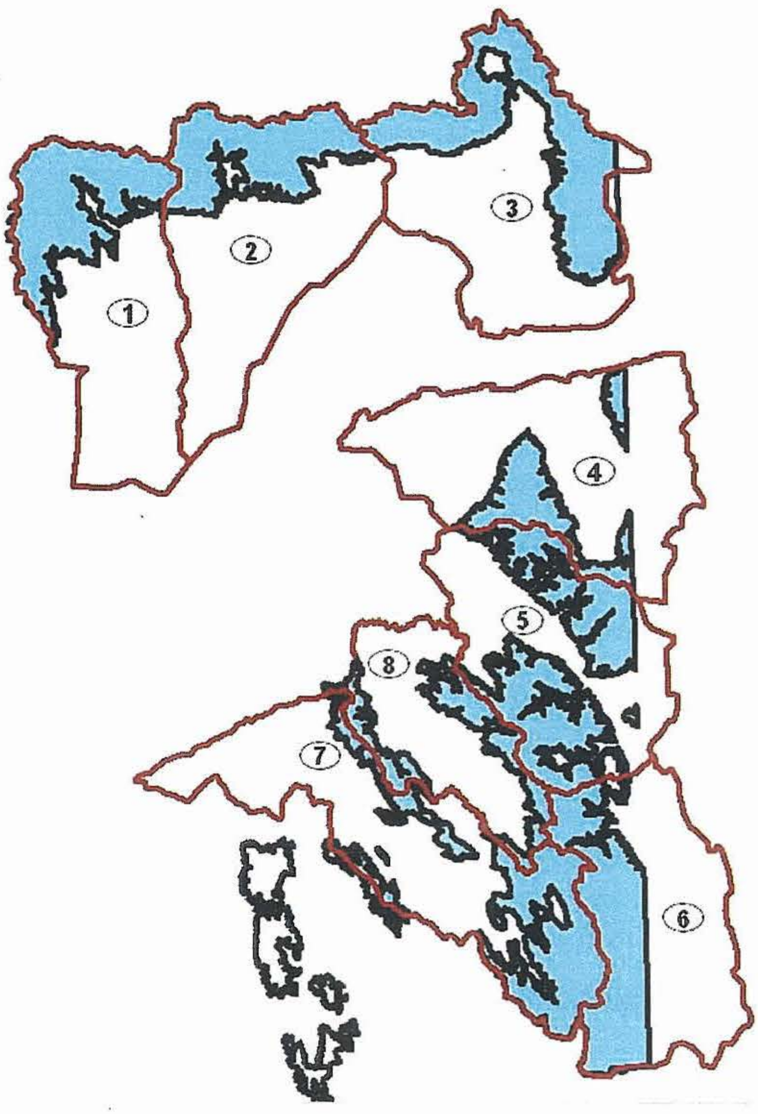


Figure 5.32 Streamflow Sub-Basins

The Willow Creek regression equation was applied to the sub-basins, with the resulting values considered to be maximum estimates of potential increases in streamflow. This is because the Willow Creek equation generates much higher percentage increases than a similar equation developed for the Salt River, across the border in Wyoming as discussed in a previous feasibility study performed by NAWC (Griffith, et al, 2006). The equation developed for the Willow Creek drainage implies that a 7.6% increase in April 1st snow water content would generate a 15.1% increase in streamflow. The Salt River analysis implies that a 10.0% increase in April 1st snow water content would generate a 10.5% increase in streamflow. It has been NAWC's experience that predicted increases in streamflow from cloud seeding programs are typically higher than predicted increases in snow water content on a percentage basis. We believe this to be due to the fact that any evapo-transpiration and ground water recharge requirements are met by the unaugmented snowpack such that increases assumed to be produced by cloud seeding are added to the snowpoack after these base requirements are met. The minimum streamflow increase estimates for each basin were based on the estimated percentage of snowpack increases (Figures 5.30 and 5.31), as well as base streamflow estimates for each sub-basin for an "average" season.

The results for each sub-basin were partitioned into ground-based seeding only, as well as ground plus aircraft seeding, so that a minimum/maximum range of estimated increases in streamflow was obtained for each seeding mode. The exception to this is sub- basins #1-2, where there is no surface water connection from streams that originate in these areas and the Snake River. There is, however, local use of streamflow from these two sub-basins as well as some ground water recharge derived from these sub-basins. Estimates of the increased total local streamflow from sub-basins 1 and 2 were calculated applying the same percentage as that for estimated snowpack increases (thus corresponding to the minimum increase estimates for the other sub-basins).

In order to apply the Willow Creek regression equation for the remaining sub-basins (#3-7 on the map), the average April 1 snowpack was first estimated for each sub-basin based on available snow measurement data. The appropriate seeding increase estimates for snowpack were then applied to the regression equation for each seeding mode, yielding (percentage) increase estimates for streamflow that are unique to each sub-basin. Sub-basins with a higher average snowpack have lower increase estimates of streamflow (on a percentage basis), and vice-versa, as generated by the regression equation. These percentages were then applied to the estimated average March-July runoff for each basin, yielding a maximum estimated increase value for an average season. Similarly, the percentage estimates for snowpack increase (Figures 5-30 and 5-31) were applied to the estimated average runoff for each sub-basin, yielding the minimum estimated increase in streamflow. Table 5-6 summarizes the results for each sub-basin, as well as the total increase estimates. Table 5-7 summarizes the totals for the North area, East area, and the North and East areas combined.

Estimates for all the sub-basins (excluding #1-2) were summed, yielding a minimum - maximum range of estimated streamflow increases for the entire drainage area for each seeding mode for an average March through July period. The only sub-basin with estimates of this type in the North area is sub-basin #3, with all the other sub-basins included in this summation being in the East area. Total March through July runoff increases due to seeding are estimated to be between **58,800 - 97,500** acre-feet for ground-based seeding only, and between about **110,500 – 188,200** acre-feet for ground plus aircraft seeding. North area (sub-basin #3) estimates range from 17,800 - 24,400 acre-feet for ground-based seeding and from 32,700 – 45,100 acre-feet for ground plus aircraft seeding, with the remainder of the total increases being derived from the East target area.

Table 5-6
Summary of Sub-Basin and Estimated Total Streamflow Increases

Sub-basin	Base Streamflow (AF)	Ground-Based Increase (AF)		Ground + Aircraft Increase (AF)	
		Min	Max	Min	Max
1 (Medicine Lodge)	61,115	1,800*	NA	3,400*	NA
2 (Beaver – Camas)	120,529	3,600*	NA	6,600*	NA
3 (Upper Henrys)	594,046	17,800	24,400	32,700	45,100
4 (Teton)	145,627	5,700	8,600	11,100	16,700
5 (Palisades)	485,903	19,000	34,000	36,900	66,600
6 (Salt River)	147,085	5,700	12,100	11,200	23,800
7 (Blackfoot)	209,757	8,200	13,400	15,900	26,400
8 (Willow Creek)	61,212	2,400	5,000	2,700	9,600
Total Streamflow (excl. #1 and 2)	1,643,630	58,800	97,500	110,500	188,200

* Considered only local not regional streamflow and ground water re-charge; not included in totals

Table 5-7
Summary of North and East Areas Estimated Average Streamflow Increases

	Ground-Based only		Ground + Aircraft	
	Min	Max	Min	Max
Northern (Basin #3)	17,800	24,400	32,700	45,100
Eastern	41,000	73,100	77,800	143,100
Total	58,800	97,500	110,500	188,200

The midpoint of the minimum - maximum range of total estimated March through July streamflow increases is 78,150 acre-feet (4.8%) for ground-based seeding only, and 149,350 (9.1%) for ground plus aircraft seeding. Given all of the

assumptions that have gone into the development of estimates of increases in streamflow due to cloud seeding, these values are perhaps most representative of the <u>average</u> increases in March through July streamflow that might be expected from the conduct of an operational cloud seeding program in the two proposed target areas. For comparison sake, these estimated average streamflow values would correspond to average increases in April 1st snow water content of approximately 3.5% for ground based seeding and 6.6% increases in April 1st snow water content for ground plus aircraft seeding.

5.12 Summary of Recommended Preliminary Design

The proposed design for the Eastern Snake River Basin Program (ESRBP) can be summarized as follows:

- The target area will be those areas in Bonneville, Clark, Fremont and Madison Counties that lie above 6,500 feet (2.0 km), which are tributaries to the Snake River.
- The primary operational period will be November through March. Seeding operations could be effectively extended into April, especially if a seeding aircraft were used on the program, although ground based seeding would still be effective as well.
- Silver iodide will be the seeding agent.
- A "core program" of lower elevation ground based generators is recommended, This core program could be supplemented by a seeding aircraft equipped with acetone/silver iodide generators if the estimated benefits constitute an acceptable multiple of the estimated costs to utilize this additional seeding mode. The use of remotely controlled ground based generators does not appear to offer any significant advantages.
- One winter season of data collection is proposed prior to the beginning of a full operational ESRBP. Data would be collected via rawinsonde observations, icing rate meter observations and possibly radiometer observations of liquid and vapor to verify some of the conclusions/assumptions contained in this preliminary design.
- The ESRBP would be operationally oriented, with the following goals: **The stated goal of the program is to increase winter snowpack in the target areas to provide additional spring and summer streamflow and recharge under-ground aquifers at a favorable benefit/cost ratio, without the creation of any significant negative environmental impacts.**
- Due to the operational nature of the proposed program, i.e., the interest in producing as much additional water as possible, the seeding decisions would not be randomized. In other words, all suitable seeding opportunities would be seeded appropriately. In addition, there would not be an ongoing research component built into the program (beyond the first season of specialized measurements which could be used to fine-tune the design if necessary), although "piggyback" research components could be added to the core operational program if interest and additional funding from other sources is present, for example, the type of research

that resulted from write-in funding to the Bureau of Reclamation for the recent Weather Damage Mitigation Program.

- Evaluations of the effectiveness of the cloud seeding program would be based upon historical target and control techniques (target and control sites with corresponding regression equations are provided elsewhere in this report), and possibly some snow chemistry analyses verifying that silver above background levels is being observed at various sampling points in the target areas. Evaluation techniques are discussed in Section 7.0
- Qualified/experienced meteorologists should direct the seeding operations.

6.0 ESTABLISHMENT OF OPERATIONAL CRITERIA (Task 4)

The RFP stipulated that "The Contractor will establish criteria for the operation of the program, in consultation with established guidelines set forth by agencies and organizations involved in weather modification. The contractor will develop the procedures for operating the program according to the established guidelines."

The American Society of Civil Engineers (ASCE) has published guidelines for weather modification programs for over 30 years. Mr. Griffith of NAWC was one of the authors of an original 1985 ASCE publication, as well as the revision to this document in 1995 (Manual 81) entitled "Guidelines for Cloud Seeding to Augment Precipitation" (ASCE, 1995). Mr. Griffith also served on a committee that recently revised ASCE Manual 81 (ASCE, 2006). In addition, Mr. Griffith served as chairman of a sub-committee of ASCE that developed a new publication entitled "Standard Practice for the Design and Operation of Precipitation Enhancement Projects" which has gone through a formal review process and was published in 2004 (ASCE, 2004). NAWC is therefore very familiar with the types of information suggested in these publications for inclusion in operational designs.

Some of the more important considerations include opportunity recognition, communication of seeding decisions, monitoring of meteorological and hydrological conditions for possible suspension of seeding activities, conformance with applicable regulations, and informing interested parties regarding the conduct of seeding activities. Regarding opportunity recognition, NAWC typically develops a table of conditions (criteria) that must be met to determine that a given storm situation is "seedable". Table 6-1 provides an example.

6.1 Opportunity Recognition Criteria

For the proposed ESRBP program seeding criteria were developed to serve as opportunity recognition tools. Basically, these criteria have been designed to recognize the combination of weather events deemed to be "seedable". These criteria have been broken down into three different categories based upon the seeding mode to be used (ground based, low-elevation, manually operated generators; high elevation, remotely operated generators; and, aircraft). The criteria are listed in Tables 6-2 and 6-3.

6.2 Communications of Seeding Decisions

The means by which seeding decisions are communicated/implemented will be a function of the type(s) of seeding methodology employed (e.g., for manually operated ground generators, telephone calls). Remotely controlled generators typically utilize cell or satellite phones for communications. Aircraft seeding typically involves locating a project office at a suitable airport near the project area. This office would be manned by one or more project meteorologists. The pilot(s) of the seeding aircraft are also based at this office. Communications regarding aircraft missions are therefore conducted prior to take-off. Communications continue between the meteorologist and pilot via VHF or UHF radios.

Table 6-1
NAWC Generalized Seeding Criteria Developed for Use in the Intermountain West

1.	CLOUD BASES ARE BELOW THE MOUNTAIN BARRIER CREST.
2.	LOW-LEVEL WIND DIRECTIONS AND SPEEDS THAT WOULD FAVOR THE MOVEMENT OF THE SILVER IODIDE PARTICLES FROM THEIR RELEASE POINTS INTO THE INTENDED TARGET AREA.
3.	NO LOW LEVEL ATMOSPHERIC INVERSIONS OR STABLE LAYERS THAT WOULD RESTRICT THE VERTICAL MOVEMENT OF THE SILVER IODIDE PARTICLES FROM THE SURFACE TO AT LEAST THE -5°C (23°F) LEVEL OR COLDER.
4.	TEMPERATURE AT MOUNTAIN BARRIER CREST HEIGHT EXPECTED TO BE -5°C (23°F) OR COLDER.
5.	TEMPERATURE AT THE 700-MB LEVEL (APPROXIMATELY 10,000 FEET) EXPECTED TO BE WARMER THAN -15°C (5°F).

Table 6-2
Opportunity Recognition Criteria
Lower Elevation Manually Operated Ground Generators

1. Cloud top temperatures expected to be $\geq$- 26 ^{0}C.
2. 700 mb level temperatures expected to be $\leq$- 5 ^{0}C.
3. Low-level temperature profile from the surface to 700 mb expected to be no more than slightly stable
4. Low-level wind directions expected to be favorable for the transport of the seeding material over the target barrier(s).
5. Cloud bases expected to be at or below target barrier crest height.

Table 6-3
Opportunity Recognition Criteria
Aircraft Seeding

1. Cloud top temperatures expected to be $\geq$- 26 ^{0}C.
2. 700 mb level temperatures expected to be $\geq$- 5 ^{0}C.
3. Mid-level wind directions expected to be favorable for the transport of the seeding material over the target barrier(s).
4. Cloud bases expected to be at or below target barrier crest height.

6.3 Seeding Suspensions

Seeding suspension criteria should be developed for this program. The primary concern will be suspension of seeding whenever flash flooding may occur during or following stormy periods (typically based upon issuance of such warnings by the local National Weather Service offices), or if unacceptably high streamflows may be produced during the spring snowmelt periods. These latter suspensions are typically based upon a sliding temporal scale of percent of normal values of higher elevation snow water contents. NAWC has established suspension criteria for several of the winter programs that we conduct in areas of the west, which are climatologically similar to the ESRBP area.

We propose the use of the following suspension criteria in the conduct of the ESRBP program, should it move forward.

Certain situations require suspension criteria to minimize either an actual or apparent contribution of seeding to a potentially hazardous situation. The ability to forecast and avoid hazardous conditions is very important in limiting any potential liability associated with weather modification and to maintain a favorable public image.

There are four hazardous situations around which suspension criteria have been developed. These are:

1. Excess snowpack accumulation
2. Rain and/or snowmelt-induced winter flooding
3. Severe weather
4. Avalanches

6.3.1 Excess Snowpack Accumulation

Snowpack begins to accumulate in the mountainous areas of Idaho in October and continues through April. The heaviest average accumulations normally occur from January through March. Excessive snowpack becomes a potential hazard because of the potential for excess snowmelt. The Natural Resources Conservation Service (NRCS) maintains a network of high elevation snow measurement sites in the State of Idaho, known as SNOTEL. The automated SNOTEL observations are routinely updated and available at least several times per day. The following set of criteria, based upon these SNOTEL site observations, has been developed as a guide for suspension of operations.

a. 200 % of average on January 1st
b. 180 % of average on February 1st
c. 160 % of average on March 1st
d. 150 % of average on April 1st

These criteria could be applied separately to the North and East areas. It is possible that these criteria could result in the suspension of seeding activities in one area and not the other. Tables 6- 4 and 6-5 contain the average 1971 – 2000 snow water content values in inches for the SNOTEL sites that are located in or near the proposed target areas. The averages for the sites in the North or East area would be used to consider whether the above suspension criteria have been exceeded. For example, if the average snow water content (of the various SNOTEL sites) on February 1^{st} of a particular season is 23.0" (58 cm) and the long-term February 1 average is 8.2", then the suspension point would be 14.5" x 1.80 = 26.1" (66.3 cm), so the seeding would not be suspended based upon this criterion. Since SNOTEL observations are available on a daily basis, suspensions (and cancellation of suspensions) can be made on a daily basis using linear interpolation of the first of month criteria. The target area snow course sites were not included in these criteria, since data from these sites are only available on a monthly basis.

Table 6-4
Monthly Target Area SNOTEL Snow Water Content Normals (1971-2000), North Area

Site Name	Jan.1	Feb. 1	Mar. 1	Apr. 1
Crab Creek	6.4	9.6	12.7	16.4
Island Park	6.5	10.6	13.7	15.7
White Elephant	11.8	18.0	23.4	29.2
Average	**8.2**	**14.5**	**16.6**	**20.4**

Table 6-5
Monthly Target Area SNOTEL Snow Water Content Normals (1971-2000), East Area

Site Name	Jan.1	Feb. 1	Mar. 1	Apr. 1
Pine Creek Pass	6.9	10.9	14.2	16.0
Sheep Mt.	5.7	10.0	13.4	14.5
Somsen Rch.	5.3	9.2	11.9	13.4
Average	**6.0**	**10.0**	**13.2**	**14.6**

Snowpack distribution with elevation, streamflow forecasts, reservoir storage levels, soil moisture content and amounts of precipitation in prior seasons are other factors of importance in seeding suspension considerations.

6.3.2 Rain-induced Winter Floods

There is the potential for wintertime flooding from excessive rainfall, particularly on top of low elevation snowpack. Every precaution must be taken to ensure accurate forecasting and timely suspension of operations during these potential flooding situations. The objective of suspension under these conditions is to eliminate the real, and avoid any perceived, impact of weather modification when any increase in precipitation has the potential of creating a flood hazard.

6.3.3 Severe Weather

During periods of hazardous weather phenomena associated with both winter orographic and convective precipitation systems, it is sometimes necessary or advisable for the National Weather Service (NWS) to issue special weather bulletins advising the public of the weather phenomena. Each phenomenon is described in terms of criteria used by the NWS in issuing special weather bulletins. Those of concern in the conduct of winter cloud seeding programs include:

- **Snow Advisory** - This is issued by the NWS when four to twelve inches of snow in 12 hours or six to eighteen inches (15 – 46 cm) in 24 hours is forecast for mountainous regions above 7000 feet (2.1 km). Lower threshold criteria (in terms of the number of inches of snow) are issued for valleys and mountain valleys below 7000 feet (2.1 km).

- **Heavy Snow Warning** - This is issued by the NWS when it expects snow accumulations of twelve inches (30 cm) or more per 12-hour period or eighteen inches or more per 24-hour period in mountainous areas above 7000 feet (2.1 km). Lower criteria are used for valleys and mountain valleys below 7000 feet (2.1 km).

- **Winter Storm Warning** - This is issued by the NWS when it expects heavy snow warning criteria to be met along with strong winds/wind chill or freezing precipitation.

- **Flash Flood Warnings** - This is issued by the NWS when flash flooding is imminent or in progress. In the Inter-mountain West these warnings are generally issued relative to, but not limited to, fall or spring convective systems.

Seeding operations may be temporarily suspended whenever the NWS issues a weather warning for or adjacent to any target area. Since the objective of the cloud seeding program is to increase winter snowfall in the mountainous areas of the state, operations will typically not be suspended when Heavy Snow or Winter Storm Warnings are issued unless there are special considerations (e.g., a heavy storm that impacts Christmas Eve travel).

Flash Flood Warnings are usually issued when intense convective activity causing heavy rainfall is expected or occurring. Although the probability of this situation occurring during the proposed operational seeding periods is low, the potential does exist, particularly during the spring months. The type of storm that may cause problems is one that has the potential of producing 1-2 inches (2.5 – 5 cm) or greater of rainfall in approximately a 24-hour period, with high freezing levels (e.g. > 8,000 feet, 2.4 km) MSL). Seeding operations will be suspended for the duration of the warning in these cases.

6.3.4 Avalanches

The topic of Avalanches is addressed in Section 8.1.3. As discussed in that section, temporary seeding suspensions based upon avalanche warnings would occur when a day is rated in either the Extreme or High category.

6.4 Communications of Seeding Activities

Arrangements may be made to communicate seeding decisions in real-time to the interested parties (e.g., project sponsors) utilizing an internet site to post activities. More often summaries of seeding activities are provided on a weekly, bi-weekly or monthly basis via written reports.

