SUMMARY OF A WEATHER MODIFICATION FEASIBILITY STUDY FOR WINTER SNOWPACK AUGMENTATION IN THE EASTERN SNAKE RIVER BASIN, IDAHO

Don A. Griffith*, Mark E. Solak and David P. Yorty

North American Weather Consultants, Inc.
Sandy, Utah 84093

Abstract. North American Weather Consultants performed a feasibility/preliminary design study for a potential operational winter cloud seeding program in the Eastern Snake River Basin Program (ESRBP) in Idaho. Two potential target areas were identified. One area was located along the south slopes of the Centennial Mountains and the Lion Head and Henrys Lake Mountains in northeastern Idaho. This area is denoted as the North Target 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. This area is denoted as the East Target area. The primary program goal would be to increase winter snowpack in the target areas through operational cloud seeding.

Average increases of 5.5% in April 1st snow water contents for the North Target area and 7.6% for the East Target Area via cloud seeding were estimated through transference of the indicated results from the Climax I and II research programs. Simulations using empirically derived snowpack-streamflow relations yielded estimated average increases in March-July streamflow from two seeding modes totaling approximately 149,350 acre-feet (1.84×10^8 m^3) for the combination of the two areas. The costs per acre-foot for the estimated increases in March-July combined area streamflow range from \$2.95 to \$4.51 per acre-foot of additional water in an average water year. A preliminary design for an operational winter cloud seeding program is described. One preliminary winter season of supercooled liquid water and lower-level temperature and wind observations is recommended to determine the presence of supercooled liquid water and low-level temperature inversions.

1. INTRODUCTION

The Idaho Water Resource Board (IWRB) contracted with North American Weather Consultants (NAWC) of Sandy, Utah for the performance of a comprehensive study of the feasibility/design of applying modern cloud seeding methodology for winter snowpack augmentation in that portion of the Eastern Snake River Basin located in Idaho (Griffith *et al.* 2008). This paper presents the key elements, findings, conclusions and recommendations of the feasibility/design study. The study included a survey of relevant prior research and operational seeding programs, considerable analysis of program area-specific historical weather data, assessment of potential cloud seeding methods, plus evaluation techniques. Procedures and recommendations of the American Society of Civil Engineers (ASCE) publication entitled "Standard Practice for the Design and Operation of Precipitation Enhancement Projects" were utilized where appropriate (ASCE 2004). A preliminary operational program design was prepared, including identification of permit and reporting requirements. The study also included hydrologic estimates of the potential program yield in terms of additional runoff and the estimated costs associated with conduct of the program, based on different seeding modes. Preliminary benefit/cost estimates for the proposed program design were also provided.

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 the Target Area
- Development of Preliminary Program Design
- Establishment of Operational Criteria
- Development of Monitoring and Evaluation

Corresponding author address: Don Griffith, North American Weather Consultants, Inc., 8180 South Highland Dr., Suite B-2, Sandy, UT; e-mail: dgriffith@nawcinc.com.

Methodology

- Review of Environmental and Legal Aspects
- Development of Cost Estimates
- Report Preparation
- Coordination Meetings and Presentations

2. PROGRAM GOALS AND SCOPE

The stated goal of the proposed seeding 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 (Hess, 1974). Evaluation procedures are to be developed and incorporated in the implementation of the proposed program design. 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 program specific rawinsonde (balloon) soundings are recommended for conduct on a phased rather than ongoing basis, to help maintain program cost effectiveness.

3. TARGET AREAS

The proposed target areas consist of the terrain above 1982 m (6,500 feet MSL) elevation in two separate mountain complexes located in Eastern Idaho. The North Target Area is comprised of the south slopes of the Centennial Mountains and the Lion Head and Henrys Lake Mountains in northeastern Idaho. The second area, denoted the East area, encompasses all or portions of the Big Hole Range, the Snake Range, the Grays Lake Mountains, and the Aspen Range located in Eastern Idaho. Streams that originate in both of these areas provide streamflow to the Snake River. The proposed target area locations are depicted in Figure 1.

Runoff from these target areas benefit hydropower production, agriculture (both surface runoff and ground water recharge), municipalities (drinking water), as well as recreational interests. Approximately 70% of the annual precipitation in the target area accumulates during the October-April period, with area average snowpack water equivalent on April 1 of 44.7 cm (17.6 in) in the North Target Area and 38.9 cm (15.3 in) in the East area.