7.0 DEVELOPMENT OF MONITORING AND EVALUATION METHODOLOGY (Task 5)

Specification of an evaluation methodology is a necessary requirement in the development of any comprehensive project design. This step represents one of the more difficult aspects of the development of a design of an operational cloud seeding project. A powerful approach, utilized in the conduct of research projects, is that of "randomly" specifying storm units to be seeded and others to be left unseeded. This is usually done on about a 50/50 seed to no seed basis. Observations and procedures are specified in advance, dictating how the project will be evaluated for detecting effects of seeding (e.g. as in Climax I and II, 24 hour amounts of precipitation at selected measurement locations within the target area). After seeding trials are conducted for several seasons, the average seeded precipitation at these key precipitation stations can be compared with the average not-seeded precipitation. The idea is that a large enough sample size will eliminate much of the natural variability that accompanies precipitation, such that a 10-15% difference can be detected with some degree of confidence. Parametric and non-parametric statistical tests can be applied to these data sets to determine how strong (significant) the indicated differences may be. Most sponsors of operational cloud seeding projects are unwilling to sacrifice a proportion of up to one-half of the potential benefit of the project (via randomization) for the purpose of documenting more precisely what the effects of seeding may have been. This is a question that would need to be addressed by the potential sponsors of the project, to randomize or not?

Assuming at this stage that the decision will be to not randomize the project, a brief discussion on the background associated with evaluation of non-randomized projects is provided in the following.

7.1 Background

The task of determining the effects of cloud seeding has received considerable attention over the years. Evaluating the results of a cloud seeding program for a particular season is rather difficult. The primary reason for the difficulty stems from the large natural variability in the amounts of precipitation that occur in a given area and between one area and another during a given season. Since cloud seeding is normally feasible only when existing clouds are near to (or already are) producing precipitation, it is not usually obvious if, and how much, the precipitation was actually increased by seeding. The ability to detect a seeding effect becomes a function of the magnitude of the seeding increase and the number of seeded events, compared with the natural variability in the precipitation pattern. Larger seeding effects can be detected more easily, and with a smaller number of seeded cases, than are required to detect small increases.

Historically, the most significant seeding results have been observed in wintertime seeding programs in mountainous areas. However, the apparent differences due to seeding are relatively small, being of the order of a 5-20 percent seasonal increase. In part, this relatively small percentage increase accounts for the significant number of cases required to establish these results (often five years or more).

Despite the difficulties involved, some techniques are available for estimation of the effects of operational seeding programs. These techniques are not as rigorous or scientifically desirable as is the randomization technique used in research, where roughly half the sample of suitable storm events is randomly left unseeded. Most clients do not wish to cut the potential benefits of a cloud seeding project by as much as half in order to better document the effects of the cloud seeding project. The less rigorous techniques do, however, offer an indication of the long-term effects of seeding on operational programs.

A commonly employed technique, and the one utilized in this assessment, is the "target" and "control" comparison. This technique is one described by Dr. Arnett Dennis in his book entitled "Weather Modification by Cloud Seeding, 1980". This technique is based on the selection of a variable that would be affected by seeding (such as precipitation or snowpack). Records of the variable to be tested are acquired for a not-seeded historical period of many years duration (20 years or more if possible). These records are partitioned into those located within the designated "target" area of the project and those in a nearby "control" area. Ideally the control sites should be selected in an area meteorologically similar to the target, but one which would be unaffected by the seeding (or seeding from other adjacent projects). The historical data (e.g., precipitation) in both the target and control areas are taken from past years that have not been subject to cloud seeding activities in either area. These data are evaluated for the same seasonal period of time as planned for the seeding evaluation. The target and control sets of data for the unseeded seasons are used to develop an equation (typically a linear regression) which predicts the amount of target area precipitation, based on precipitation observed in the control area. This regression equation is then applied to the seeded period, to estimate what the target area precipitation would have been without seeding, based on that observed in the control area. This allows a comparison to be made between the predicted target area natural precipitation and that which actually occurred during the seeded period, to look for any differences potentially caused by seeding activity. This target and control technique works well where a good historical correlation can be found between target and control area precipitation. Generally, the closer the target and control areas are geographically, and in terms of elevation, the higher the correlation will be. Control sites that are too close to the target area, however, can be subject to contamination by the seeding activities. This can result in an underestimate of the seeding effect. For precipitation and snowpack assessments, a correlation coefficient (r) of 0.90 or better would be considered excellent. A correlation coefficient of 0.90 would indicate that over 80 percent of the variance (r^2) in the historical data set would be explained by the regression equation used to predict the variable (expected precipitation or snowpack) in the seeded years. An equation indicating perfect correlation would have an r value of 1.0.

For a large-scale winter project sponsored by the Denver Water Board, NAWC documented a historical regression (unseeded) period target/control relationship *a priori* and then applied the predetermined and published target/control evaluation methodology after the seeding took place, to evaluate the results. This operational seeding project was conducted by another cloud seeding contractor, to affect some of the higher elevation drainages of the central Colorado Rockies (Solak, et al, 2003). In this manner, an independent evaluation method was developed.

Experience has shown that it is virtually impossible to provide an accurate assessment of the effectiveness of cloud seeding based on one or two seeded seasons for this type of winter-season program. However, as the data sample size increases, it becomes possible to provide at least a qualitative answer to the question, "How effective was the seeding?" Even if the results are somewhat imprecise, the ability to provide a credible estimate of project effectiveness is critical to the health and longevity of any program, as noted in an earlier section.

7.2 Target/Control Evaluations

7.2.1 Background

It is proposed that a non-randomized target/control evaluation method be developed as one means to evaluate the ESRBP program. One issue that could have been discussed in the earlier section on the equipment and observation requirements (section 5.7) was the need or desire to install additional precipitation measurement sites in the intended target areas. The motive would be primarily to use such additional measurements in the evaluation of the effectiveness of the seeding. Although at first this seems like a logical suggestion, albeit one with potential considerable associated expense, it is in fact not worthwhile unless the project is randomized. The reason for this is that if additional sites are installed and a seeding project initiated, there will not be any representative not-seeded data (i.e., no historical data) that can be used in evaluating the effects of seeding at these sites (ASCE, 2004). As a consequence, the utilization of the historical target/control evaluation technique needs to rely upon measurement sites that are still in use but that also have a significant (15 or more years) historical record as well. Since higher elevation areas receive considerable quantities of snowfall during the winter, they are naturally the preferred target areas in which cloud seeding is directed. Historical measurements of precipitation in these areas of the intermountain west have typically been made by the former SCS (currently the NRCS) and in some cases by state water resources agencies. Since approximately 1980, monthly manual snow course measurements of snow water content have been mostly replaced by automated measurements several times per day of snow water content and precipitation, provided by two different sensors (e.g. snow pillows and standpipe storage gages). Both types of data will be used in the development of historical target/control evaluation techniques. Typically evaluations are performed using both types of data, such as April 1st snow water contents and November–March or December-March precipitation amounts. Each type of observation has different advantages and disadvantages.

Several lessons have been learned over the years in performing these types of target/control evaluations. Some of the concerns/considerations in performing historical target/control evaluations are discussed in the following.

The number of sites operated by agencies such as the NRCS (especially snow course sites) is continually being reduced. Even some cooperative program observer sites, which are managed by the National Weather Service, have either been discontinued or become inactive at several locations. This can necessitate changes in the regression equations developed to evaluate cloud seeding projects.

Another consideration in the selection of control sites is the potential downwind effects of other cloud seeding projects beyond the intended target areas. Some earlier weather modification research program evaluations have indicated that the precipitation can be modified not only within the intended target areas, but also in areas downwind of the intended target areas. Analyses of some of these programs have indicated increases in precipitation in these downwind areas out to distances of 50-100 miles (80-160 km). NAWC recently completed an analysis of the potential downwind effects of cloud seeding, utilizing a long-term program that has been conducted in central and southern Utah (Solak, et al, 2003). Historical regression equations were developed for that study to examine the possible existence of downwind effects. Figure 7.1 (taken from the study) shows ratio values of actual over predicted precipitation for several sites in southeast Utah and southwest Colorado, downwind of the seeding project target area shown in the figure. This figure indicates possible positive downwind effects from this program out to at least some locations near the Utah/Colorado border, a distance of approximately 100 miles (160 km) from the location of the intended target area.

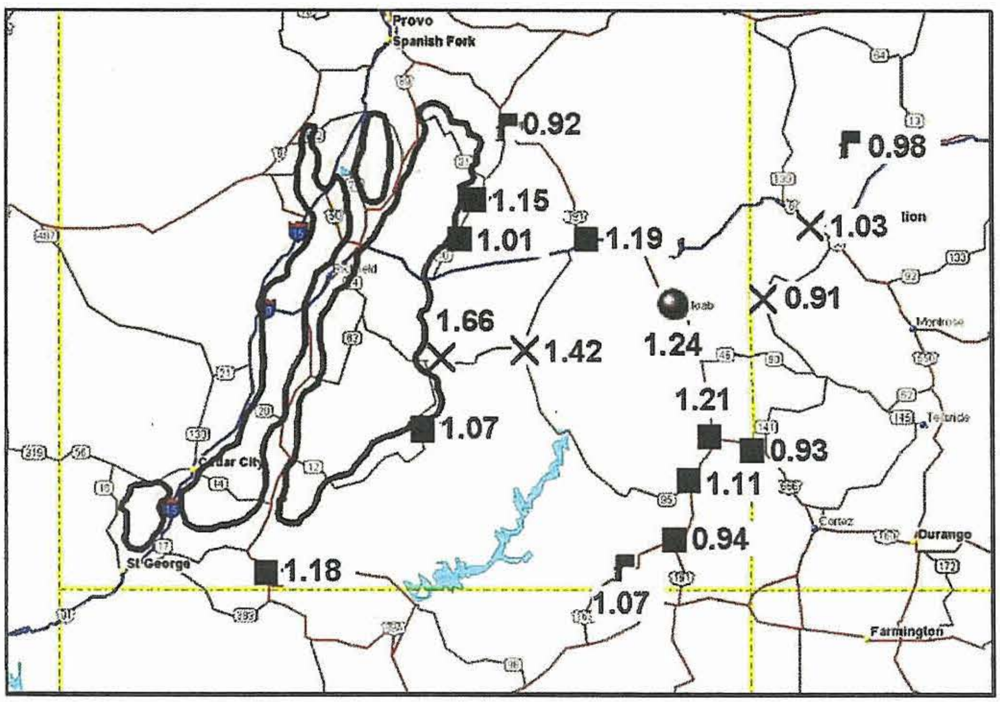


Figure 7.1 Actual/Predicted Downwind Ratios from Utah Study (target area enclosed by solid lines)

The normal approach in selecting control sites for a new project is to look for sites in meteorologically similar areas that will geographically bracket the intended target area. The reason for this approach is that some winter seasons are dominated by a particular upper airflow pattern while other seasons are dominated by other flow patterns. The result of different upper airflow patterns often results in heavier precipitation in one area versus the other. For example, a strong El Nino pattern may favor the production of heavy winter precipitation in the southwestern United States while a strong La Nina pattern may favor below normal precipitation in that region. Having control sites on either side of (geographically bracketing) the target area relative to typical windflow patterns, particularly with regards to latitude, can improve the prediction of target area precipitation under these variable upper air flow pattern situations and result in more consistency in the evaluation results

An additional consideration in the selection of control sites for the development of an historical target/control relationship is one of data quality. A potential control site may be rejected due to poor data quality, which is usually manifested in terms of missing data. Fortunately, missing data (typically on a daily basis) are noted in the historical database so that sites can be dropped from consideration if they have much missing data. A site is normally dropped if it has more than 2 or 3 days of missing data in a month for 4 or 5 months during the historical period we are considering, which could be a 15–30 year period. Data quality may appear to be satisfactory but another consideration is whether the station has been moved during its history. If a significant move (more than a mile or change in elevation of 100-200 feet, 33-66 meters) is indicated in the station records, then a double mass analysis may be performed of the station of interest versus another station in the vicinity with good records and location stability. The double mass plot (an engineering tool) will indicate any changes in relationships between the two stations. If these changes (deflections in the slope of the line connecting the points) are coincident with station moves and they suggest a significant difference in the relationship, the site is dropped from further consideration.

Another factor should be noted. That is concerned with the two types of precipitation observations typically available from mountainous areas in the west: standpipe storage precipitation gages and snow pillows. There are potential problems associated with each type of observation. With the advent of the Natural Resources Conservation Service's (NRCS) SNOTEL data acquisition system in the late 1970's, access to precipitation and snowpack (water equivalent) data in mountainous locations became routine. Before the system was developed, these data were acquired by actually visiting the site to make measurements, a practice which is still being done at some sites. Figure 7.2 is a photo of an NRCS SNOTEL site taken in the fall, to allow the reader a better understanding of the two types of observation systems. The vertical tube is the standpipe storage gage, which is approximately 12" (30.4 cm) in diameter. The gages are approximately 20' (6.1 m) in height so that their sampling orifices remain above the snowpack surface. There are at least two types of problems associated with high elevation

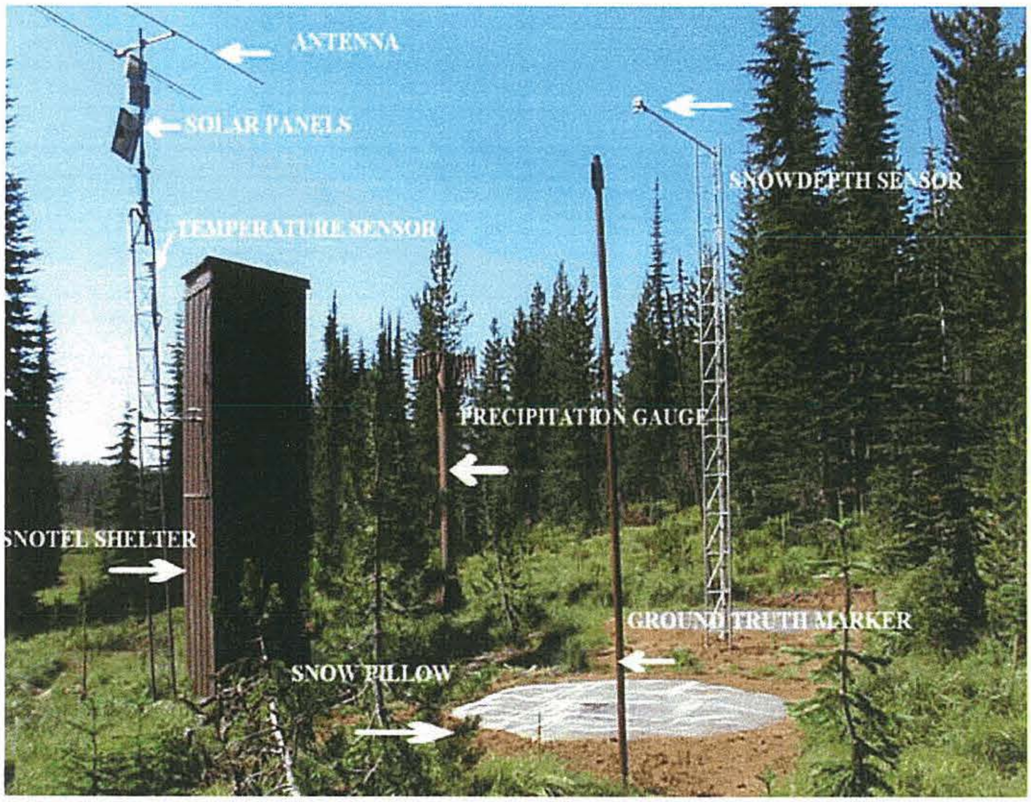


Figure 7.2 SNOTEL Site in the Fall

observations of the water equivalent of snowfall, as measured by standpipe precipitation storage gages. The two areas of concern are clogging at the top of the standpipe storage gage, and blow-by of snowflakes past the top of the standpipe gage. Either situation would result in an underestimate of the actual precipitation that fell during such periods. In the fall, the storage gage is charged with antifreeze, which melts the snow that falls to the bottom of the gage. A pressure transducer records the weight of the solution. The weight of the antifreeze is subtracted from the total weight, giving the weight of the precipitation water, which is then converted into inches. Heavy, wet snow may accumulate around the top of the standpipe storage gage, affecting its catch, either reducing or stopping snow from falling into the standpipe, resulting in an underestimate of precipitation. Snow that falls with moderate to strong winds may blow past the top of the gage, which can also result in an underestimate of precipitation. NRCS sites are normally located in small clearings in forested areas to help reduce the impacts of wind problems. Sites that are near or above timberline are more likely to be impacted by catch deficiency due to wind since sheltered sites may be difficult to find in these areas. The snow pillow pictured in the foreground in Figure 7.2 is filled with antifreeze. This system weighs the snowpack, providing time-resolved records of the snowpack water content. Snow pillows can also have difficulty in providing accurate measurements of snow water content, because of wind either adding or removing snow from the measurement site when snow conditions are favorable for drifting.

The bottom line is that it is difficult to accurately measure snow water equivalent at unmanned high-elevation sites. Both types of NRCS observations (gage and snow pillow) can best be viewed as approximations of the actual amount of water that falls during a winter season. NRCS SNOTEL sites frequently provide the only type of precipitation observations available from higher elevation areas targeted by winter cloud seeding programs. They are well suited for use in estimations of seeding effects, but interpretation of the indicated seeding effects must keep in mind the limitations of the measurement systems and their data.

One final consideration; air pollution from major cities or from power plants in the west may be impacting mountainous precipitation downwind of these source regions. Givati and Rosenfeld, 2004 documented reductions in ratios of mountainous precipitation to upwind valley precipitation for regions downwind of major cities in Israel and California. They attributed these changes to the effects of air pollution. NAWC recently investigated this potential problem in Utah (Griffith et al, 2005). This study indicated reductions in mountainous precipitation were occurring downwind of the Salt Lake City urban complex as well, out to distances of ~50 nm (111 km). Both studies further pointed out how such changes in precipitation patterns might impact the ability to estimate the effects of cloud seeding.

Even with the above caveats, **NAWC still considers the historical target/control technique to be the best choice in evaluations of non-randomized, operational wintertime cloud seeding projects if the goal of such an evaluation is to establish some quantitative estimate of the increase in precipitation due to seeding**. The development of regression equations using the target/control technique *a priori*, i.e., **before any seeding is conducted,** offers a means of eliminating any question of bias on the part of those conducting the subsequent evaluations. This is a step that is encouraged by the Weather Modification Association; that is, procedures to be used in evaluations should be specified in advance. This approach was applied to the evaluation work conducted for the Denver Water Board (Solak, 2003). Some statistical tests may be applied to test the significance of any indications of possible seeding effects obtained using the target/control analyses, although in the strict sense the application of such tests is only valid when applied to randomized data sets.

7.2.2 Precipitation and Snow Water Content Target/Control Evaluations

NAWC was contacted last fall by the sponsors of an operational program being conducted in the same areas as those of interest in this study. Those sponsors requested that NAWC perform an independent assessment of the effectiveness of this program during the 2007-2008 winter season. These sponsors also contacted the Idaho Water Resource Board (IWRB) to determine if they could offer some financial assistance in the performance of such an evaluation. It was ultimately decided that the local sponsors and the IWRB would jointly support this evaluation work. As a consequence, NAWC's contract with the IWRB to conduct this feasibility study was amended to include this evaluation work as one of the tasks in this contract. The results of that evaluation work are discussed separately in Section 12.0 of this report. The concerns expressed in Section

7.2.1 were addressed in the evaluation work described in Section 12.0. It is NAWC's recommendation that the evaluation methodology described in Section 12.0 serve as one of the primary means of evaluating the ESRBP program, should it be implemented. Minor updates/modifications to this methodology may be required from time to time (e.g., a reporting station in either the target or control areas is eliminated or a new cloud seeding program is developed that impacts one or both of the control areas).

7.3 Randomization

Randomization of experimental units, where approximately half of the events are seeded and the other half are not, is a tool used in the conduct of research programs. Normally, approximately a five-season period is needed to demonstrate statistically significant results from the conduct of such a program. The five-year pilot program approved for the Wind River, Sierra Madre/Medicine Bow Ranges in Wyoming is employing the randomization technique. Research programs of that type are much more costly to conduct than those where every potentially favorable event is seeded. The tradeoff is that when a randomized approach is applied, the determination of the results of seeding is more certain. This current study assumes that randomization will not be employed for the ESRBP area, should the decision be reached to proceed with a winter cloud seeding program.

7.4 Silver in Snow Evaluations

The results from a statistical evaluation, such as a target/control analysis, can be strengthened through supporting physical studies. This recommended was made by the Weather Modification Association, in its website response to a National Research Council Report (2004). One technique that has been employed by the Desert Research Institute (DRI) in the assessment of the effectiveness of at least the targeting (if not the magnitude) of seeding effects of winter programs that use silver iodide as the seeding agent is that of analyzing samples of snow from the target area during seeded periods to determine whether silver is present in the snowpack (Warburton, et al, 1996) (Warburton, et al, 1995b).