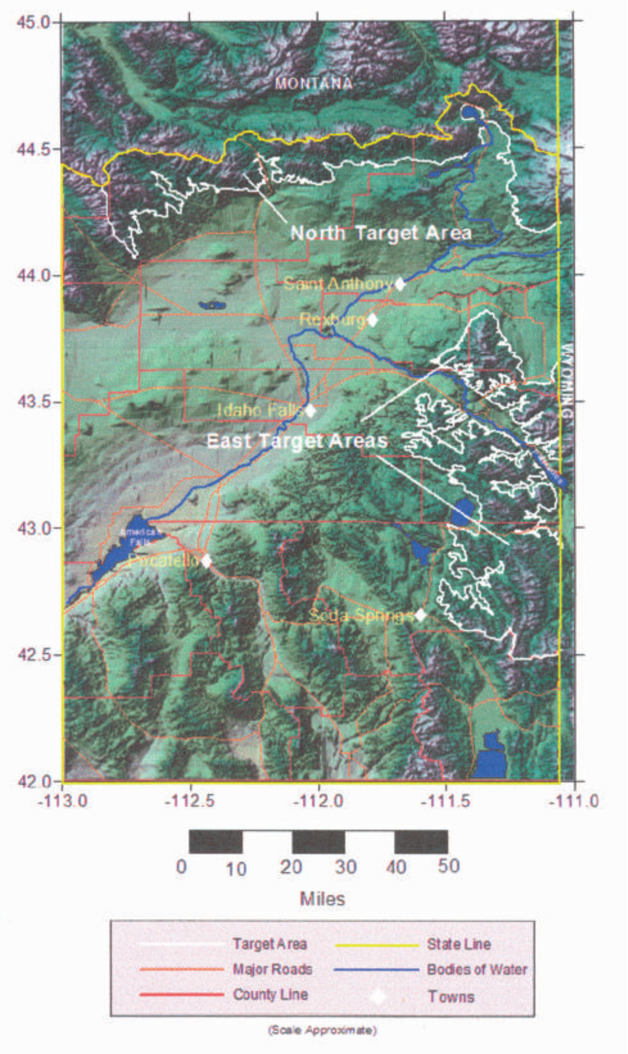

Figure 1. Proposed North and East Target Areas

4. SEEDING PROGRAM PRELIMINARY DESIGN

4.1 Seeding Methods and Materials

Storm periods affecting the potential target areas were identified for five winter seasons (water years 2003-2007) for the October-April period. Precipitation data from several Natural Resource Conservation Service's SNOwpack TELemetry (SNOTEL) sites were considered, and six-hour time blocks were selected when precipitation was clearly occurring in the target areas (in general, at least 0.254cm, 0.10 in) of precipitation during the six-hour period reported at one or more of the target SNOTEL sites). In all, 170 six-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. Detailed analyses of these storm periods were performed that included information on:

- Precipitation amounts and timing of occurrence
- 700 mb temperatures and winds
- Low-level atmospheric stability

Analyses were performed using this data set to estimate the percentage of the time the six-hour events would be considered "seedable" in each target area. These analyses, which are described in Section 5, indicated 37% of the events in the North Target Area and 38% of the events in the East area were considered seedable based upon cloud top temperature criteria.

Information obtained from the analysis of those six-hour precipitation periods was utilized to develop a number of the recommendations contained in the preliminary design. Some of these recommendations are summarized in the following.

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. Recall that the seedable events were estimated to only be 37 to 38% of the total number of storm periods that were analyzed. The manual generator seeding method has been used for decades to good effect on a seeding program for the Thomas and Smiths Forks located in southeastern Idaho and southwestern Wyoming from the 1950's through the mid-1980's (Griffith et al. 1983) as well as in various mountainous target areas in Utah from the 1970's to the present (Griffith et al. 2009). Recommended ground based generator locations are in the foothills and near the mouths of canyons. The recommended "core" operational program 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. Inversions were identified and documented in analysis of atmospheric soundings (NWS Boise and Salt Lake) taken during storm periods. 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. In addition to these factors, analyses described in Section 5.1 indicate that remote generators would only add less than a 1% increase in precipitation. An initial winter season of project area-specific rawinsonde measurements has been recommended, to allow closer consideration of the atmospheric stability and seeding material transport issues as they relate to the project design.