The revision to the ASCE Manual 81(ASCE, 2006) contains the following summary of this technique.

"Occasionally, samples of newly fallen snow are collected for an analysis of silver content. This is an evaluation technique encountered more frequently in research projects due to the expense involved. Snow samples collected prior to cloud seeding or from non-seeded storms are analyzed to establish the natural background silver content (if measurable with available analysis techniques) for comparison with snow samples taken from seeded storms. This technique is only valid for projects using silver iodide as the cloud seeding agent, although some analysis techniques are applicable to other possible cloud seeding agents as well (i.e., lead iodide). Several analysis techniques have been developed for use in such analyses, including neutron activation, proton excitation, and flameless

atomic absorption. An example of an analysis of the downwind transport of silver iodide outside of primary target areas is given by (Warburton 1974). Warburton, et al, (1996) demonstrates how trace chemical assessment techniques strengthen traditional target and control precipitation analyses.

A modification of this trace chemistry assessment technique involves the simultaneous release of a control aerosol along with an active seeding aerosol (Warburton, et al. 1995). Such tracers have properties very similar to the seeding agent, with the key exception that it does not nucleate ice. It is insoluble in water, has an extremely low natural background in precipitation and is only removed from the atmosphere by passive precipitation scavenging mechanisms. Both the seeding agent and tracer are transported and scavenged in very similar manners when conditions are not conducive for effective seeding. Given similar release rates, detecting the same concentrations of silver and indium in precipitation samples at downwind locations indicates that the two aerosols were most likely removed from the atmosphere solely by scavenging. On the other hand, when sufficient supercooled liquid water (SLW) exists and temperatures are cold enough for the active seeding material to nucleate new ice crystals, the ratio of silver to tracer in target area precipitation samples can be much greater than unity. This indicates that some fraction of the seeding material was directly responsible for the nucleation of ice crystals that eventually produced additional snowfall."

This technique may be of potential value on the ESRBP, if the decision is made to proceed with this project. The combination of silver in snow along with model predictions of the transport of seeding plumes over sampling sites would provide support to the indications of positive effects of seeding that might be provided through statistical evaluations such as the target-control technique described earlier.

7.5 Computer Simulations

Those designing operational programs need to stay abreast of new developments in this field or related fields that have the potential to improve the performance of existing project designs. Such improvements could include the use of computer models to predict the transport of seeding plumes and fallout of artificially created precipitation, or the use of snow chemistry to estimate the effectiveness of the seeding operations. The use of computer models, while intriguing, can produce pitfalls if model results are accepted at face value without independent validation via observations. For example, the plume transport type output is much more acceptable if a tracer is released and tracked through the clouds of interest to verify the model predictions. Some work of this type utilizing SF_6 to depict seeding plumes was conducted on some Utah storm events (Holroyd, et al, 1995; Heimbach, et al, 1997).

Sophisticated atmospheric models have the potential to calculate the amounts of natural precipitation for short intervals (e.g., 6 hours, 12 hours) in mountainous areas. **If** these predictions were accurate and had been validated by observations, they could be compared with the amount of precipitation that fell during seeded periods within the intended target area to determine the impact of seeding on target area precipitation. An attempt to verify the output of the Regional Atmospheric Modeling System (RAMS) computer model developed at Colorado State University versus observed and predicted modified precipitation due to cloud seeding was made for the 2003-2004 winter season in central Colorado, with rather mixed results. Some of the conclusions from the final report (Colorado Water Conservation Board, 2005):

- When model simulated precipitation was compared to measured 24-hour precipitation at 61 SNOTEL sites the model exhibited a mean precipitation bias of 1.88.
- Comparison of model-predicted precipitation (control) versus seeded precipitation revealed that there was essentially no difference between the 86-day seed and control average totals.

Reasons given why there were no differences between seed and control precipitation included:

- The model-predicted seedability could be real; however, because of the model over-prediction bias and low amounts of supercooled liquid water content, this possibility is doubtful.
- There is circumstantial evidence that the model-predicted supercooled liquid water content is too low, thereby underestimating seedability.
- The low-level warm temperature bias in the model results in delayed AgI nuclei activation and reduced effectiveness of the seeding agent in the model.

Some commercial cloud seeding operators believe that computer models have not progressed to the stage that they can be used to quantitatively evaluate operationally conducted winter cloud seeding programs. Computer models certainly hold considerable promise for use in this way in the future. Some existing models, such as Desert Research Institute's Lagrangian particle dispersion model (LAP), have been used to predict the plume transport from ground based silver iodide generators, although they currently do not predict the nucleation, growth and fall-out of artificially created snowflakes. Some of these simulations have been subject to the important step of independent verification though studies of the silver content of snow.

8.0 REVIEW OF ENVIRONMENTAL AND LEGAL ASPECTS (Task 6)

8.1 Environmental Considerations

There are a number of issues related to the conduct of a cloud seeding program that are concerned with perceived or potential negative impacts from the seeding program on the environment or on residents in and downwind of the region of the cloud seeding operations area. A summary of what is known regarding the items of particular concern is provided in the following.

8.1.1 Downwind Effects

Perhaps the most frequently asked question regarding the possible establishment of a cloud seeding program in an area that has not previously been involved in cloud seeding programs is: "Won't you be robbing Peter to pay Paul if you conduct a cloud seeding program in this area?" In other words, won't areas downwind of the intended target area experience less precipitation during the seeded periods? The perhaps surprising answer to this question is "no." This answer is based upon analysis of precipitation in a number of areas downwind of research and operationally oriented cloud seeding programs. In a review paper on this topic, Long (2001) provides information from a variety of both winter and summer programs. One winter research program that is perhaps most relevant to wintertime programs was one conducted by Colorado State University scientists in the Climax, Colorado area. That area is located in a mountainous region in the Central Colorado Rockies. The randomized seeding program was conducted in two phases that came to be known as Climax I and Climax II. Quoting from Long (2001), "Janssen, Meltsen and Grant (1974) investigated downwind effects of the Climax I and II programs. They noted that their investigation was post hoc and as such was exploratory rather than confirmatory. In order to detect downwind precipitation effects drifting from the Climax target area, various time lags ranging from 3 to 187 hours in precipitation data from hourly stations in downwind locales were considered. Significant ratios of seeded to not-seeded precipitation, with low probabilities of being due to chance, were found downwind east and northeast of the Climax area. These ratios were in the range of 1.15 to 1.25 during the 3-12 hour time lag period." This suggests **increases** in precipitation on the order of 15-25% downwind of the intended target area. Long makes a summary statement in his paper as follows: "Downwind precipitation effects have been observed in geographic areas and time frames that are about the same magnitude as primary effects intended for the target area. There is little evidence of a decrease in precipitation outside the target area."

An example of an analysis of potential downwind effects from an operational winter program is found in Solak, et al, 2003. That paper examined the precipitation that fell in areas located in eastern and southeastern Utah and western Colorado, located downwind of a long-term winter program that has been conducted most winters since 1974 in the central and southern Wasatch Mountains of Utah. The abstract from this paper is as follows: "Estimations of effects on precipitation downwind of a long-standing operational snowpack augmentation program in Utah are made, using an adaptation of the historical target/control regression technique which has been used to estimate the seasonal effects over more than twenty seasons within the program's target area. Target area analyses of December-March high elevation precipitation data for this program indicate an overall seasonal increase of about 14%. Estimations of downwind effects are made for distance bands downwind as far as 150 miles. The downwind analyses indicate increases of similar magnitude to those for the target, expressed as percentages or ratio values, extending to about 100 miles downwind. Beyond 100 miles the ratio values decay, reaching about 1.0 (e.g., no effect) at about 125 miles. Expressed as average-depth precipitation amounts, the target area precipitation difference is about 1.4 inches of additional water, while the values within downwind distance bands range from 0.4 to 0.25 inches, reaching zero at about 125 miles."

8.1.2 <u>Toxicity of Seeding Agents</u>

By far the most common seeding agent in use today on winter orographic cloud seeding programs is silver iodide. The potential environmental impacts of silver iodide have been studied extensively. Klein (1978) in a book entitled "Environmental Impacts of Artificial Ice Nucleating Agents" concludes that "The major environmental concerns about nucleating agents (effects on plant growth, game animals, and fish, etc.) appear to represent negligible environmental hazards. The more subtle potential effects of silver-based nucleating agents, such as their possible ability to potentiate the movement or effects of other materials of environmental concern, or to influence the activity of microorganisms in soils and aquatic environments after being bioconcentrated by plants, warrant continued research and monitoring. Effects, if they occur, are not expected to involve unacceptable risks. The long-term use of silver iodide and the confidence which the weather modification profession has in delivery systems and in the efficacy of this material, make it unlikely that other agents, with the exception of dry ice, will be used on a large scale, unless there are improvements in delivery systems and major changes in the economics of silver availability." In the same book a summary of potential impacts on humans is presented as follows: "The effects on humans of ingestion or topical contact with silver iodide used in cloud seeding can be considered negligible. Decade-long observations of cases (unrelated to cloud seeding) of ingestion of large silver doses revealed no physiological concern. In addition, surveys of seeding generator operators who have had long-term intensive contact with silver iodide reveal that they have not experienced medical difficulties."

A report prepared by the Metropolitan Water District of Southern California (Ryan, 2005) contains the following summary on the topic of possible toxicity of silver iodide:

> *"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 programs, many of which have been in operation for 30 to 40 years (WMA, 1996)".

The concentration of silver in rainwater or snow from a seeded cloud using the above information is on the order of 1000 times less than the EPA Standard.

Also worth noting here is a statement by the Weather Modification Association in its formal policy statement (WMA 2005):

> *"The potential environmental impacts of cloud seeding have been addressed in many studies. No significant adverse environmental impacts have been found due to use of silver iodide, the most commonly used seeding material, even in program areas where seeding has been conducted for fifty years or more".*

Specific to silver concentrations in snowmelt water, Marler (2007) reported on lake water and sediment studies conducted for two long-term seeding programs operated by the Pacific Gas and Electric Company (PG&E) in the Sierra Nevada of California. Samples from a number of surface sites were analyzed for their silver content. The program areas are subject to moderate seeding material releases over periods of nearly fifty years, with annual amounts varying from 9-90 pounds for the Mokelumne area and from 45-180 pounds for the Lake Almanor area.

The report presented the following characteristics regarding silver iodide and silver chloro-iodide compounds used in cloud seeding.

- *"Have extremely low solubility in water*
- *Remain solid particles in air, cloud, precipitation*
- *Do not ionize to produce Ag+ under ambient environmental conditions*
- *Are not very bio-available in the environment*
- *Background Ag concentrations in Sierra snow < 2.0 ppt(ppt= gAg/ml x 10-12)*
- *[Ag] in seeded snow typically range 40–60 ppt in layers sandwiched between unseeded snow.*
- *Total snowpack profile mean Ag concentrations average 5-20 ppt in highly effective seeding programs"*

Conclusions from the overall study include the following (from Marler, 2007)

- *"High resolution analysis of water, sediment and biological samples from areas subjected to long-term, 50 year+, cloud seeding programs,* *specifically PG&E's Mokelumne and Lake Almanor cloud seeding programs, support the following:*

- *The amount of silver iodide released to the atmosphere in cloud seeding is small, and even after many years of cloud seeding operations the resulting environmental concentrations very small to non-detectable.*
- *Given the stability of silver iodide compounds, extreme insolubility of silver iodide in water and the absorptions of ionic silver by colloids found in the sediments and aquatic vegetation, silver concentrations in the Mokelumne and Lake AlmanorBasin from cloud seeding are expected to be minimal.*
- *Since the monitored levels are low, usually below the detection limit in the target watershed, it is unlikely that continued cloud seeding operations would result in any significant increase in silver concentrations in the target watersheds.*
- *Silver concentrations were below regulatory standards. Therefore, continued operations should not result in any significant chronic effect to sensitive aquatic organisms.*
- *There is little to suggest the silver from cloud seeding gets into the system and bio-accumulates in organisms."*

8.1.3 Avalanche Considerations

Avalanche hazard is a factor worthy of consideration due to the amount of backcountry recreational activity in the program area. Contact with the USDA Forest Service in the region of the program area yielded a referral to the avalanche information and advisories issued via the *Backcountry Avalanche Hazard & Weather Forecast* produced from Jackson Hole, Wyoming, in cooperation with the Bridger-Teton National Forest. Two districts covered in those advisories, the Greys River and Teton Districts, abut the eastern boundary of the eastern portion of the seeding program area. Additional information for the near region is available from the Gallatin National Forest Avalanche Center, which operates from Bozeman, Montana. Their forecast and advisory area abuts the seeding program area on the north, including the West Yellowstone-Targhee Pass-Lionhead Mountain region. Monitoring of these sources could provide an index of general conditions in the highest elevation backcountry portions of the seeding program area. An additional potential source is the Sawtooth National Forest Avalanche Center in Ketchum, Idaho. That group is focused on avalanche conditions for the central mountains of Idaho, but apparently may occasionally issue a statement for the program area. However, this would not be considered a primary source.

Conditions are assessed daily during the winter months and reported to the named central locations from which daily advisories are issued. The information is readily available via the internet in the form of a *Backcountry Avalanche Hazard & Weather Forecast* which can be accessed at www.jhavalanche.org from the Jackson Hole source and the *Gallatin National Forest Avalanche Advisory* from Montana at www.mtavalanche.com. The Sawtooth National Forest Avalanche Center website can be viewed via www.avalanche.org.

The daily products typically consist of a weather summary for the preceding 24-hr period, mountain weather forecasts for the current day (and in some cases, three days), and a General Avalanche Advisory. That advisory includes an avalanche hazard rating within the widely-accepted national standard range of five levels of hazard. During the latter portion of the winter season, when more spring-like conditions can occur, separate hazard ratings may be shown for morning and afternoon. The five national hazard categories and their published definitions are shown here.

Low:	Mostly stable snow exists. Avalanches are unlikely except in isolated pockets.
Moderate:	Areas of unstable snow exist. Human triggered avalanches are possible. Larger triggers may be necessary as the snowpack becomes more stable. Use caution.
Considerable:	Dangerous unstable slabs exist on steep terrain on certain aspects. Human triggered avalanches probable. Natural avalanches possible.
High:	Mostly unstable snow exists on a variety of aspects and slope angles. Natural avalanches are likely. Travel in avalanche terrain is not recommended.
Extreme:	Widespread areas of unstable snow exist and avalanches are certain on some slopes. Backcountry travel should be avoided.

The Jackson Hole web site includes archives of the daily advisories for a period of the most recent one or two years. Daily data from the archive for two winter seasons were tabulated for the Greys River District (east of the program area), noting the highest hazard category shown for each of 312 total days. The seasonal occurrence and average proportion of days within each category are shown in Table 8-1, providing a snapshot of the magnitude and hazard level in a neighboring region.

Table 8-1
Avalanche Advisories for the 2001-2002 and 2002-2003 Winter Seasons
Greys River District (western Wyoming)

Hazard Cat.	2001-2002	2002-2003	Total	Percentage
Extreme	0	0	0	0%
High	10	14	24	8%
Considerable	45	58	103	33%
Moderate	67	60	127	40%
Low	28	30	58	19%

The information contained in the daily advisories appears to be adequately objective and consistently provided to be of use in suspension considerations in the ESRBP program. From the language in the category definitions, it would seem that days rated as in the Extreme or High categories should trigger a temporary seeding suspension. Further discussion with the program sponsors will determine how the avalanche information should best be incorporated into operational decision-making.

8.1.4 Snow Removal

Some have questioned what the associated costs are related to the removal of snow that is created by winter cloud seeding programs. This topic was addressed in a couple of studies. One such study was performed by the Colorado Department of Natural Resources (Sherretz and Loehr, 1983). The conclusions from this study are as follows:

> *"Simulating the effects of cloud seeding on the costs of snow removal indicates that the costs do increase when recorded snow amounts, in approximately one-third of the storms in selected winters, are augmented by 25 percent. The increases in costs range from 0.8 percent to 12.6 percent in the counties studied. Average increases are 6.1 percent in winters of high and average snowfall, and 4.9 percent in winters of low snowfall. Costs in winters of low snowfall average 81 percent of costs in winters of average snowfall, while costs in winters of high snowfall average 141 percent of costs in winters of average snowfall. These variations of 19 percent and 41 percent indicate that costs generally change more with natural variations in seasonal snowfall than with augmentation.*
>
> *Actual effects of cloud seeding on the costs of removing snow cannot be determined definitively, however, until more accurate records of employee and equipment expenses are available and until atmospheric scientists determine if, and by how much, seeding can increase snowfall. Recommendations for record-keeping include daily accounting of the hours employees spend performing removal tasks, hours machines are used, maintenance costs and fuel consumption."*

The Bureau of Reclamation supported contractors that designed and conducted a winter cloud seeding research program in the American River Basin of the northern Sierra Nevada Mountains of California. This program was known as the Sierra Cooperative Pilot Program (SCPP). The SCPP preliminary studies included assessments of the effect of the program upon highway use, safety, and operation and maintenance costs.

A California Department of Transportation (CALTRANS) memorandum report (CALTRANS, 1976) discussed socio-environmental effects that might occur. The study considered:

1) The effect if accumulated snowpack were increased up to 15 percent per annum in normal or below-normal years
2) Manpower and equipment requirements for snow removal per year and per storm under historical conditions
3) The costs for dry, average, and wet years

The report noted that avalanche control has been required only on Route 50 in El Dorado County between Echo Summit and Meyers. No substantive correlation was found between an incremental storm increase and the cost of highway avalanche control.

The study found little direct relationship to increased costs for small incremental changes in storm size because of the amount of equipment and manpower necessary to maintain a traversable roadway under frost conditions or handle the problems of freeze-thaw of snowbanks adjacent to the roadway which cause icy conditions. Also, road closures are more frequently caused by blowing and drifting snow or severe icing conditions rather than the amount of snowfall.

Existing recorded data do not allow an analysis of costs involved in snow removal for small incremental increases in precipitation. However, data are available for maintenance costs related to storm severity.

8.1.5 Delay of Snowmelt

One concern formerly mentioned in conjunction with cloud seeding programs in the west was: Would the increases in snow due to cloud seeding extend the snow melt period? This concern was voiced by ranchers having grazing rights in some of the targeted areas who wondered if the cloud seeding would delay their moving of livestock into these areas in the springtime. This topic was addressed in an environmental study conducted in the Uinta Mountains of Utah, which was funded by the Bureau of Reclamation offices in Denver (Harper, 1981). The conclusion reached in this study was that "An increase of 10% in the average snowpack is estimated to retard the 75% snow-free date 0.7 – 1.5 days." In other words, this should not be a significant concern.

8.1.6 General Statements on the Potential Environmental Impacts of Winter Cloud Seeding

A large number of studies have been conducted in the western United States related to the potential environmental impacts of winter cloud seeding. Most of these studies were funded under the Bureau of Reclamation's "Skywater Program". Four programs of note concerned with wintertime programs were:

- Potential Ecological Impacts of Snowpack Augmentation in the Uinta Mountains, Utah. A 1981 report from Brigham Young University authored by Kimball Harper (Harper, 1981) summarizing the results of a four-year study.

- Ecological Impacts of Snowpack Augmentation in the San Juan Mountains, Colorado. A 1976 report edited by Harold Steinhoff (Colorado State University) and Jack Ives (University of Colorado) summarizing the results of a five-year study (Steinhoff and Ives, 1976).
- The Medicine Bow Ecology Program. A 1975 report on studies conducted in the Medicine Bow Mountains of southern Wyoming (Knight, 1975).
- The Sierra Ecology Study. A five-volume report summarizing work on possible impacts on the American River Drainage in California (Smith, et al, 1980).

In general, the findings from these studies were that significant environmental effects due to the possible conduct of cloud seeding programs in these areas were not expected to occur. A couple of examples that support this conclusion are as follows: A statement made in the final report on the San Juan Mountains program (Steinhoff and Ives, 1976): "The results of the San Juan Ecology Program suggest that there should be no immediate, large-scale impacts on the terrestrial ecosystems of these mountains following an addition of up to 30 percent of the normal snowpack, but with no addition to maximum snowpacks. Further, much of the work reported here suggests that compensating mechanisms within the study's ecosystems are such that any impacts would be buffered, at least for short periods of time, and of lesser magnitude than the changes in snow conditions required to produce them."

The Bureau of Reclamation published an "Environmental Assessment and Finding of No Significant Impact (Harris, 1981) for the Sierra Cooperative Pilot Program. Quoting from the introduction of this report:

"This document and the program environmental assessment serve as the basis for determination that no further action is necessary to comply with the National Environmental Policy Act of 1969 (Public Law 91-190) for the following reasons:

1) *The Sierra Cooperative Pilot Program Environmental Assessment examines a research program designed to seed, on a randomized basis, some of the cloud types which occur within winter storms in the Sierra Nevada of California and Nevada. The increase in annual precipitation expected from seeding all eligible storms during an average or less-than-average year would be 10 to 15 percent. The annual precipitation increase expected from randomized seeding of selected cloud types would be 5 to 7.5 percent. The report analyzes the potential effect of these increases upon weather elements, hydrologic and physiographic phenomena, plant and animal communities, the human environment, and land and water resource use in the program area. It also discusses possible impacts of the seeding agents, dry ice and silver iodide. The report concludes the research program will not result in significant or adverse effects upon the environment.*
2) *Consultation with Federal and State agencies has resulted in the determination that this program will not affect endangered or threatened species of plants or wildlife or their habitats in a significant or adverse manner.*
3) *Archeological and historic sites and sites of extraordinary aesthetic value will not be significantly or adversely affected by the program.*

4) *Program activities and resultant increases in precipitation will not affect the human environment, lifestyle, or existing land and water resource use in a significant or adverse manner. The program design includes suspension criteria to prevent operations during periods that would lead to public safety hazards."*

The American Society of Civil Engineers has published its Manual 81 on Engineering Practice, entitled *Guidelines for Cloud Seeding to Augment Precipitation* (ASCE 2006). A section of that publication addresses environmental issues relating to weather modification. A key summary paragraph from Manual 81 is shown here.

"The essence of the results is that changes that might be expected in the environmental factors (1) were most often subtle, nil, or indiscernible in relation to other natural influences (e.g., effects of fire or insects on forest vegetation); (2) would be of the same type and magnitude as would result from a sustained increase of a corresponding percent(age) in natural precipitation (e.g., as a gradual change in herb species composition might occur in a wetter climate); (3) might be beneficial as often as not and depending on point of view (e.g., as when fish habitat increases with lake level); and (4) would have net outcomes that strongly affect ecosystem management practices (e.g., as when increased weed growth and grassland productivity occur together). During the 1970's, seeding agents, chemical complexes of silver iodide, were examined for ecological effects (Cooper and Jolly, 1970; Klein, 1978). Conclusions from those studies point to little or no effects on terrestrial or aquatic biological communities, either immediately or after many, many years of silver iodide application in the small dosages possible from cloud seeding (Reinking et al. 1995)."

8.2 General Legal Implications

There are legal implications associated with the conduct of cloud seeding programs. For example, who owns any additional water produced from cloud seeding activities? Most state regulations claim ownership of these waters remains with the state to be distributed according to the existing water rights in the area. There are permitting and reporting requirements normally associated with the performance of cloud seeding programs. There would be both state and national requirements associated with the ESRBP program. These requirements are summarized in Section 8.3.

Another possible legal consideration is the level of exposure the program sponsors may have regarding legal responsibility for any perceived damages caused by the seeding activities? For example, if seeding was conducted and a flood occurred in or near the program's target area, would the sponsors be held liable? Such situations are sometimes referred to as the possible "consequential effects" of cloud seeding. The first line of defense in such circumstances is to have adequate safeguards built into the design of the seeding program to suspend seeding operations if/when questionable circumstances develop (as discussed in Section 7.3). A few lawsuits have been filed over the years, claiming damages caused by cloud seeding programs. According to ASCE Manual No. 81 (1995): "Defendants have won almost all liability suits." The primary reason for this outcome is that the burden of proof falls upon the plaintiffs to prove that the cloud seeding activities caused or contributed to the damages.

Some weather modification operators also carry a special type of insurance commonly known as "consequential effects of cloud seeding liability insurance." This insurance protects both the operator and sponsors of insured programs.

Another type of legal requirement is program permitting and reporting requirements. There will be some permitting and reporting requirements associated with the conduct of a cloud seeding program should the decision be made to proceed to an operational phase based upon this preliminary design work.

8.3 Permit and Reporting Requirements

8.3.1 State of Idaho Permit Requirements

The State of Idaho has a statute that requires the registration of producers of artificial rainfall. The reference is Title 22, Chapter 32, Rainfall- Artificial Production, Section 22-3201 (registration) and 22-3202 (log of activities).

Section 22-3201 states that "Any person, persons, association, firm, or corporation conducting or intending to conduct within the state of Idaho operations to assist artificially in production of or to produce artificially rainfall shall register with the department of agriculture of the state of Idaho. Such registration shall require the filing of the name of the person, association, or corporation, its residence, or principal place of business in the state of Idaho and the general nature of the business to be conducted."

Section 22-3202 states that "Such person, persons, association, firm or corporation shall thereafter file with the said department of agriculture a log of all its activities in the production, artificially, within this state, of rainfall."

NAWC has been granted a number of annual permits following the procedures established by the Idaho Department of Agriculture.

8.3.2 U.S. Forest Service and Bureau of Land Management Permits

Permits are normally required to install any type of equipment on U.S. Forest Service or BLM lands. Since we are tentatively recommending that remotely controlled silver iodide generators be considered in the conduct of the ESRBP, special use permits may be required. Similar permits would be required for either Forest Service or BLM lands. There would likely also be some permit or approval process when siting equipment on Indian Tribal Lands.

8.3.3 National Oceanic and Atmospheric Administration Reporting

In 1971, Public Law 92-205 was enacted that required all non-federally sponsored attempts to modify the weather be reported to the Secretary of Commerce of the United States. Public Law 92-205 requires the submittal of Initial, Interim and Final reports covering weather modification activities for individual target areas. An initial report is required each year seeding is planned and at least 10 days prior to the start of activity. Interim reports are required for those programs active on January 1st of each year and must be filed within 45 days of that date. A Final report must be submitted within 45 days after the completion of the weather modification activity (Golden, 1995). The information required in the interim activity and final reports include: 1) number of weather modification days each month, 2) number of modification days for purposes of increasing rain or snow, reduction of hail, fog or other, 3) hours of apparatus operation (airborne or ground), and 4) type and amount of cloud seeding agent used.

It is important to note that Public Law 92-205 is a reporting requirement but establishes no regulatory authority.

9.0 COST ESTIMATES (Task 7)

Preliminary cost estimates have been prepared for: 1) a pre-seeding season of sampling, 2) annual cost of a program only utilizing manually operated, ground based silver iodide generators (core program) and, 3) the annual cost of adding one turbine cloud seeding aircraft to the core program. Costs are provided for a five-month operational period (tentatively November through March). Costs include estimates of the reimbursable expenses of seeding (e.g., seeding materials and flight hours).

9.1 Estimated Cost to Conduct One Winter Season of Preliminary Data Acquisition

As mentioned in Section 5.7 NAWC recommends one winter season of project specific data collection prior to the beginning of any seeding activities. Data of primary interest will be the presence, frequency and magnitude of supercooled liquid water (slw) in winter clouds over and upwind of the proposed target areas and the temperature, moisture and wind structure of the lower atmosphere during winter storm periods. It is proposed that one icing rate meter be installed at a suitable location in each of the proposed target areas to collect the slw information and that rawinsondes (weather ballons) be launched every six hours during storm periods. A passive microwave radiometer could be added to provide more comprehensive slw measurements if additional funding is available. The radiometer and radiosonde receiver would be located at a suitable location between the two program areas and the icing rate meters installed at exposed mountainous ground locations that are accessible and have electrical power available. It is proposed that these systems be operated for the five-month period of November through March. The preliminary estimated costs for the three systems are as follows:

Microwave Radiometer, Icing Rate Meter and Rawinsondes

<u>Set-up, Take-Down, Data Analysis and Reporting</u>

Personnel		$17,000
Direct		
Land leases		$ 3,000
Travel/per diem		$ 1,000
Report		$ 750
	Total	$21,750

<u>Five Months of Operations</u> (Nov-Mar)

Rawinsonde Observations		$110,000
Icing Rate Meter (2) Observations		$ 60,000
Radiometer Observations		$ 50,000
	Total	$220,000

Estimated Grand Total $243,750

Rawinsonde observations are budgeted for 100 releases during the November through March period. Radiometer observations would be acquired using a dual channel (water vapor and water liquid) microwave radiometer. The three types of observations are listed in descending order of priority. In other words, rawinsonde observations are listed as the first priority. This was done in case financial resources are not available to fund all three types of observations.

9.2 Manually Operated Silver Iodide Ground Generator Program (Core Program) North Area

Assumptions: Five month program (Nov. – Mar.), 17 ground based generators sited at suitable local residences; estimated 3,000 seeding hours; local, part-time technician performing generator installation and removal, re-charging and maintenance tasks; direction of seeding activities from the contractor's headquarters; annual final report preparation including an analysis of possible effectiveness of the seeding operations, attendance at public meetings regarding the program as needed.

<u>Set-up, Take-down and Reporting Costs</u>

Personnel		$30,250
Direct		
Equipment (generators, propane tanks)		$10,100
Mileage, public meetings		$ 3,200
Insurance		$ 2,500
Final Report		$ 1,500
	Sub-total	$17,300
	Total	$47,550

<u>Five Months Fixed Costs</u>

Personnel		$60,225
Direct (technician travel, per diem, telephone calls, computer use charges, etc.)		$ 8,000
	Total	$68,225

<u>Estimated Five Months Reimbursable Costs</u>

Generator Usage, 3000 hours at $8.00/hr.	$24,000

Estimated Grand Total $139,775

9.3 Manually Operated Silver Iodide Ground Generator Program (Core Program) East Area

Assumptions: Five month program (Nov. – Mar.), 23 ground based generators sited at suitable local residences; estimated 4,000 seeding hours; local, part-time technician performing generator installation and removal, re-charging and maintenance tasks; direction of seeding activities from the contractor's headquarters; annual final report preparation including an analysis of possible effectiveness of the seeding operations, attendance at public meetings regarding the program as needed.

Set-up, Take-down and Reporting Costs

Personnel		$30,250
Direct		
Equipment (generators, propane tanks)		$12,800
Mileage, public meetings		$ 4,000
Insurance		$ 2,500
Final Report		$ 1,500
	Sub-total	$20,800
	Total	$51,050

Five Months Fixed Costs

Personnel		$65,225
Direct (technician travel, per diem, telephone calls, computer use charges, etc.)		$10,000
	Total	$75,225

Estimated Five Months Reimbursable Costs

Generator Usage, 4000 hours at $8.00/hr.		$32,000
	Estimated Grand Total	**$158,275***

* The generator hours are estimates. Client is typically invoiced based on actual usage. Therefore the estimated total cost could be lower depending on the frequency of seedable conditions.

9.4 Manually Operated Silver Iodide Ground Generator Program (Core Program) Combined North and East Areas

Assumptions: Five month program (Nov. – Mar.), 40 ground based generators sited at suitable local residences; estimated 7,000 seeding hours; local, part-time technician performing generator installation and removal, re-charging and maintenance tasks; direction of seeding activities from the contractor's headquarters; annual final report preparation including an analysis of possible effectiveness of the seeding operations, attendance at public meetings regarding the program as needed.

Set-up, Take-down and Reporting Costs

Personnel		$45,375
Direct		
Equipment (generators, propane tanks)		$22,900
Mileage, public meetings		$ 5,000
Insurance		$ 2,500
Final Report		$ 2,000
	Sub-total	$32,400
	Total	$77,750

Five Months Fixed Costs

Personnel		$81,530
Direct (technician travel, per diem, telephone calls, computer use charges, etc.)		$15,000
	Total	$96,530

Estimated Five Months Reimbursable Costs

Generator Usage, 7000 hours at $8.00/hr.		$56,000
	Estimated Grand Total	**$230,280***

* The generator hours are estimates. Client is typically invoiced based on actual usage. Therefore the estimated total cost could be lower depending on the frequency of seedable conditions.

9.5 Addition of One Seeding Aircraft to Core Program (section 9.2, or 9.3, or 9.4)

Assumptions: lease of turbine engine aircraft equipped with acetone/silver iodide generators for 5 months, one aircraft pilot, base of operations established at suitable airport near target areas, project meteorologist stationed at operations base (seeding decisions will be made from this location), one project meteorologist assistant, no project dedicated weather radar (NWS NEXRAD radar to be used).

Set-up, Take-down

Personnel	$17,000
Direct	
One-half month lease of aircraft	$25,000
Pilot, meteorologist per diem and travel	$ 3,000
Sub-total	$45,000

Five Months Operations

Personnel	$ 74,500
Direct	
Aircraft lease	$250,000
Office, hangar, computers, utilities	$ 10,000
2 vehicles	$ 7,500
pilot/meteorologist per diem	$ 20,000
Sub-total	$362,000

Estimated Reimbursable Costs

100 Flight hours @ $300/hr	$ 30,000
80 hours of airborne generator usage @ $80/hr	$ 6,400
Sub-total	$ 36,400
Grand Total	**$443,400***

These costs would be in addition to the core program costs.

* The flight hours and generator hours are estimates. Client is typically invoiced based on actual usage. Therefore the estimated total cost could be lower depending on the frequency of seedable conditions.

10.0 REPORT PREPARATION (Task 8)

As required by contract, monthly status reports, a final report (NAWC report No. 08-11), and an Executive Summary were provided to the Idaho Water Resource Board.

11.0 COORDINATION MEETINGS AND PRESENTATIONS (Task 9)

The RFP mentions the following meetings or presentations:

- A study kick-off coordination meeting with the IWRB's staff.
- A presentation of the study results to the IWRB's staff.
- A presentation of the study results to the ESPA Advisory Committee.
- A presentation of the study results to the IWRB.
- A presentation of the study results to the Natural Resources Interim Legislative Committee.
- Additional Coordination Meetings as necessary with the IWRB's staff.

Table 11-1 summarizes the meetings/presentation that were conducted regarding this contract.

Table 11-1
Meetings and Presentations

Presentation	Location	Group	Date(s)
Kick-off Meeting	Boise	IWRB staff	Feb. 12, 2008
Results of Statistical Analysis- Task 10	Rexburg	Cloud Seeding Committee	June 5, 2008
Results of Statistical Analysis- Task 10	Pocatello	Committee of Nine	September 11, 2008
Summary of Report Findings	Pocatello	Advisory Committee Eastern Snake Plain Aquifer	September 25, 2008
Summary of Study Results	Boise	IWRB	Not scheduled at the time this report was completed
Summary of Study Results	Boise	Natural Resources Interim Legislative Committee	Not scheduled at the time this report was completed

12.0 STATISTICAL ANALYSES OF A 2007-2008 WINTER CLOUD SEEDING PROGRAM IN EASTERN IDAHO (Task 10)

An operational winter cloud seeding program was conducted in eastern Idaho during the 2007-2008 winter season. Figure 12.1 provides the approximate target area and associated ground generator seeding locations for this upper Snake River cloud seeding program. A local group, Let it Snow headquartered in Clark County, was selected through a competitive bid process to conduct this program for the 2007-2008 winter season. It is perhaps worth mentioning that NAWC had also bid on the performance of this work.

Following the award of the contract to Let it Snow, North American Weather Consultants was contacted by the High Country Resource Conservation and Development Council and subsequently by the Idaho Water Resource Board (IDWR) concerning the development of an evaluation method that could be used to assess the potential impact of cloud seeding in this area for the 2007-2008 winter season. Both groups elected to fund this evaluation. In the case of the IDWR, a separate task to perform this work was added to another contract that had been awarded to NAWC to conduct a weather modification feasibility study for the upper Snake River Basin in Idaho.

The following sections provide the results of the work performed by NAWC on this task.

12.1 Background

One commonly employed statistical technique that has been utilized in the evaluation of operational cloud seeding programs is the "target" and "control" comparison. This technique is described by Dr. Arnett Dennis in his book entitled "Weather Modification by Cloud Seeding (1980)". This technique is based on the selection of a variable that would be affected by seeding (e.g., liquid precipitation, snowpack or streamflow). Records of the variable to be tested are acquired for an historical (not seeded) period of many years duration (20 years or more if possible). These records are partitioned into those located within the designated "target" area of the program and those in a nearby "control" area. Ideally the control sites should be selected in an area meteorologically similar to the target, but one that would be unaffected by the seeding (or seeding from other adjacent programs). The historical data (e.g., precipitation) in both the target and control areas are taken from past years that have not been subject to cloud seeding activities in either area. These data are evaluated for the same seasonal period as that of the proposed or previous seeding. The target and control sets of data for the unseeded seasons are used to develop an equation (typically a linear regression) that estimates the amount of target area precipitation, based on precipitation observed in the control area. This regression equation is then applied to the seeded period to estimate what the target area precipitation would have been without seeding, based on that observed in the control area(s). This allows a comparison between the predicted target area natural precipitation and that, which actually occurred during the seeded period to determine if there are any differences potentially caused by cloud seeding activities.

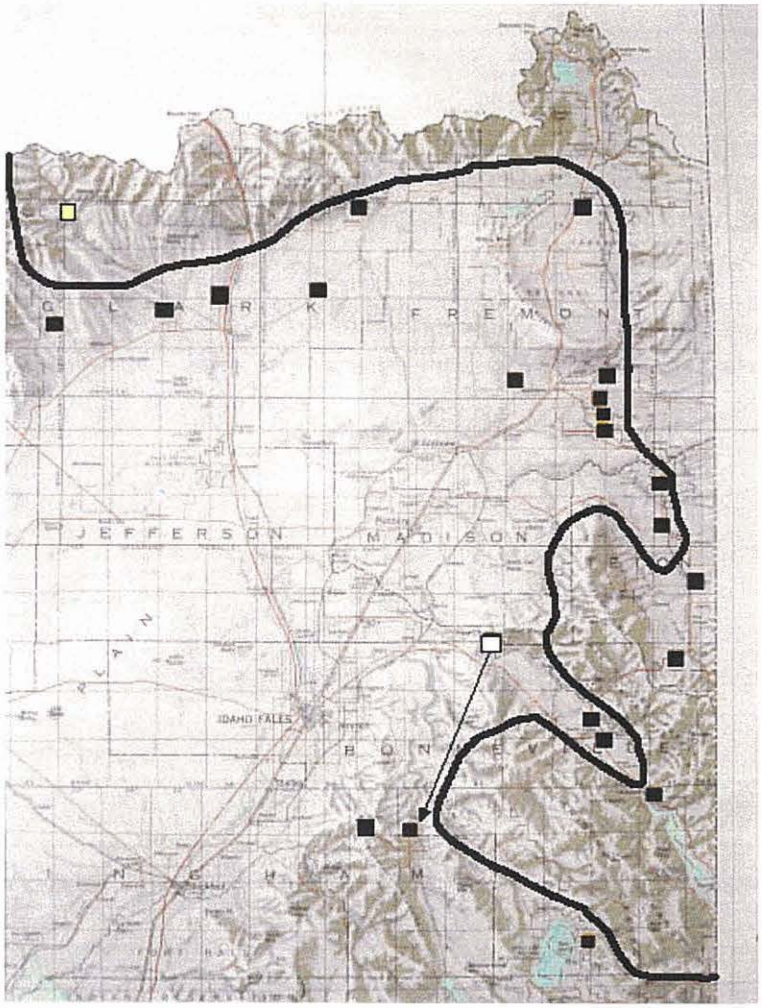


Figure 12.1 Map Showing Target Area and Seeding Generator Sites for the 2007-2008 Upper Snake Operational Seeding Program (one generator site, white box, moved during the season; one new generator site, yellow box, added during the season)

This target and control technique works well where a good historical correlation can be found between target and control area precipitation. Generally, the closer the target and control areas are in terms of elevation and topography, the higher the correlation will be. Control sites that are too close to the target area, however, can be subject to contamination by the seeding activities. This can result in an underestimate of the seeding effect. For precipitation and snowpack assessments, a correlation coefficient (r) of 0.90 or better would be considered excellent. A correlation coefficient of 0.90 would indicate that over 80 percent of the variance (r^2) in the historical data set would be explained by the regression equation used to predict the variable (expected precipitation or snowpack) in the seeded years. An equation indicating perfect correlation would have an r value of 1.0.

12.2 Development of Target/Control Evaluation Method for the Upper Snake River Basin

North American Weather Consultants (NAWC) had originally proposed that the development of this evaluation method be completed ***a priori***, i.e. prior to the start of the cloud seeding program on December 1, 2007. Due to delays in contracting, this was not possible. This approach would have unequivocally eliminated any question of possible bias on NAWC's part in selection of the control sites. In other words, there would be no way we would know the outcome of the evaluation based upon the control sites that were selected before the cloud seeding began as would be the case had we developed the evaluation equations after the end of the seeding program when the 2007-2008 winter data were available. Since we are completing this analysis in late February, the question of potential bias on our part is still low since there is over a month of seeding yet to be performed. In fact, at this time, we would only have two months of manual snow course observations available to us if we chose to consider this information (which we have not) since these measurements are scheduled to occur on or about the first of each winter month (typically January through April or May). Subsequent sections will indicate the importance of these manual snow course observations in the development of the evaluation methodology.