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-level atmospheric inversions. Assuming the ability to fly safely in the areas upwind of the intended target area, a seeding aircraft could be flown at a temperature level appropriate for near instantaneous activation of the silver iodide nuclei. Data analysis indicates that the use of aircraft seeding would enable seeding of the remainder of the seedable storm periods not considered seedable by the manual generator method. This represents an additional 42-43% beyond the 57-58% that are considered to be effectively seeded using manually operated ground 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 that one aircraft could seed a large majority of these events (i.e., two aircraft would not be required). Potential bases of operations for the aircraft include airports at Pocatello and Idaho Falls. A decision regarding inclusion of aircraft seeding in the program design can be made at the sponsor's discretion. This decision could be based upon a benefit/cost analysis of this option.

4.2 Supplemental Meteorological Measurements

One winter season of supplemental data collection specific to the program area is proposed prior to a decision being made as to whether the fully operational ESRBP seeding program should be implemented. Measurements would include program specific rawinsonde (balloon) soundings to better characterize the structure of the storm environment, especially levels below mountain crest height and associated low level stability from the surface to crest height. A strategically located ridge-top icing rate detector site would document the occurrence of supercooled liquid water. Microwave radiometer observations (typically vertically pointing) 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 the 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.

4.3 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 final 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. Control sites selected for use in the development of the historical target/control evaluation methodology were selected in an attempt to avoid any potential contamination from cloud seeding programs being conducted in the Payette and Boise River Basins located northeast and east of Boise.

4.4 Summarized Key Elements of the Recommended Preliminary Seeding Program Design

- The target area will be those areas in Bonneville, Clark, Fremont and Madison Counties that lie above 2.0 km (6,500 feet), 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 would 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 and atmospheric inversions to verify some of the conclusions and assumptions contained in the 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 in the final report), and possibly some snow chemistry analyses verifying that silver above background levels is being observed at various sampling points in the target areas.

- Qualified/experienced meteorologists should direct the seeding operations.

5. POTENTIAL YIELD/BENEFITS

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 I and II (Mielke *et al.* 1981, Hess 1974) to estimate the anticipated effects for the ESRBP. These increases were +25% for cloud top temperatures of –20 to -5^{0}C and +10% for cloud top temperatures of –25 to –21^0 C. In this analysis these estimated seeding effects were applied to the six-hour precipitation events that fell within these ranges during a multi-season period. An event was considered "seedable" if the estimated cloud top temperature during the six-hour event was $\geq$ -26^{0}C. The resulting percentage of "seedable" six-hour periods was 37% in the North Target Area and 38% in the East Target Area. Using these results, the multi-season average estimated increases for the North and East Target Areas were calculated for the ground and airborne seeding modes (remote generators were not included based upon the discussion in Section 4.1 and in the following paragraph). The determination of whether a six-hour event was deemed "seedable" by the three different seeding modes was based upon the following stratifications:

For lower elevation manually-operated silver iodide generators

1. The low-level atmospheric stability (surface to the 700 mb level) was neutral or slightly stable.
2. The 700 mb temperature was ≤ -5^0 C.

For higher elevation remotely-operated silver iodide generators

1. The low-level atmospheric stability was moderately or very stable
2. The 700 mb temperature was ≤ -5^0 C.

For aircraft silver iodide seeding

1. The 700 mb temperature was > -5^0 C.

These increases were then applied to the April 1st snow water contents to estimate the potential average increases in snow water contents. Tables 1 and 2 summarize this information.

For the North Target Area there was an estimated 3.0% increase using ground-based generators, a 0.7% increase using remote generators and an additional 1.8% increase using aircraft seeding yielding a combined total of 5.5%. For the East Target Area there was an estimated 3.9% increase using ground-based generators, a 0.5% increase using remote generators and an additional 3.2% increase using aircraft seeding yielding a combined total of 7.6%. Due to the small indicated increases (less than 1%) through the use of remote generators in both areas, the decision was made to recommend that aircraft seeding could be used to supplement a manually-operated ground-based generator program. As a consequence, those cases which were indicated to be seedable from remote generators were assumed to be covered by aircraft seeding, so the aircraft seeding percentages were increased taking this factor into account. Such results compare favorably with a review of the estimated results of several similar winter orographic seeding programs conducted in the western states, some for decades, supporting the potential for precipitation augmentation. These estimates are also supported by the published Capability Statement of the Weather Modification Association (2005), which states "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." A Capability Statement of the American Meteorological Society (AMS 1998) states in part regarding precipitation increases "There is considerable evidence that, under certain conditions, precipitation from supercooled orographic clouds can be increased with existing techniques. Statistical analyses of precipitation records from long-term projects indicate that seasonal increases on the order of 10% have been realized." 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 (ASCE 2004, 2006).