NAWC examined several different types of data for possible use as target and control data for an evaluation of this program. NRCS SNOTEL sites, located in mountainous areas of the state, report both precipitation and snow water content data throughout the year. The SNOTEL sites were typically installed at prior manually observed snow course sites. The establishment of SNOTEL sites began in 1981 at most sites. Precipitation gage data, as well as manual snowcourse data, is available for most of these sites for years prior to 1981. These data were utilized along with the post-1981 SNOTEL data. The manual snowcourse data at these sites was compared to the SNOTEL snow water data for the first 10 years or so after installation of the SNOTEL sites. Adjustments were made by the NRCS to the snowcourse data to match, in as much as possible, the SNOTEL data. Sites that continue to be operated as manual snowcourses provide snow water content measurements near the first of each month during the winter and spring. The measurements are normally made within a few days before or after the first of the month at these snowcourse locations. NWS co-op sites, generally in valley locations, provide monthly precipitation totals throughout the year. Evaluations of both precipitation and snow water content are viable using these different data sources. NAWC personnel entered available data from these sources into data files for additional analysis.

For the precipitation evaluation (December – March period), both SNOTEL precipitation data (as well as pre-1981 gage data) and valley co-op site data were examined. The co-op data was considered only for sites with a good stable record and with minimal missing data. Estimates were made in a few cases for months with 3 or more missing days, using data from nearby sites (it turned out for other reasons that none of the valley co-op sites were included in the final equations anyway). Double-mass plots, an engineering technique where data are accumulated sequentially for two locations and plotted on a graph, were produced for both the SNOTEL and co-op sites and sites. Questionable sites were eliminated based on these plots. Figure 12.2 provides an example of a plot of December through March precipitation data with a break in the relationship between two stations (Giveout and Pine Creek Pass). This plot indicates questionable data at one of the sites. Comparison of the Giveout site with another site (Sheep Mountain) indicates a stable relationship (Figure 12.3). It was therefore concluded that the Pine Creek Pass site had some discontinuity in its data, and it was among those excluded from the development of the regression equations.

For the snow water content evaluations (April 1st), both SNOTEL snow water data (including NRCS-adjusted pre-1981 snowcourse data for these sites) and data from current snowcourse sites were considered. Double-mass plots were made in this case also with questionable sites eliminated. Control site combinations best correlated with sites located in the target area were selected.

An historical period beginning in 1961 was selected on which to base the development of the regression equations. NAWC had conducted winter seeding programs in the target area shown in Figure 12.1 during the 1989, 1993 and 1995 water years (Risch, et al, 1995). It was NAWC's original understanding that winter cloud seeding programs were subsequently conducted during the 1997 through 2007 water years that affected both the North and East areas. We subsequently learned that this was not the case. One area was seeded in some years and not the other and vice versa. Also, there was some seeding in the 1996 Water Year in both areas. Nevertheless NAWC excluded these seeded seasons were from the data set and kept the 1996 water year as non-seeded historical year, which resulted in 30 years of data on which the regression equations would be developed. Sites without records going back to 1961 were not considered. In addition, the target area was divided into a "northern" portion (areas north of the Ashton area) and "eastern" portion (south and east of the Ashton area) due to significant climatological and terrain differences between these two areas. These two areas are indicated on Figure 12.4. Regression equations for precipitation and snow water content were considered for each portion; it was discovered that a precipitation evaluation was not feasible for the eastern portion. This is because there is only one precipitation measurement site (Pine Creek Pass) in this portion of the target and double-mass plots showed poor precipitation data reliability at that SNOTEL site (refer to Figures 12.2 and 12.3).

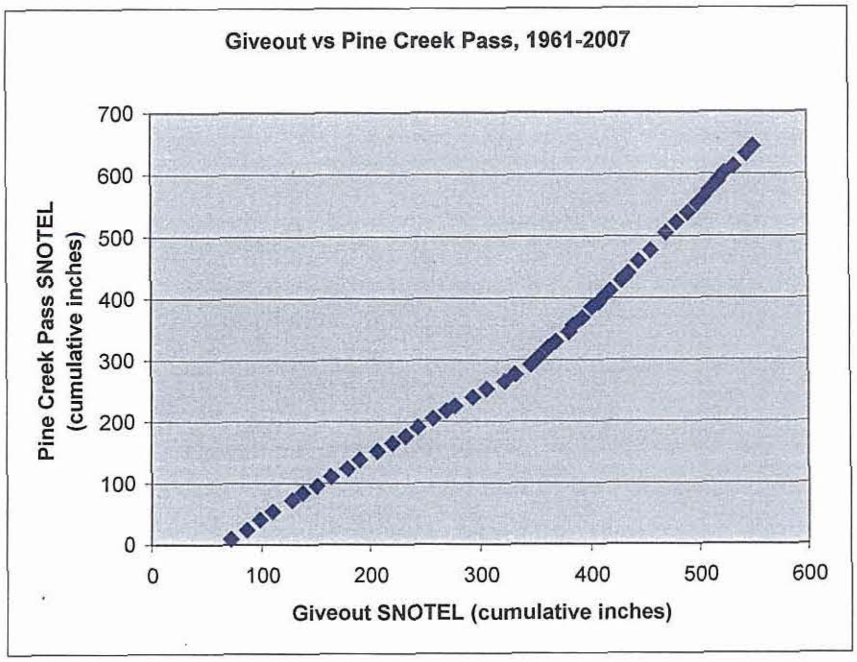


Figure 12.2 Pine Creek Pass Plotted Against the Giveout SNOTEL Site
(shows very poor agreement)

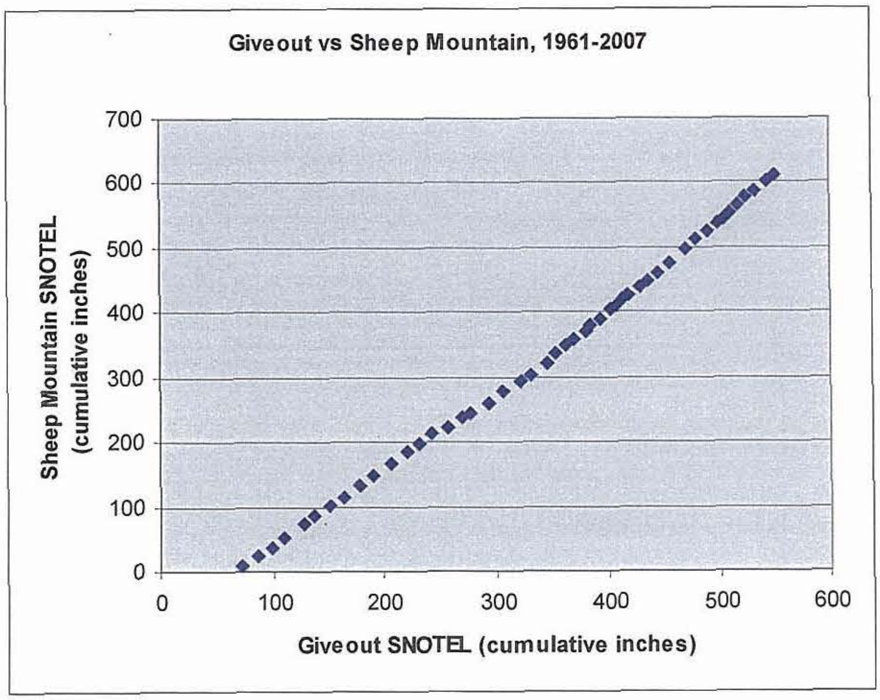


Figure 12.3 Sheep Mountain Plotted Against the Giveout SNOTEL Site
(plot shows relatively good agreement)

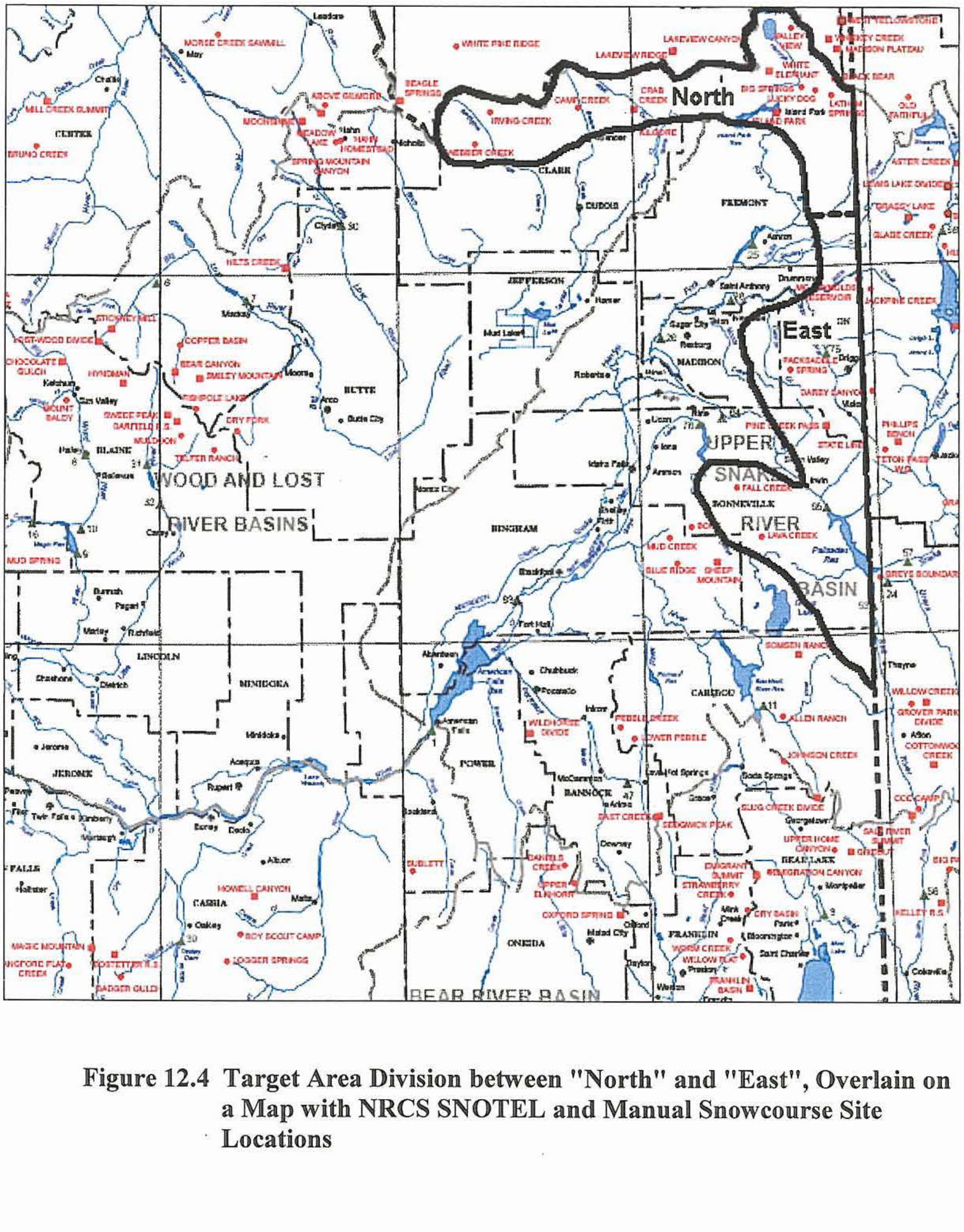


Figure 12.4 Target Area Division between "North" and "East", Overlain on a Map with NRCS SNOTEL and Manual Snowcourse Site Locations

Table 12-1 contains a list of sites excluded from consideration due to the double-mass plot analyses. Table 12-2 provides target and control sites selected for the evaluations, as well as the resulting linear and multiple linear equations. Figures 12.5 through 12.7 provide the locations of the target and control sites for the North target precipitation and snow water content, and the East target snow water content regression equations.

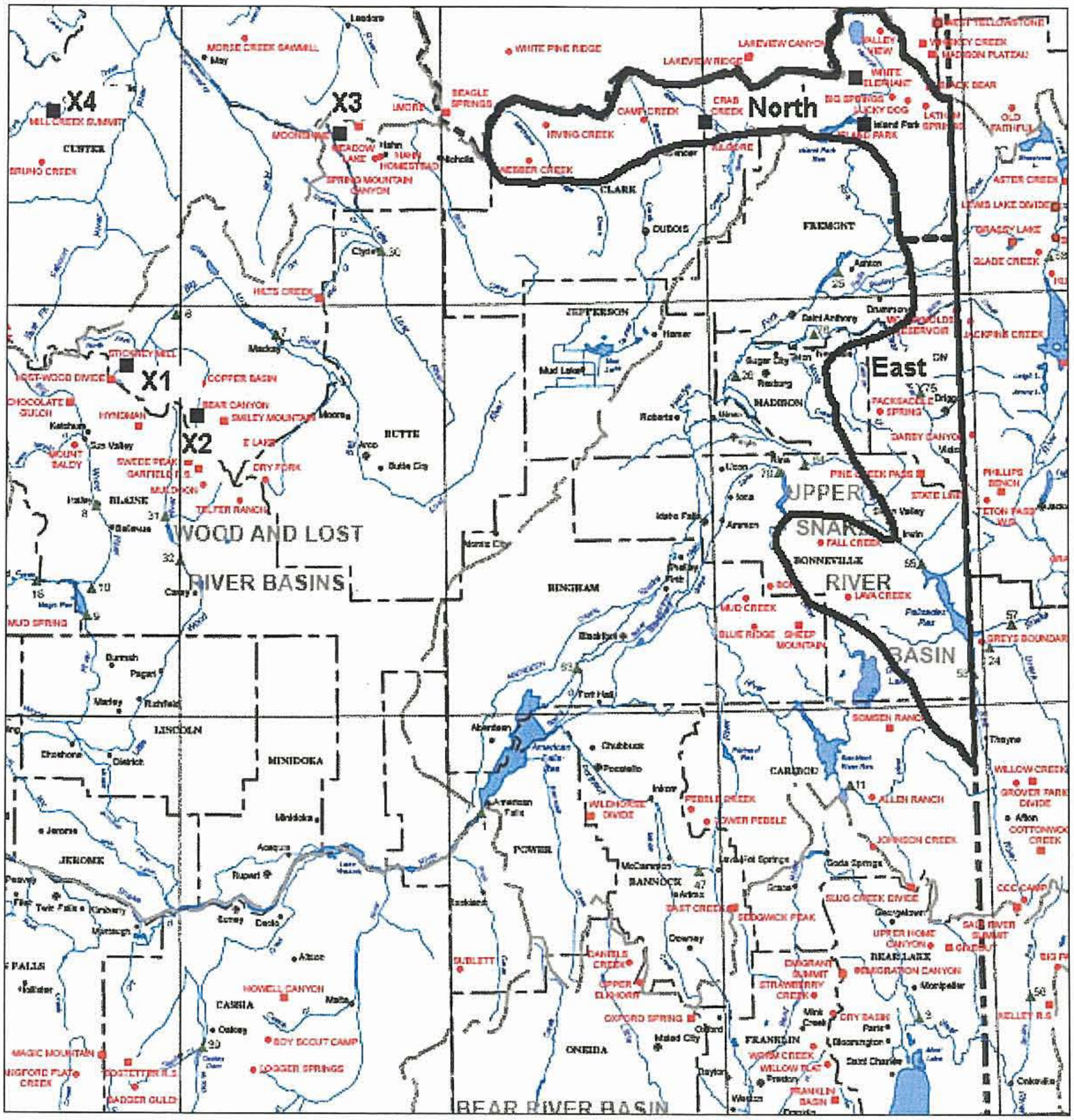


Figure 12.5 Map with Final Precipitation Evaluation Sites for the North Target Highlighted as Black Squares
(control sites labeled to correspond with Table 12-2)

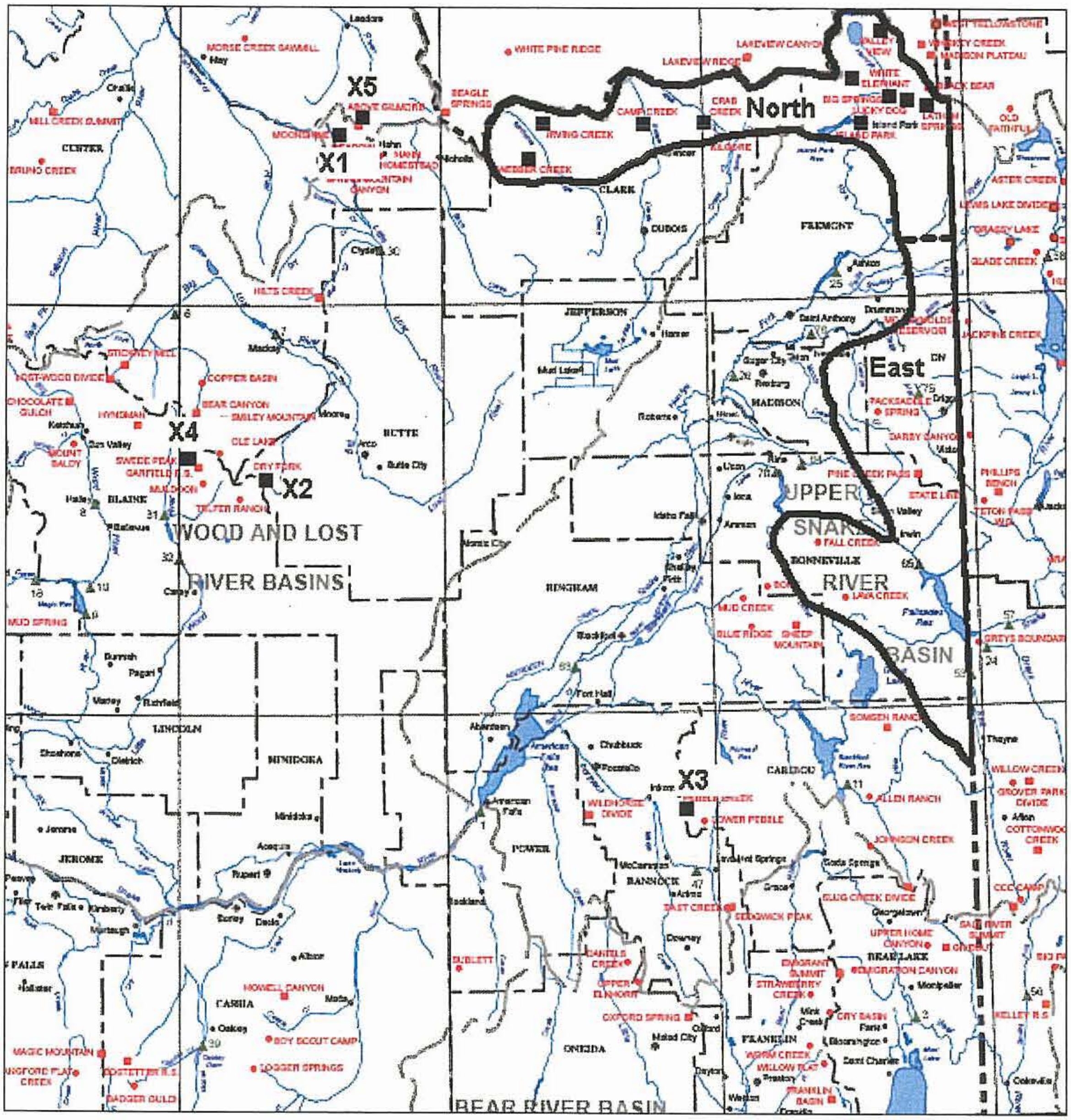


Figure 12.6 Map with Final Snowpack Evaluation Sites for the North Target Area

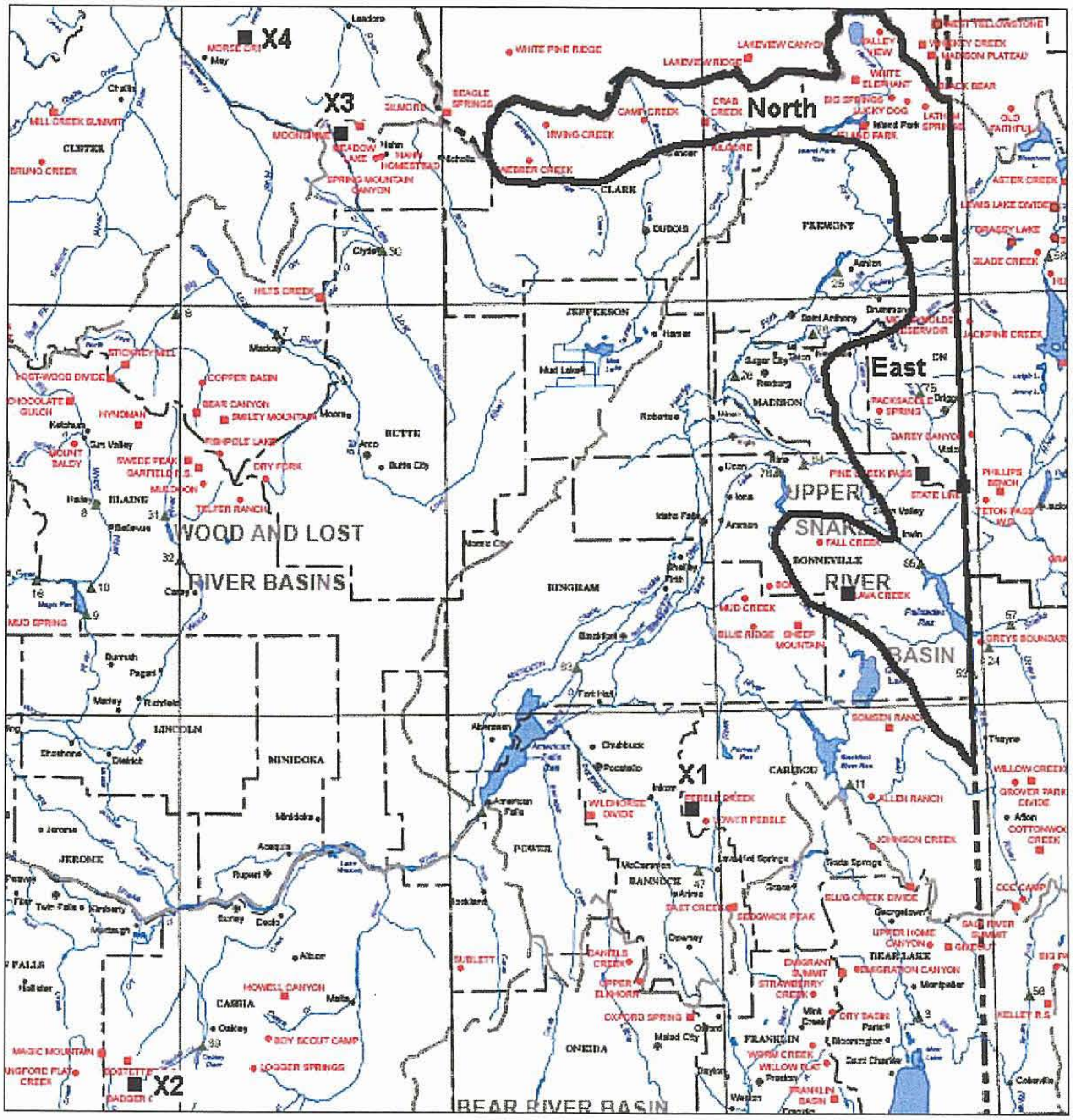


Figure 12.7 Map with Final Snowpack Evaluation Sites for the East Target Area

Table 12-1
Sites Excluded Based on Double Mass Plots

<u>Dec-Mar Precip (SNOTEL)</u>
Howell Canyon
Hilts Creek
Pine Creek Pass
Beagle Springs

<u>Dec-Mar Precip (NWS Co-op)</u>
Hamer 4NW
Dubois Exp Station

<u>April 1 Snow (SNOTEL)</u>
Bear Canyon
Oxford Spring

<u>April 1 Snow (Snowcourse)</u>
Langford Flat Creek
Daniels Creek
Bone

The difference between a linear and a multiple-linear equation is that for a linear equation all the potential control sites data for a specific season are averaged together. An equation is then developed between the single control area average values by season versus the single average target area values. Multiple-linear equations are those that allow the regression technique to consider individual site data instead of an average to correlate with the average target area values. In this manner, the regression technique weights the individual correlation of each control site with the target area average to obtain the best correlation.

In this analysis there were only very small differences indicated in the use of linear versus multi-linear equations. This conclusion is based on the very high and similar r values found using either technique. Recall that a perfect correlation would have an r value of 1.0. Therefore, the r values of .95 achieved in this analysis are considered quite high. This means that use of the selected control sites to predict the natural target area precipitation or snow water content for the 2007-2008 winter season should provide a good estimate. These high correlations should strengthen our ability to detect any differences that might be attributed to the seeding program.

This regression equation development work was completed in late February 2008, which is an important point since we cannot be accused of selecting control sites that yielded a desired indication. This could be possible if the equations were developed following the completion of the seeding activities.

Table 12-2
Regression Equations

North Target – December through March Precipitation:

Control (X)	Target (Y)
Stickney Mill SNOTEL (X_1)	Crab Creek SNOTEL
Bear Canyon SNOTEL (X_2)	White Elephant SNOTEL
Moonshine SNOTEL (X_3)	Island Park SNOTEL
Mill Creek Summit SNOTEL (X_4)	

Linear: $Y = 1.05(X) + 3.9$ $(r = 0.94)$
Multiple Linear: $Y = 0.56(X_1) + 0.21(X_2) + 0.21(X_3) + 0.12(X_4) + 4.5$ $(r = 0.95)$

North Target – April 1st Snowpack:

Control (X)	Target (Y)
Moonshine SNOTEL (X_1)	Crab Creek SNOTEL
Dry Fork snowcourse (X_2)	Island Park SNOTEL
Pebble Creek snowcourse (X_3)	White Elephant SNOTEL
Swede Peak SNOTEL (X_4)	Lucky Dog snowcourse
Above Gilmore snowcourse (X_5)	Big Springs snowcourse
	Valley View snowcourse
	Camp Creek snowcourse
	Irving Creek snowcourse
	Webber Creek snowcourse
	Latham Springs snowcourse

Linear: $Y = 1.05(X) + 3.4$ $(r = 0.95)$
Multiple Linear: $Y = 0.54(X_1) + 0.10(X_2) + 0.19(X_3) + 0.19(X_4) + 0.03(X_5) + 3.6$ $(r = 0.96)$

East Target – April 1 Snowpack:

Control (X)	Target (Y)
Pebble Creek snowcourse (X_1)	Pine Creek Pass SNOTEL
Badger Gulch snowcourse (X_2)	Lava Creek snowcourse
Moonshine SNOTEL (X_3)	State Line snowcourse
Morse Creek Sawmill snowcourse (X_4)	

Linear: $Y = 1.05(X) + 2.4$ $(r = 0.95)$
Multiple Linear: $Y = 0.30(X_1) + 0.28(X_2) + 0.25(X_3) + 0.15(X_4) + 2.82$

12.3 Results

The next step in this work was to collect the relevant target and control data from the 2007-2008 winter season once the winter season ended on March 31, 2008. The target and control station information was inserted into the appropriate equation provided in Table 12-2. In this manner, predictions of the average natural December-March target precipitation (for the North target area) or average target area April 1st snow water content (for both the North and East target areas) were obtained. These predicted amounts were then compared to the observed (actual) precipitation or snow water content values to see if there were any indicated differences that potentially could be attributed to the cloud seeding program. Calculations were also made for the historical seeded winter seasons of 1997-2007. Originally, we were only contracted to provide estimates for the 2007-2008 winter season (WY 2008) but, once the evaluation equations were developed, it was a simple matter to determine and include the 1997-2007 estimates (we did not evaluate the 1996 water year seeding since we had originally understood there had been no seeding conducted this year and we therefore included this year in our historical period from which the regression equations were developed in February, 2008). Our original work reported on in May 2008 in this regard was revised since we later found that the North and East areas were not always seeded during this historical period. It should be understood that we did not look at the possible seeding effects from these earlier seeded seasons in determining the mix of target and control sites on which to base our evaluations for the 2007-2008 winter season. Appendix B provides the historical seeding information provided to us by the High Country Resource Conservation and Development Council. Data found in this Appendix indicates that the amount of seeding conducted varied from periods as short as three months to as long as six months. Also, the number of seeding generators for the same target area varied from year to year. One would therefore expect varying indications of the effects of seeding from year to year. Also, estimates of any seeding effects in the months of April and May are not covered since our analyses is based either upon December through March precipitation or April 1st snow water contents. Based upon data provided in Appendix B, the water years that were considered seeded for the North area were 1997-2002, 2004, and 2006-2008 (eleven seeded seasons). The water years considered to be seeded for the East area were 2002-2005 and 2008 (five seeded seasons).

Tables 12-3 through 12-8 provide the linear and multi-linear equation method calculated values and results for the seeded seasons.

Table 12-3
North Target, April 1st Snow Water Content,
Linear Regression Equation Results

YEAR	XOBS	YOBS	YCALC	RATIO	EXCESS
1997	18.22	25.02	22.55	1.11	2.47
1998	11.44	15.16	15.43	0.98	-0.27
1999	15.58	20.15	19.77	1.02	0.38
2000	10.96	16.21	14.93	1.09	1.28
2001	5.54	8.78	9.24	0.95	-0.46
2002	9.88	14.90	13.79	1.08	1.11
2004	8.18	15.22	12.01	1.27	3.21
2006	18.02	19.94	22.34	0.89	-2.40
2007	5.96	9.57	9.68	0.99	-0.11
2008	**13.7**	**18.7**	**17.80**	**1.05**	**0.93**
Mean*	11.7	16.4	15.8	1.04	0.62

* missing data, 2003

Table 12-4
North Target, April 1st Snow Water Content,
Multiple-Linear Regression Equation Results

YEAR	Moonshine	Dry Fork	Pebble Creek	Swede Peak	Above Gilmore	YOBS	YCALC	RATIO	EXCESS
1997	14.80	20.40	18.40	24.00	13.50	25.02	22.20	1.13	2.82
1998	8.90	11.80	14.30	14.20	8.00	15.16	15.32	0.99	-0.16
1999	13.00	18.20	15.80	19.90	11.00	20.15	19.65	1.03	0.50
2000	8.30	12.40	11.90	13.40	8.80	16.21	14.48	1.12	1.73
2001	3.70	5.40	6.40	7.70	4.50	8.78	9.01	0.97	-0.23
2002	5.90	11.30	12.40	12.20	7.60	14.90	12.91	1.15	1.99
2004	7.00	6.10	10.90	10.30	6.60	15.22	12.27	1.24	2.95
2006	14.30	19.90	19.90	23.50	12.50	19.94	22.04	0.90	-2.10
2007	5.80	4.10	6.80	6.70	6.40	9.57	9.95	0.96	-0.38
2008	**12.6**	**12.8**	**17.6**	**15.0**	**10.5**	**18.8**	**18.28**	**1.03**	**0.47**
Mean*	9.4	12.2	13.4	14.7	8.9	16.4	14.9	1.10	1.49

Table 12-5
North Target, December – March Precipitation,
Linear Regression Equation Results

YEAR	XOBS	YOBS	YCALC	RATIO	EXCESS
1997	17.13	25.13	21.89	1.15	3:24
1998	8.75	15.10	13.10	1.15	2.00
1999	12.40	18.67	16.93	1.10	1.73
2000	10.65	15.67	15.10	1.04	0.57
2001	4.70	7.57	8.85	0.85	-1.29
2002	9.50	13.80	13.89	0.99	-0.09
2003	10.43	11.53	14.86	0.78	-3.33
2004	10.53	16.33	14.97	1.09	1.37
2006	14.78	20.07	19.42	1.03	0.64
2007	7.68	10.97	11.98	0.92	-1.01
2008	**12.0**	**17.9**	**16.46**	**1.09**	**1.44**
Mean	10.8	15.7	15.2	1.03	0.48

Table 12-6
North Target, December – March Precipitation,
Multiple-Linear Regression Equation Results

YEAR	Stickney Mill	Bear Canyon	Moonshine	Mill Creek Summit	YOBS	YCALC	RATIO	EXCESS
1997	12.80	19.20	13.20	23.30	25.13	21.29	1.18	3.84
1998	6.10	11.20	7.80	9.90	15.10	13.10	1.15	2.00
1999	8.00	14.60	10.50	16.50	18.67	16.24	1.15	2.43
2000	7.20	12.10	10.60	12.70	15.67	14.83	1.06	0.84
2001	3.30	5.10	4.90	5.50	7.57	9.11	0.83	-1.54
2002	6.30	11.40	7.60	12.70	13.80	13.55	1.02	0.25
2003	6.80	12.50	7.50	14.90	11.53	14.31	0.81	-2.78
2004	7.60	13.20	9.90	11.40	16.33	14.98	1.09	1.35
2006	11.40	19.10	12.60	16.00	20.07	19.47	1.03	0.59
2007	4.60	7.40	6.80	11.90	10.97	11.49	0.95	-0.53
2008	**8.0**	**13.4**	**11.8**	**14.6**	**17.9**	**16.03**	**1.12**	**1.87**
Mean	7.5	12.7	9.4	13.6	15.7	14.9	1.05	0.76

Table 12-7
East Target, April 1st Snow Water Content,
Linear Regression Equation Results

YEAR	XOBS	YOBS	YCALC	RATIO	EXCESS
2002	10.58	12.47	13.48	0.92	-1.01
2003	6.35	12.87	9.06	1.42	3.81
2004	9.13	12.47	11.96	1.04	0.50
2005	8.65	11.67	11.47	1.02	0.20
2008	**14.0**	**17.5**	**17.09**	**1.03**	**0.44**
Mean	9.7	13.4	12.6	1.06	0.79

Table 12-8
East Target, April 1st Snow Water Content,
Multiple-Linear Regression Equation Results

YEAR	Pebble Creek	Badger Gulch sc	Moonshine	Morse ck sawmill sc	YOBS	YCALC	RATIO	EXCESS
2002	12.40	15.80	5.90	8.20	12.47	13.64	0.91	-1.17
2003	7.50	4.20	4.70	9.00	12.87	8.76	1.47	4.11
2004	10.90	13.00	7.00	5.60	12.47	12.28	1.02	0.19
2005	12.50	9.80	6.90	5.40	11.67	11.79	0.99	-0.13
2008	**17.6**	**16.8**	**12.6**	**9.1**	**17.53**	**17.24**	**1.02**	**0.29**
Mean	12.2	11.9	7.4	7.5	13.4	12.7	1.05	0.66

Tables 12-9 and 12-10 summarize the results obtained using the historical target/control methodology for April 1st snow water content, aka snow water equivalent (SWE), and December through March precipitation. A reminder, there were/are not enough high elevation precipitation stations in the East target to establish December through March precipitation regression equations. Results are shown for both the linear and multiple-linear regression equations.

Table 12-9
Results for April 1st Snow Water Content

Target	Predicted Apr. 1 SWE	Observed Apr. 1 SWE	Ratio Predicted/Observed SWE	Observed minus Predicted SWE (inches)
North Linear Eq. WY 2008	17.8	18.7	1.05*	0.93
North Linear Eq. All Seeded WY	15.8	16.4	1.04*	0.62
North Multi-Linear Eq. WY 2008	18.3	18.8	1.03	0.47
North Multi-Linear Eq. All Seeded WY	14.9	16.4	1.10	1.49
East Linear Eq. WY 2008	17.1	17.5	1.03	0.44
East Linear Eq. All Seeded WY	12.6	13.4	1.06	0.79
East Multi-Linear Eq. WY 2008	17.2	17.5	1.02	0.29
East Multi-Linear Eq. All Seeded WY	12.7	13.4	1.05	0.66

- Missing data in WY 2003, not included in calculations.

Table 12-10

Results for December – March Precipitation, North Area

Target	Predicted Dec. – Mar. Precipitation (inches)	Observed Dec. – Mar. Precipitation (inches)	Ratio Predicted/Observed Dec. – Mar. Precipitation	Observed minus Predicted Dec. – Mar. Precipitation (inches)
North Linear Eq. WY 2008	16.5	17.9	1.09	1.44
North Linear Eq. All Seeded WY	15.2	15.7	1.03	0.48
North Multi-Linear Eq. WY 2008	16.0	17.9	1.12	1.87
North Multi-Linear Eq. All Seeded WY	14.9	15.7	1.05	0.76

12.4 Discussion of Results

It is noted that the estimates from the linear and the multi-linear equations provide very similar estimates. This is a desirable result that indicates stability in the target and control relationships. Discussion of the results is broken down into the North and East target areas.

North Target Area

The ratios of observed over calculated April 1st snow water content for WY 2008 using the linear and multi-linear equations suggest a 3-5 % increase in water content. Results for the eleven seeded seasons suggest average increases in water content of 4-10%. The average estimated increases in April 1st snow water content for WY 08 are in the range of 0.47 to 0.93 inches of additional water content. Similar estimates for the entire seeded period range from 0.62 to 1.49 inches.

The ratios of observed over calculated December through March precipitation using the linear and multi-linear equations suggest a 9-12 % increase in water content for WY 2008. Results for all of the seeded seasons, WY 97-08, suggest average increases in

December through March precipitation of 3-5%. The average estimated increases in December through March precipitation for WY 08 are in the range of 1.44 to 1.87 inches of additional water content. Similar estimates for the entire seeded period range from 0.48 to 0.76 inches.

East Target Area

The ratios of observed over calculated April 1st snow water content for WY 2008 using the linear and multi-linear equations suggest a 2-3 % increase in water content. Results for the five seeded seasons suggest average increases in water content of 5-6%. The average estimated increases in April 1st snow water content for WY 08 are in the range of 0.29 to 0.44 inches of additional water content. Similar estimates for the entire five season seeded period range from 0.66 to 0.79 inches.

Other Considerations

The estimated increases in snow water content or December through March precipitation are area averages and can be visualized as being spread over the target area. For example, the 0.47 to 0.93 inches of additional snow water content for the northern target area in WY 2008 could be assumed to be distributed equally over the target area. The results for the northern area April 1st snow water contents may be more representative of possible seeding effects since there were more target area gages available for inclusion in that analysis plus there have been more seeded seasons in this area. This points out an observation we have made over the years when employing individual season analysis. One season's result may not be indicative of the long-term effects of cloud seeding. Averages for multi-season programs provide much better indications of the average increases (or decreases) in target area precipitation that may be attributed to cloud seeding activities.

13.0 Executive Summary

North American Weather Consultants, Inc. (NAWC) received a Request for Proposals entitled "Consultant Services for the Upper Snake River Basin Weather Modification Feasibility Study." This RFP was issued by the Idaho Water Resource Board (IWRB) in July 2007. NAWC responded to this RFP with a formal proposal (NAWC # 07-209), which was due September 4, 2007. NAWC was notified on October 26, 2007 that it had been selected to perform this work. A contract to conduct the work was finalized on January 8, 2008.

13.1 Contractual Requirements

As stated in the RFP: "The purpose of this study is to assess the feasibility of conducting weather modification (cloud seeding) programs in the Upper Snake River Basin for winter snowpack augmentation. The Consultant will analyze the climatology of the region, including storm frequencies and characteristics, barriers, seeding potential, and other factors. Program designs are to be developed, including methods and materials, equipment, siting issues, operational criteria, and evaluation of program results through monitoring and statistical methods. Cost estimates are to be developed. Monthly status reports will be required of the Consultant and the IWRB will review draft reports prior to report finalization." Nine tasks to be completed were identified in the RFP. Subsequent discussions between the IRWB, the High Country Resource Conservation and Development Council (HCRC&DC), and NAWC during the latter part of January 2008 led to the addition of a tenth task; the development of a statistical technique to evaluate the possible impacts of a cloud seeding program being conducted in the area of interest during the 2007-2008 winter season. The proposed program is designated the Eastern Snake River Basin Program (ESRBP).

The specific task areas comprising the full feasibility/design study included:

- Review and Summary of Prior Studies and Research
- Review and Analysis of Climatology of Target Area
- Development of a Preliminary Program Design
- Establishment of Operational Criteria
- Development of Monitoring and Evaluation Methodology
- Review of Environmental and Legal Aspects
- Development of Cost Estimates
- Report Preparation
- Coordination Meetings and Presentations
- Statistical Analysis of 2007-2008 Winter Cloud Seeding Project in Eastern Idaho

13.2 Program Goals and Scope

The stated goal of the program is to increase winter snow pack in the target areas to provide additional spring and summer streamflow and recharge underground aquifers at a favorable benefit/cost ratio without the creation of any significant negative environmental impacts.

Seeding operations are to be conducted on a non-randomized basis. Randomization is a technique often used in the conduct of research programs whereby approximately one-half of the potential seed cases are left unseeded to allow a comparison with the seeded cases. Evaluation efforts are to be developed and incorporated. Limited investigational elements are included in the design, whereby measurements highly focused on a) identifying the presence of supercooled liquid water, the substance targeted by glaciogenic (ice forming) seeding methods and b) characterizing the vertical atmospheric structure via project specific rawinsonde (balloon) soundings are recommended for conduct on a phased rather than ongoing basis, to help maintain program cost effectiveness. Beyond a recommended "core program", "piggybacked" research components could be added on a non-interference basis if interest develops and adequate additional funding from other sources is obtained.

13.3 Program Area

There are two rather geographically different areas within the Eastern Snake River Basin in Eastern Idaho that were selected as target areas for the proposed program. One area is located along the south slopes of the Centennial Mountains and the Lion Head and Henrys Lake Mountains in northeastern Idaho. We have denoted this area the North Area. The other area encompasses all or portions of the Big Hole Range, the Snake Range, the Grays Lake Mountains, and the Aspen Range in eastern Idaho. We have denoted this area the East Area. The target areas are defined as those areas lying above 6,500 feet in these two areas. We decided to separate the proposed target area into these two areas since the mountain range orientations are more oriented more west-east in the North Area and more north-south in the East Area. We anticipated that different types of storms would be of interest in these areas due to these orientations. There could be political differences as well since different watersheds are involved. These factors support a distinction between the two areas for the purpose of the feasibility work. Figure 13.1 provides the locations of the two proposed target areas.