Table 1. Estimated Increases in April 1st Snow Water Content for the North Target Area Based on Estimated November – March Precipitation Increases for Storm Periods using Cloud Top Temperature Estimates. Values in cm and (in)

Site	Apr. 1 SWE	Total Incr (5.5%)	Ground (3.0%)	Remote (0.7%)	Air (1.8%)
Big Springs SC	49.0 (19.3)	2.69 (1.06)	1.47 (0.58)	0.35 (0.14)	0.89 (0.35)
Camp Creek SC	24.9 (9.8)	1.37 (0.54)	0.74 (0.29)	0.18 (0.07)	0.46 (0.18)
Crab Creek*	41.7 (16.4)	2.29 (0.90)	1.24 (0.49)	0.28 (0.11)	0.76 (0.30)
Irving Creek SC	14.5 (5.7)	0.79 (0.31)	0.43 (0.17)	0.10 (0.04)	0.25 (0.10)
Island Park*	39.9 (15.7)	2.18 (0.86)	1.19 (0.47)	0.28 (0.11)	0.71 (0.28)
Latham Springs SC	83.8 (33.0)	4.62 (1.82)	2.81 (0.99)	0.58 (0.23)	1.50 (0.59)
Lucky Dog SC	64.0 (25.2)	3.53 (1.39)	1.93 (0.76)	0.46 (0.18)	1.14 (0.45)
Valley View SC	39.1 (15.4)	2.16 (0.85)	1.17 (0.46)	0.28 (0.11)	0.71 (0.28)
Webber Creek SC	5.0 (5.9)	0.81 (0.32)	0.46 (0.18)	0.10 (0.04)	0.28 (0.11)
White Elephant*	4.2 (29.2)	4.09 (1.61)	2.24 (0.88)	0.51 (0.20)	1.35 (0.53)
Mean	**44.7 (17.6)**	**2.46 (0.97)**	**1.35 (0.53)**	**0.30 (0.12)**	**0.81 (0.32)**

* SNOTEL site

Table 2. Estimated Increases in April 1st Snow Water Content for the East Target Area Based on Estimated November – March Precipitation Increases for Storm Periods using Cloud Top Temperature Estimates. Values in cm and (in)

Site	Apr 1 SWE	Total Incr (7.6%)	Ground (3.9%)	Remote (0.5%)	Air (3.2%)
Allen Ranch	26.7 (10.5)	2.03 (0.80)	1.04 (0.41)	0.13 (0.05)	0.86 (0.34)
Fall Creek	18.5 (7.3)	1.40 (0.55)	0.71 (0.28)	0.10 (0.04)	0.58 (0.23)
Lava Creek	39.9 (15.7)	3.02 (1.19)	1.55 (0.61)	0.20 (0.08)	1.27 (0.50)
Packsaddle Spring	74.4 (29.3)	5.66 (2.23)	2.90 (1.14)	0.38 (0.15)	2.39 (0.94)
Pine Creek Pass*	40.6 (16.0)	3.10 (1.22)	1.57 (0.62)	0.20 (0.08)	1.30 (0.51)
Somsen Ranch	34.0 (13.4)	2.59 (1.02)	1.32 (0.52)	0.20 (0.07)	1.09 (0.43)
State Line	38.1 (15.0)	2.90 (1.14)	1.50 (0.59)	0.20 (0.08)	1.24 (0.48)
Mean	**38.9 (15.3)**	**2.95 (1.16)**	**1.52 (0.60)**	**0.20 (0.08)**	**1.24 (0.49)**

* SNOTEL site

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 2. Estimates were made of conservative and liberal levels (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 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. Some of the streamflow from sub-basins 1 and 2 is absorbed by the underlying porous volcanic rock common throughout eastern Idaho. Water from these porous underground aquifers emerges in the form of large springs along the banks of the Snake River in the area known as the "Thousand Springs" located northwest of Twin Falls.