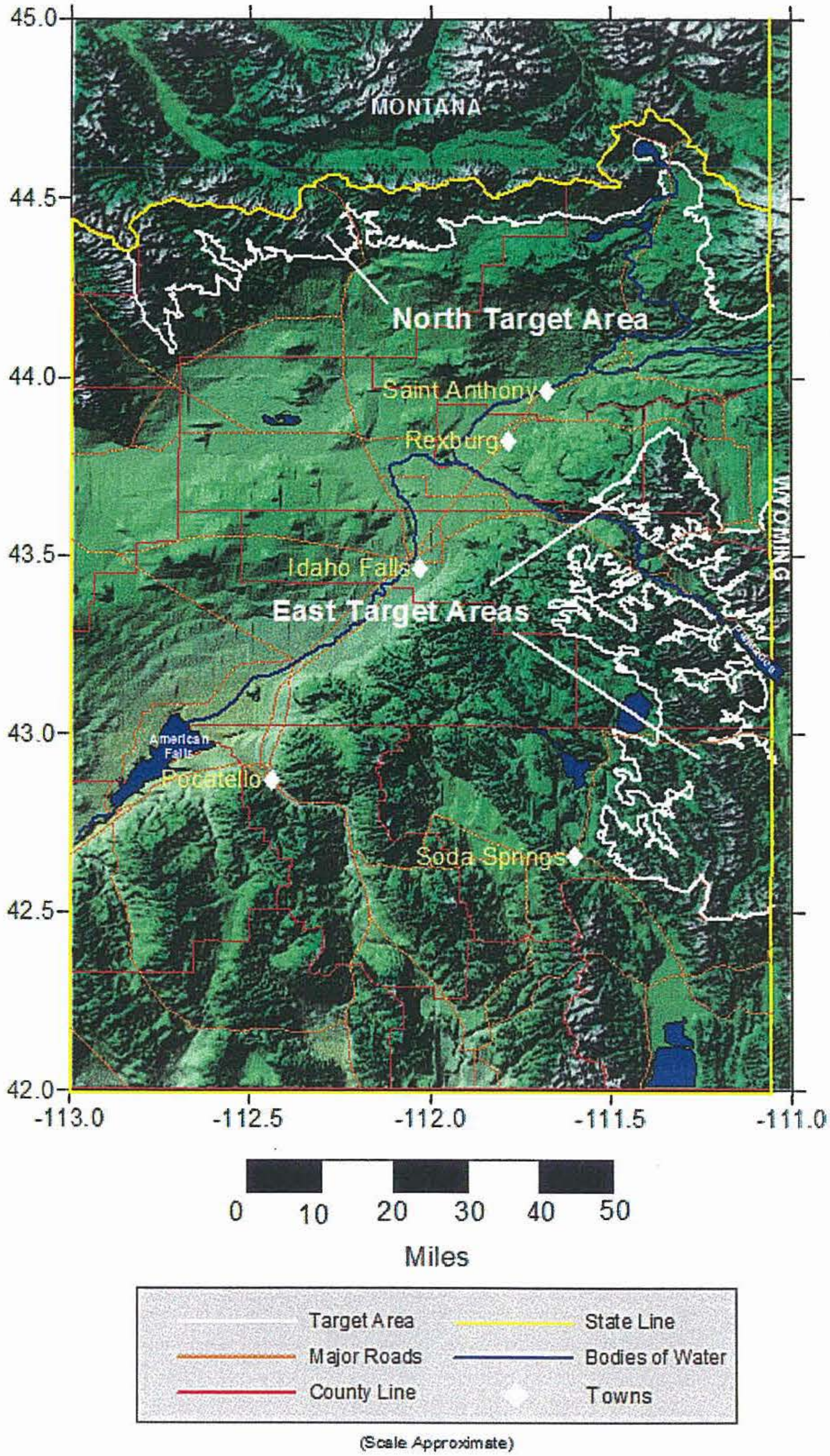


Figure 13.1 Proposed North and East Target Areas

13.4 Preliminary Design

13.4.1 Seeding Methods and Materials

Prevailing temperature regimes favor use of silver iodide, the most commonly used glaciogenic seeding agent, as the most effective seeding material. Evaluation of representative atmospheric (weather balloon) soundings, which document the vertical structure of the winter storm environment, suggests that effective seeding can frequently be accomplished using ground-based silver iodide nuclei generators. The data also show that in 57–58% of the seedable storm periods manually operated generators at lower elevations (the lowest cost release method) can be effective. That seeding method has been used for decades to good effect on a seeding project for the Thomas and Smiths Forks located in southeastern Idaho and southwestern Wyoming from the 1950's through the mid-1980's as well as in other climatologically and topographically similar areas of the west. Recommended ground based generator locations are in the foothills and near the mouths of canyons. **The recommended "core" operational project design, therefore, incorporates this method as its foundation.** A network of about seventeen sites for the North area and twenty-three sites for the east area is recommended. Given the relatively narrow mountain barriers in the target area, use of a fast-acting silver iodide solution formulation is recommended.

Atmospheric temperature inversions could inhibit the vertical transport of seeding materials from lower elevations to the in-cloud supercooled liquid water regions over the upwind barrier slopes in some of the storm periods. This factor was identified and documented

in analysis of atmospheric soundings. During seedable situations these conditions were indicated to occur relatively infrequently. This factor plus the narrow width of the target area mountain barriers resulted in the recommendation that remotely controlled ground based generators not be considered for this program. Remote locations could potentially result in the release of seeding material above the inversions but the narrow barriers would not allow much time for the growth of ice crystals into snowflakes that could fall in the intended target areas.

Airborne seeding with silver iodide may be conducted when the temperatures near the mountain crest height are too warm for silver iodide released from ground-based sites to be effective. Airborne seeding could also be effective in conditions where there are low elevation inversions. Assuming the ability to fly safely in the desired areas upwind of the intended target area, aircraft can be flown at a temperature level appropriate for activation of the temperature dependent silver iodide nucleation process. Data analysis indicates that use of aircraft seeding would enable seeding of an additional 42-43% of the total number of seedable storm periods, beyond the 57-58% considered to be effectively seedable using manually operated lower elevation generators. If airborne seeding is to be conducted, it is recommended that turbine engine aircraft be used. This recommendation is based primarily on aircraft performance as it relates to safety considerations, given the airframe icing that occurs during seeding operations. From some analyses of the timing of the seedable events, it appears one aircraft could seed a large majority of these events (i.e., two aircraft would not be required. Potential bases of operations for aircraft include airports at Pocatello and Idaho Falls. A decision regarding inclusion of aircraft seeding in the project design can be made at the sponsor's discretion. This decision could be based upon a benefit/cost analysis of this option.

13.4.2 Operational Period

The primary seedable period extends from November through March. Although some seeding opportunities can occur outside this period, that five-month period is recommended for active operations because it typically includes the majority of the seedable storm periods. An extension of the operations into the month of April cloud be considered on a year-to-year basis.

13.4.3 Supplemental Meteorological Measurements

One winter season of supplemental data collection specific to the project area is proposed prior to a decision being made as to whether the fully operational ESRBP seeding program should be implemented. Measurements would include rawinsonde (balloon) soundings to better characterize the structure of the storm environment, especially levels below mountain crest height. A strategically located ridge-top icing rate detector site would document the occurrence of supercooled liquid water. Microwave radiometer observations (typically vertically pointed) could be added to document the vapor and liquid water integrated through the entire atmosphere during the winter storms. Analysis of data from these systems would help fine-tune this preliminary operational design. Comparison of the ice detector records with the radiometer data will indicate the extent to which a permanent ice detector site would be helpful in real time operational cloud seeding decision-making.

13.4.4 Seeding Effectiveness Evaluation

Seasonal evaluations of the effectiveness of the cloud seeding program will be based on historical target and control techniques (target and control sites with the corresponding regression equations are provided in the report). As an option, some snow chemistry analyses could be added to verify that silver above background levels is observed at various sampling points in the target areas.

13.4.5 Key Elements of the Recommended Preliminary Program Design

- The target area will be those areas in Bonneville, Clark, Fremont and Madison Counties that lie above 6,500 feet (2.0 km), which are tributary to the Snake River.
- The primary operational period will be November through March. Seeding operations could be effectively extended into April, especially if a seeding aircraft were used on the program, although ground based seeding would still be effective as well.

- Silver iodide will be the seeding agent.
- A "core program" of lower elevation ground based generators is recommended, This core program could be supplemented by a seeding aircraft equipped with acetone/silver iodide generators if the estimated benefits constitute an acceptable multiple of the estimated costs to utilize this additional seeding mode. The use of remotely controlled ground based generators does not appear to offer any significant advantages.
- One winter season of data collection is proposed prior to the beginning of a full operational ESRBP. Data would be collected via rawinsonde observations, icing rate meter observations and possibly radiometer observations of liquid and vapor to verify some of the conclusions/assumptions contained in this preliminary design.
- The ESRBP would be operationally oriented, with the following goals: **The stated goal of the program is to increase winter snowpack in the target areas to provide additional spring and summer streamflow and recharge underground aquifers at a favorable benefit/cost ratio, without the creation of any significant negative environmental impacts.**
- Due to the operational nature of the proposed program, i.e., the interest in producing as much additional water as possible, the seeding decisions would not be randomized. In other words, all suitable seeding opportunities would be seeded appropriately. In addition, there would not be an ongoing research component built into the program (beyond the first season of specialized measurements which could be used to fine-tune the design if necessary), although "piggyback" research components could be added to the core operational program if interest and additional funding from other sources is present, for example, the type of research that resulted from write-in funding to the Bureau of Reclamation for the recent Weather Damage Mitigation Program.
- Evaluations of the effectiveness of the cloud seeding program would be based upon historical target and control techniques (target and control sites with corresponding regression equations are provided elsewhere in this report), and possibly some snow chemistry analyses verifying that silver above background levels is being observed at various sampling points in the target areas. Evaluation techniques are discussed in Section 7.0
- Qualified/experienced meteorologists should direct the seeding operations.

13.5 Potential Yield/Benefits

13.5.1 Estimated Increases in Precipitation

Analysis of the variability in storm temperature structure over the program areas for a five winter season period was performed and then applied in conjunction with cloud top temperature partitioned seeding results from a research program in Colorado (Climax) to estimate the anticipated effects for the ESRBP. The analysis applied the varying Climax seeding effects within cloud top temperature categories according to their seasonal occurrence in the ESRBP cloud top temperature data during a multi-year period. The resulting percentage of seedable events was 37% in the North area and 38% in the

East area. Using these results, the multi-season average estimated increases for the North and East areas were calculated for the ground and airborne seeding modes. These increases were then applied to the April 1st snow water contents to estimate the potential average increases in snow water contents. Tables 13-1 and 13-2 summarize this information.

For the North area was there was an estimated 3.0% increase using ground based generators and an additional 2.5% increase using aircraft seeding yielding a combined total of 5.5%. For the East area there was an estimated 3.9% increase using ground based generators and an additional 3.7% increase using aircraft seeding yielding a combined total of 7.6%. Such results compare favorably with a review of the estimated results of several similar winter orographic seeding projects conducted in the western states, some for decades, supporting the potential for precipitation augmentation ranging from about 5% to 15%. Additionally, these estimates can be supported by the published policy statements of the Weather Modification Association and the American Meteorological Society, which state that there is statistical evidence that precipitation from supercooled (clouds whose temperatures are colder than 32 ^{0}F) orographic clouds (clouds that develop over mountains) has been seasonally increased by about 5% to 15%. A similar statement published by the World Meteorological Organization also indicates that there is statistical evidence for precipitation increases from supercooled orographic clouds, although not stating a range of effect. The American Society of Civil Engineers supports and encourages development of atmospheric water (also known as weather modification or cloud seeding) for beneficial uses, and has published a standard and manual of professional practice for cloud seeding for the purpose of precipitation enhancement.

Table 13-1

Estimated Increases in April 1st Snow Water Content for the North Area Based on Estimated November – March Precipitation Increases for Storm Periods using Cloud Top Temperature Estimates

Site	Apr 1 Snow	Total Increase (5.5%)	Ground (3.0%)	Remote (0.7%)	Air (1.8%)
Big Springs SC	19.3	1.06	0.58	0.14	0.35
Camp Creek SC	9.8	0.54	0.29	0.07	0.18
Crab Creek*	16.4	0.90	0.49	0.11	0.30
Irving Creek SC	5.7	0.31	0.17	0.04	0.10
Island Park*	15.7	0.86	0.47	0.11	0.28
Latham Springs SC	33.0	1.82	0.99	0.23	0.59
Lucky Dog SC	25.2	1.39	0.76	0.18	0.45
Valley View SC	15.4	0.85	0.46	0.11	0.28
Webber Creek SC	5.9	0.32	0.18	0.04	0.11
White Elephant*	29.2	1.61	0.88	0.20	0.53
Mean	**17.6**	**0.97**	**0.53**	**0.12**	**0.32**

* SNOTEL site

Table 13-2

Estimated Increases in April 1st Snow Water Content for the East Area Based on Estimated November – March Precipitation Increases for Storm Periods using Cloud Top Temperature Estimates

Estimates in April 1 Snow Water Increase (using Nov-Mar percentages):

Site	Apr 1 Snow	Total Incr (7.6%)	Ground (3.9%)	Remote (0.5%)	Aircraft (3.2%)
Allen Ranch	10.5	0.80	0.41	0.05	0.34
Fall Creek	7.3	0.55	0.28	0.04	0.23
Lava Creek	15.7	1.19	0.61	0.08	0.50
Packsaddle Spring	29.3	2.23	1.14	0.15	0.94
Pine Creek Pass*	16.0	1.22	0.62	0.08	0.51
Somsen Ranch	13.4	1.02	0.52	0.07	0.43
State Line	15.0	1.14	0.59	0.08	0.48
Mean	**15.3**	**1.16**	**0.60**	**0.08**	**0.49**

* SNOTEL site

13.5.2 Estimated Increases in Streamflow

The estimated increases in precipitation were used to estimate the potential average increases in March through July surface runoff from the two target areas. These analyses were conducted for the eight sub-basins shown in Figure 13.2. Estimates were made of minimum and maximum increases in average March through July surface runoff from six of the eight sub-basins. The first two sub-basins (numbers 1 and 2 in Figure 13.2) have no surface water connection to the Snake River. There is, however, some local use of streamflow from these two sub-basins as well as some ground water recharge derived from these sub-basins.

Estimates for all the sub-basins (excluding #1-2) were summed, yielding a minimum - maximum range of estimated streamflow increases for the entire drainage area for each seeding mode for an average March through July period. The only sub-basin with estimates of this type in the North area is #3, with all the other sub-basins included in this summation being in the East area. Total estimated average March through July runoff increases due to seeding are estimated to be between **58,800 – 97,500** acre-feet for ground-based seeding only, and between about **110,500 – 188,200** acre-feet for ground plus aircraft seeding. Basin #3 estimates range from 17,800 - 24,400 acre-feet for ground-based seeding and from 32,700 – 45,100 acre-feet for ground plus aircraft seeding, with the remainder of the total increases being derived from the East target area.

Table 13-3 summarizes the results for each sub-basin, as well as the total increase estimates. Table 13-4 summarizes the totals for the North area, East area, and the North and East areas combined.

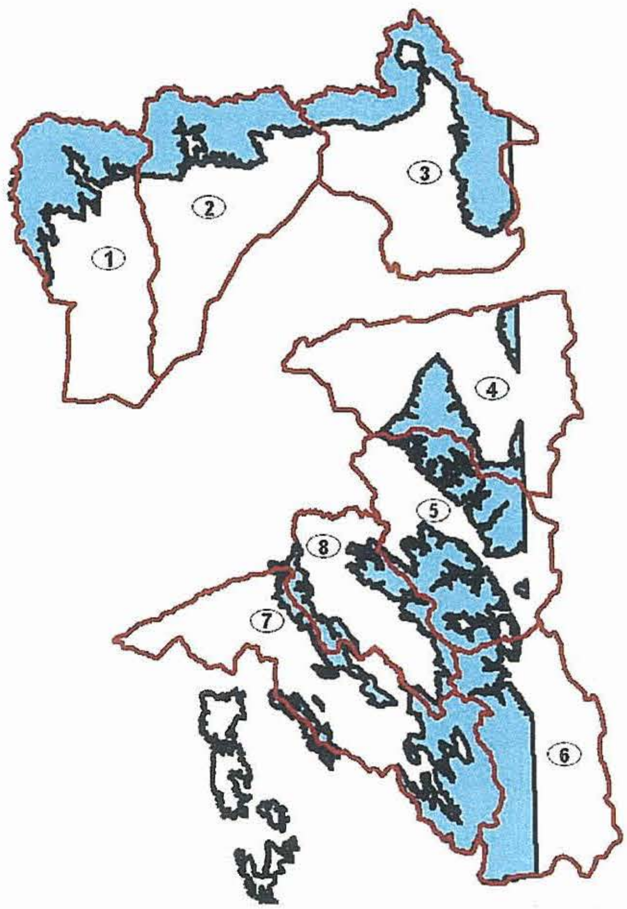


Figure 13.2 North and East Target Area Sub-basins

Table 13-3
Summary of Sub-Basin and Estimated Total Streamflow Increases

Sub-basin	Base Streamflow (AF)	Ground-Based Increase (AF)		Ground + Aircraft Increase (AF)	
		Min	Max	Min	Max
1 (Medicine Lodge)	61,115*	1,800*	NA	3,400*	NA
2 (Beaver – Camas)	120,529*	3,600*	NA	6,600*	NA
3 (Upper Henrys)	594,046	17,800	24,400	32,700	45,100
4 (Teton)	145,627	5,700	8,600	11,100	16,700
5 (Palisades)	485,903	19,000	34,000	36,900	66,600
6 (Salt River)	147,085	5,700	12,100	11,200	23,800
7 (Blackfoot)	209,757	8,200	13,400	15,900	26,400
8 (Willow Creek)	61,212	2,400	5,000	2,700	9,600
Total Streamflow (excl. #1 and 2)	1,643,630	58,800	97,500	110,500	188,200

* Considered only local not regional streamflow and ground water re-charge; not included in totals

Table 13-4
Summary of North and East Areas Estimated Average Streamflow Increases

Target Area	Ground-Based only		Ground + Aircraft	
	Min	Max	Min	Max
Northern (Basin #3)	17,800	24,400	32,700	45,100
Eastern	41,000	73,100	77,800	143,100
Total	58,800	97,500	110,500	188,200

The midpoint of the minimum - maximum range of total (combined North and East target areas) estimated average March through July streamflow increases for the North area is 21,100 acre-feet for ground-based seeding only, and 38,900 acre-feet for ground plus aircraft seeding.

The midpoint of the minimum - maximum range of total estimated average March through July streamflow increases for the East area is 57,050 acre-feet for ground-based seeding only, and 110,450 acre-feet for ground plus aircraft seeding.

The midpoint of the minimum - maximum range of total estimated March through July streamflow increases is 78,150 acre-feet (4.8%) for ground-based seeding only, and 149,350 (9.1%) for ground plus aircraft seeding. Given all of the assumptions that have gone into the development of estimates of increases in streamflow due to cloud seeding, these values are perhaps most representative of the average increases in March through July streamflow that might be expected from

the conduct of an operational cloud seeding program in the two proposed target areas. For comparison purposes, these estimated average streamflow values would correspond to average increases in April 1st snow water content of approximately 3.5% for ground based seeding and 6.6% increases in April 1st snow water content for ground plus aircraft seeding.

Table 13-4 indicates that higher amounts of streamflow may be produced from the East area when compared with the North area although there are some benefits in terms of enhanced local streamflow and ground water recharge from seeding in the North area that are not counted in such a comparison.

13.6 Cost Considerations

Estimated increases in runoff for a "core program" using only manually operated silver iodide generators were calculated along with the attendant estimated costs. The estimated additional runoff and attendant costs were then calculated for the addition of one cloud seeding aircraft to the "core program." Preliminary estimates of the potential increases in runoff from the North and East target areas separately and the combination of the two target areas and associated costs are summarized in Tables 13-5 through 13-7. The combined costs in Table 13-7 contain some cost savings for the core program if operations are conducted for both areas. In a similar manner for the ground seeding plus aircraft seeding mode it is assumed that the costs of one seeding aircraft are divided between the two program areas.

The estimated cost per acre-foot of additional runoff ranges from $2.77 to $14.99 depending upon the target area and method(s) of seeding used. It is beyond the scope of this report to estimate the potential value of the increased runoff. Should such an analysis be attempted, calculations of benefit/cost ratios could be calculated. The additional water would benefit regional water supplies for agricultural and municipal use as well as hydroelectric power generation. If the value of the additional water volume to recreation, fisheries, tourism, threatened and endangered species, and downstream uses could be quantified and included, the projected value would be even greater.

Table 13-5
Estimated Average Costs to Produce Additional March – July Streamflow, North Area

	Core Program (CP)	CP Plus Aircraft
Ave. Cost to Produce Extra Water	$139,775	$583,175
Ave. Water Year Streamflow Increase	21,100	38,900
Cost Per Acre-foot	$6.62	$14.99

Table 13-6
Estimated Average Costs to Produce Additional March – July Streamflow, East Area

	Core Program (CP)	CP Plus Aircraft
Ave. Cost to Produce Extra Water	$158,275	$601,675
Ave. Water Year Streamflow Increase	57,050	110,450
Cost Per Acre-foot	$2.77	$5.45

Table 13-7
Estimated Average Costs to Produce Additional March – July Streamflow, Combined North and East Areas

	Core Program (CP)	CP Plus Aircraft
Ave. Cost to Produce Extra Water	$230,280	$673,680
Ave. Water Year Streamflow Increase	78,150	149,350
Cost Per Acre-foot	$2.95	$4.51

The values in Tables 13-5 through 13-7 are for an average water year. Costs per acre-foot would decline in above normal water years and increase in below normal water years. These values are also for the mid-point values between calculated minimum and maximum increases in streamflow; similar costs could be calculated for the minimum and maximum estimated streamflow increases using the data provided in this section

13.7 Concluding Remarks

This feasibility/design study has determined that an effective winter cloud seeding program can be established and operated for a portion of the Eastern Snake River Basin located in eastern Idaho. The program has the potential to enhance the snowpack by 3-7.6% during an average winter season, with the resultant March through July runoff estimated to range from 78,150 to 149,350 acre-feet depending upon whether just ground seeding or ground seeding plus airborne seeding is utilized.

The estimated costs to achieve these increases in March through July streamflow are $2.95 to $4.51 per acre-foot. Conduct of the proposed single winter season of area-specific meteorological monitoring prior to the start of operational seeding would serve to refine this preliminary program design. The estimated cost of this one season of observations is $243,750.

The operation of a joint program between the East target area identified in this study and adjacent mountain ranges in western Wyoming should be considered. North American Weather Consultants conducted a similar design/feasibility study for the Salt and Wyoming Ranges in western Wyoming (Griffith, et al, 2006). As in this study, it was concluded that an operational winter cloud seeding program was feasible for these Wyoming Mountain Ranges. There could be some economy of scale and other mutual benefits in developing an inter-state program covering the East target area in Idaho and the Salt and Wyoming Ranges in Wyoming.

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APPENDIX A

ORGANIZATIONAL CAPABILITY STATEMENTS OR POLICIES

Organizations with Capability Statements or Policies

The principal societies or associations concerned with weather modification capabilities in all or part include the following:

- The Weather Modification Association (WMA)
- The American Meteorological Society (AMS)
- The World Meteorological Organization (WMO)
- The American Society of Civil Engineers (ASCE)

Each group maintains and publishes a policy or capability statement regarding weather modification in its primary categories. Excerpted from their overall statements, the statements of each organization pertaining to winter precipitation augmentation are presented here.

<u>Weather Modification Association</u> (2005*)*

"Winter Precipitation Augmentation

The capability to increase precipitation from wintertime orographic cloud systems has now been demonstrated successfully in numerous "links in the chain" research experiments. The evolution, growth and fallout of seeding-induced (and enhanced) ice particles have been documented in several mountainous regions of the western U. S. Enhanced precipitation rates in seeded cloud regions have been measured in the range of hundredths to >1 mm per hour. Although conducted over smaller temporal and spatial scales, research results tend to be consistent with evaluations of randomized experiments and a substantial and growing number of operational programs where 5% - 15% increases in seasonal precipitation have been consistently reported. Similar results have been found in both continental and coastal regions, with the potential for enhanced precipitation in coastal regions appearing to be greater in convective cloud regimes. The consistent range of indicated effects in many regions suggests fairly widespread transferability of the estimated results.

Technological advances have aided winter precipitation augmentation programs. Fast-acting silver iodide ice nuclei, with higher activity at warmer temperatures, have increased the capability to augment precipitation in shallow orographic cloud systems. Numerical modeling has improved the understanding of atmospheric transport processes and allowed simulation of the meteorological and microphysical processes involved in cloud seeding. Improvements in computer and communications systems have resulted in a steady improvement in remotely controlled cloud (ice) nuclei generators (CNG's), which permit improved placement of CNG's in remote mountainous locations.

Wintertime snowfall augmentation programs can use a combination of aircraft and ground-based dispersing systems. Although silver iodide compounds are still the most commonly used glaciogenic (causing the formation of ice) seeding agents, dry ice is *used in some warmer (but still supercooled) cloud situations. Liquid propane also shows some promise as a seeding agent when dispensers can be positioned above the freezing level on the upwind slopes of mountains at locations adequately far upwind to allow growth and fallout of precipitation within the intended target areas. Dry ice and liquid propane expand the window of opportunity for seeding over that of silver iodide, since they can produce ice particles at temperatures as warm as -0.5° C. For effective precipitation augmentation, seeding methods and guidelines need to be adapted to regional meteorological and topographical situations.*

Although traditional statistical methods continue to be used to evaluate both randomized and non-randomized wintertime precipitation augmentation programs, the results of similar programs are also being pooled objectively in order to obtain more robust estimates of seeding efficacy. Objective evaluations of non-randomized operational programs continue to be a difficult challenge. Some new methods of evaluation using the trace chemical and physical properties of segmented snow profiles show considerable promise as possible means of quantifying precipitation augmentation over basin-sized target areas."

American Meteorological Society (1998)

"Precipitation Increase

There is statistical evidence that precipitation from supercooled orographic clouds (clouds that develop over mountains) has been seasonally increased by about 10%. The physical cause-and-effect relationships, however, have not been fully documented. Nevertheless, the potential for such increases is supported by field measurements and numerical model simulations."

World Meteorological Organization (2004)

"Precipitation (Rain and Snow) Enhancement

This section deals with those precipitation enhancement techniques that have a scientific basis and that have been the subjects of research. Other non-scientific and unproven techniques that are presented from time to time should be treated with the required suspicion and caution.

Orographic mixed-phase cloud systems

In our present state of knowledge, it is considered that the glaciogenic seeding of clouds formed by air flowing over mountains offers the best prospects for increasing precipitation in an economically-viable manner. These types of clouds attracted great interest in their modification because of their potential in terms of water management, i.e. the possibility of storing water in reservoirs or in the snowpack at higher elevations.

There is statistical evidence that, under certain conditions, precipitation from supercooled orographic clouds can be increased with existing techniques. Statistical analyses of surface precipitation records from some long-term projects indicate that seasonal increases have been realized.

Physical studies using new observational tools and supported by numerical modeling indicate that supercooled liquid water exists in amounts sufficient to produce the observed precipitation increases and could be tapped if proper seeding technologies were applied. The processes culminating in increased precipitation have also been directly observed during seeding experiments conducted over limited spatial and temporal domains. While such observations further support the results of statistical analyses, they have, to date, been of limited scope. The cause and effect relationships have not been fully documented, and thus the economic impact of the increases cannot be assessed.

This does not imply that the problem of precipitation enhancement in such situations is solved. Much work remains to be done to strengthen the results and produce stronger statistical and physical evidence that the increases occurred over the target area and over a prolonged period of time, as well as to search for the existence of any extra-area effects. Existing methods should be improved in the identification of seeding opportunities and the times and situations in which it is not advisable to seed, thus optimizing the technique and quantifying the result.

Also, it should be recognized that the successful conduct of an experiment or operation is a difficult task that requires scientists and operational personnel. It is difficult and expensive to fly aircraft safely in supercooled regions of clouds. It is also difficult to target the seeding agent from ground generators or from broad-scale seeding by aircraft upwind of an orographic cloud system."

American Society of Civil Engineers (2006)

A more general statement, the ASCE's policy (Policy Statement #275, 2006) is based largely on evidence in winter precipitation augmentation operations and research.

Policy

The American Society of Civil Engineers (ASCE) 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 to the public.

Issue

Atmospheric water management capabilities are still developing and represent an evolving technology. Longer-term commitments to atmospheric water resource management research and operational programs are necessary to realize the full potential of this technology.

Rationale

Water resources worldwide are being stressed by the increasing demands placed upon it by competing demands generated by population growth and environmental concerns. As a result, nations have become more sensitive to year-to-year variations in natural precipitation. The careful and well-designed management of atmospheric water offers the potential to significantly augment naturally-occurring water resources, while minimizing capital expenditures or construction of new facilities. New tools, such as radar and satellite tracking capabilities and other imaging devices, atmospheric tracer techniques and advanced numerical cloud modeling offer means through which many critical questions might now be answered. Continued development of atmospheric water-management technology is essential. ASCE has developed materials providing guidance in the use of atmospheric water-management technology with weather modification organizations for dissemination to local communities and governments as well as state, regional and international interest.

APPENDIX B

EASTERN SNAKE RIVER BASIN DETAILED SEEDING HISTORY

Cloud Seeding Archives

Region most likely impacted	County	Location	Hours Run 1996			Hours Run 1996-1997				
			Feb	Mar	Apr	Nov	Dec	Jan	Feb	Mar
North	Clark	Crooked Creek								
North	Clark	Kilgore								
North	Clark	Lone Pine	9.25	22.25	31.25	11	15.25			17
North	Clark	Lower Medicine Lodge	23.5	32	16.75	31.75	18			24
North	Clark	Radar	27.25	37.5	32.75	81.5	15			3
North	Clark	Sheep Station	21.75	33.5	24.25	52.75	15			3
North	Clark	Small								
North	Clark	Upper Medicine Lodge								
North	Clark	Warm Springs	32.5	36.25	13.75	25.25	16.25			6
East	Bonneville	Bone								
East	Bonneville	Gray's Lake	23.75	24.5						
East	Bonneville	Herman	24.25	6.5						
East	Bonneville	Pine Creek								
East	Bonneville	Sheep Creek								
East	Bonneville	Swan Valley	39.5	43						
North	Fremont	Ashton	28.5	66.25						
Both ?	Fremont	Fall River								
Both ?	Fremont	Green Timber								
North	Fremont	Herys Lake (Valley View)	22	51						
North	Fremont	Island Park (Last Chance)	37	60.25						
Both ?	Fremont	Lamont								
North	Fremont	Sadoris								
Both ?	Fremont	Squirrell								
North	Fremont	Swan Lake (Pine Haven)	47.75	43.25						
East	Madison	Green Canyon	30	60	4.75					
East	Madison	Kelly Canyon	13.5	4.5						
East	Teton	Driggs	72.25	45						
East	Teton	Felt								
East	Teton	Tetonia (Robison)	48	21.5	3					
East	Teton	Victor	19	75.5						

Cloud Seeding Archives

Region most likely impacted	County	Location	Hours Run 1998				Hours Run 1998-1999		
			Jan	Feb	Mar	Dec	Jan	Feb	Mar
North	Clark	Crooked Creek							
North	Clark	Kilgore		73.25	18.5	25.5	80	33	10.75
North	Clark	Lone Pine	20	9.75	5.5	15.5	32	1.5	10
North	Clark	Lower Medicine Lodge	51	48.5	11.5	28.5	46.25	49.5	9
North	Clark	Radar	42.5	24.5	19.75	16.5	52.25	21.75	12
North	Clark	Sheep Station	41.5	45	14.5	16.75	35.5	14.75	3.75
North	Clark	Small							
North	Clark	Upper Medicine Lodge		52	17		20.25	20	9.5
North	Clark	Warm Springs	34	61	12	11.75	59.5	34.5	5.5
East	Bonneville	Bone							
East	Bonneville	Gray's Lake							
East	Bonneville	Herman							
East	Bonneville	Pine Creek							
East	Bonneville	Sheep Creek							
East	Bonneville	Swan Valley							
North	Fremont	Ashton							
Both ?	Fremont	Fall River							
Both ?	Fremont	Green Timber							
North	Fremont	Herys Lake (Valley View)							
North	Fremont	Island Park (Last Chance)							
Both ?	Fremont	Lamont							
North	Fremont	Sadoris							
Both ?	Fremont	Squirrell							
North	Fremont	Swan Lake (Pine Haven)							
East	Madison	Green Canyon							
East	Madison	Kelly Canyon							
East	Teton	Driggs							
East	Teton	Felt							
East	Teton	Tetonia (Robison)							
East	Teton	Victor							

Cloud Seeding Archives

Region most likely impacted	County	Location	Hours Run 2000 Jan	Hours Run 2000 Feb	Hours Run 2000 Mar	Hours Run 2000-2001 Dec	Hours Run 2000-2001 Jan	Hours Run 2000-2001 Feb	Hours Run 2000-2001 Mar
North	Clark	Crooked Creek							
North	Clark	Kilgore	18.25	95	47.5	21	69	45	20
North	Clark	Lone Pine	41.75	49.25	18.75	30.75	69	21.5	12
North	Clark	Lower Medicine Lodge	10	89.5	36	25	70	45	12
North	Clark	Radar	14.75	62.25	19.25	26	64	46.5	3.5
North	Clark	Sheep Station	5.5	90.5	19.5	26.25	64.5	46.5	4
North	Clark	Small							
North	Clark	Upper Medicine Lodge	6.5	87.5	11	24	61.75	54.5	6.5
North	Clark	Warm Springs	27.5	65.75	36.5	24.25	37.5	14.75	
East	Bonneville	Bone							
East	Bonneville	Gray's Lake							
East	Bonneville	Herman							
East	Bonneville	Pine Creek							
East	Bonneville	Sheep Creek							
East	Bonneville	Swan Valley							
North	Fremont	Ashton							
Both ?	Fremont	Fall River							
Both ?	Fremont	Green Timber							
North	Fremont	Herys Lake (Valley View)							
North	Fremont	Island Park (Last Chance)							
Both ?	Fremont	Lamont							
North	Fremont	Sadoris							
Both ?	Fremont	Squirrell							
North	Fremont	Swan Lake (Pine Haven)							
East	Madison	Green Canyon							
East	Madison	Kelly Canyon							
East	Teton	Driggs							
East	Teton	Felt							
East	Teton	Tetonia (Robison)							
East	Teton	Victor							

Region most likely impacted	Cloud Seeding Archives County	Location	Hours Run 2001-2002 Dec	Jan	Feb	Mar	Apr	May	Nov	Hours Run 2002-2003 Dec	Jan	Feb	Mar	Apr
North	Clark	Crooked Creek												
North	Clark	Kilgore	71	29.5	30	18			1	82.75	55.5	30.5	19	16.5
North	Clark	Lone Pine	68.5	10	22	13.5			11.5	33.5	32.5	7	20.5	
North	Clark	Lower Medicine	65.5	10.5	13	9			4.5	23.25	33.5	13.5	8.5	10
North	Clark	Radar	53.5	16.25	17.5	9.5			7.25	48.5	28.75	24.25	5	
North	Clark	Sheep Station	52.5	14	17.5	9			7.25	46.75	27.25	26.25	5	
North	Clark	Small							8.5	48	40	27.75		
North	Clark	Upper Medicine	28.5	10.5										
North	Clark	Warm Springs	26.25		6.5				9	50	5.5	33		
East	Bonneville	Bone		80.75	30	58.25	39.25	18		134.25	45.42	102	78.75	
East	Bonneville	Gray's Lake								143.5	71	10.75	24.25	9.5
East	Bonneville	Herman												
East	Bonneville	Pine Creek	47	15.75	17.5	27.25	21		17	60.75	31	59.75	9	
East	Bonneville	Sheep Creek									37	27	43	
East	Bonneville	Swan Valley	26	45		34	9		18	92.5	36.5	59	20.5	
North	Fremont	Ashton												
Both ?	Fremont	Fall River							13	44	52	27	3	13
Both ?	Fremont	Green Timber							14.5	88	52.25	48.75	4	3.5
North	Fremont	Herys Lake												
North	Fremont	Island Park	23.25	55.75	18.5	3.5	32.5		6	61.25	53	55	19.25	2.75
Both ?	Fremont	Lamont												
North	Fremont	Sadoris	35.5	37	13	9	47.5		17.5	56.75	35	28.5		
Both ?	Fremont	Squirrell	65.5	58.5	13.25	26	10.25	4	9.25	148.5	80	35	11.5	
North	Fremont	Swan Lake												
East	Madison	Green Canyon												
East	Madison	Kelly Canyon	11	17.5	37	60.5				10.5	23	79.5	32	
East	Teton	Driggs	97.5	64	10	86		4.5	13.25	122.25	79.5	64.5	52	
East	Teton	Felt	41.5	52.5	21	37	28			116	76.5	36.5	56.5	
East	Teton	Tetonia								77.25	45.5	25		
East	Teton	Victor	40.5	27.5	22.5	20	22.5		9.25	11.5	67.25	68	29.25	11

Cloud Seeding Archives

Region most likely impacted	County	Location	Hours Run 2003-2004 Nov	Dec	Jan	Feb	Mar	Hours Run 2004-2005 Nov	Dec	Jan	Feb	Mar	Apr
North	Clark	Crooked Creek											
North	Clark	Kilgore	24.5	73	31	76.5	6.5						
North	Clark	Lone Pine		39	53.75								
North	Clark	Lower Medicine Lodge	24.5	58.5	11	39.5	5						
North	Clark	Radar	15.25	74.25	28	65							
North	Clark	Sheep Station	14	66	27.5	68.75							
North	Clark	Small		104	7.5	34.5							
North	Clark	Upper Medicine Lodge											
North	Clark	Warm Springs		80	10.5	74							
East	Bonneville	Bone		60	42.25	28.25		21.25	41.25	49	29.75	10.75	
East	Bonneville	Gray's Lake		117.75	97.5	49.5		21.25	60.75	28.25	73	75.75	14
East	Bonneville	Herman											
East	Bonneville	Pine Creek		101.5	107.5	43	6.5	17	17	36	33.5	16.5	
East	Bonneville	Sheep Creek		321	6	135	52	28.5	100	81.5	73	83	30
East	Bonneville	Swan Valley		79.5	18.25	89.5	6	12.5	15	18	48	28	15
North	Fremont	Ashton											
Both ?	Fremont	Fall River		10.5	34.25	52	16.5	16	64.5	50	9.5	24	21.5
Both ?	Fremont	Green Timber		45.75	42	72.5	2		60.5	45.5	42.5	42.5	27.5
North	Fremont	Herys Lake (Valley View)											
North	Fremont	Island Park (Last Chance)		65.5	35.75	58	4	7.5	33.5	26	10.25	57.75	7.5
Both ?	Fremont	Lamont						21.5	25.5	52.5	58.5	63	33.5
North	Fremont	Sadoris		54	50.5	43		9	27.5	86.5	44	16.5	21
Both ?	Fremont	Squirrell		24.25	7	44							
North	Fremont	Swan Lake (Pine Haven)											
East	Madison	Green Canyon											
East	Madison	Kelly Canyon		97	60.5	54.5				19.5	85		
East	Teton	Driggs		173.5	71	77	43.5	149	44	108.5			
East	Teton	Felt		66.5	46.5	114.5	32	8	47	62.5	23	47	17.75
East	Teton	Tetonia (Robison)		10.5	15	29		11	9	13	42	14	14.5
East	Teton	Victor		69.75	46.5	19			92	100	59	66.75	24

Region most likely impacted

Cloud Seeding Archives

	County	Location	Hours Run 2005-2006					Hours Run 2006-2007			
			Nov	Dec	Jan	Feb	Mar	Nov	Dec	Jan	Feb
North	Clark	Crooked Creek							48.75	16.25	44
North	Clark	Kilgore	37	84.5	81	34	66	20	30.5	37	63.5
North	Clark	Lone Pine		11.5	16.25		17				
North	Clark	Lower Medicine Lodge	14	41	51	14.5	68.5		13	8	53
North	Clark	Radar	12.75	89.5	47	27.5	71		30.25	8.25	23.75
North	Clark	Sheep Station	11.75	88.5	47.75	24	68.5		30.25	8.75	17.5
North	Clark	Small							23	10	23
North	Clark	Upper Medicine Lodge	12	63	58	17	52.5				
North	Clark	Warm Springs		76			44				
East	Bonneville	Bone									
East	Bonneville	Gray's Lake									
East	Bonneville	Herman									
East	Bonneville	Pine Creek									
East	Bonneville	Sheep Creek									
East	Bonneville	Swan Valley									
North	Fremont	Ashton									
Both ?	Fremont	Fall River									
Both ?	Fremont	Green Timber									
North	Fremont	Herys Lake (Valley View)									
North	Fremont	Island Park (Last Chance)									
Both ?	Fremont	Lamont									
North	Fremont	Sadoris									
Both ?	Fremont	Squirrell									
North	Fremont	Swan Lake (Pine Haven)									
East	Madison	Green Canyon									
East	Madison	Kelly Canyon									
East	Teton	Driggs									
East	Teton	Felt									
East	Teton	Tetonia (Robison)									
East	Teton	Victor									