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 Target Area is #3, with all the other sub-basins included in this summation being in the East Target 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 only 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 3 summarizes the results for each sub-basin, as well as the total increases estimates. Table 4 summarizes the totals for the North Target Area, East Target Area, and the North and East Areas combined.

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 Target 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 Target Area is 57,050 acre-feet for ground-based seeding only, and 110,450 acre-feet for ground plus aircraft seeding.

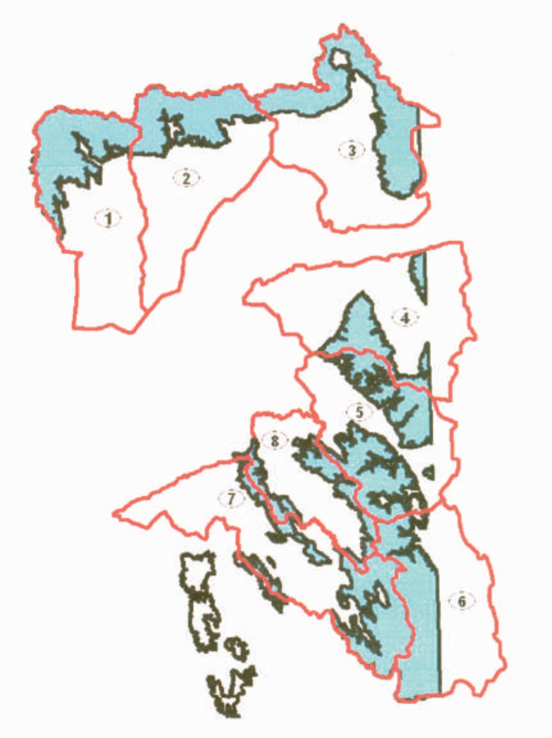

Figure 2. North and East Target Area Stream Sub-basins

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

Sub-basin	Base Streamflow (AF)	Ground-Based Increase (AF)		Aircraft Increase AF		Ground + Aircraft Increase (AF)	
		Min	Max	Min	Max	Min	Max
1 (Medicine Lodge)	61,115*	1,800*	NA	1600*	NA	3,400*	NA
2 (Beaver – Camas)	120,529*	3,600*	NA	3000*	NA	6,600*	NA
3 (Upper Henrys)	594,046	17,800	24,400	14,900	20,700	32,700	45,100
4 (Teton)	145,627	5,700	8,600	5,400	8,100	11,100	16,700
5 (Palisades)	485,903	19,000	34,000	17,900	32,600	36,900	66,600
6 (Salt River)	147,085	5,700	12,100	5,500	11,700	11,200	23,800
7 (Blackfoot)	209,757	8,200	13,400	7,700	13,000	15,900	26,400
8 (Willow Creek)	61,212	2,400	5,000	300	4,600	2,700	9,600
Total (excl. #1 and 2)	1,643,630	58,800	97,500	51,700	90,700	110,500	188,200

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

Table 4. Summary of North and East Target 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 (North and East Target Areas) 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 4 indicates that higher amounts of streamflow may be produced from the East Target Area when compared with the North Target Area although there are some benefits in terms of enhanced local streamflow and ground water recharge from seeding in the North Target Area that are not accounted for in this comparison.

6. BENEFIT AND 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 increase 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 5 through 7. The combined costs in Table 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, estimates 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.

The values provided in Tables 5 through 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.

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 5.5 - 7.6% during an average winter season, with the resultant additional average March through July runoff estimated to range from 78,150 to 149,350 acre-feet depending upon whether ground seeding only or ground seeding plus airborne seeding is utilized.

The estimated costs to achieve these increases in March through July combined area 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 the preliminary program design. The estimated cost of this one season of observations is $243,750.

A review was conducted of the potential environmental impacts of the proposed program that included consideration of downwind effects, toxicity of seeding agents, avalanches, snow removal, and previous environmental impact studies. This review concluded that no significant environmental impacts would occur through implementation of this program.

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.* 2007). It was concluded that an operational winter cloud seeding program was feasible for those 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.

Table 5. Estimated Average Costs to Produce Additional March – July Streamflow, North Target 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 6. Estimated Average Costs to Produce Additional March – July Streamflow, East Target 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 7. Estimated Average Costs to Produce Additional March – July Streamflow, Combined North and East Target 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

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