***Funding for WRDS and the creation of this electronic document was provided by the Wyoming Water Development Commission (http://wwdc.state.wy.us)***

# Weather Modification Level III Feasibility Study

# Laramie Range Siting and Design

## Executive Summary


Frank McDonough, John F. Mejia, Kacie N. Shourd, Rosemary W. Carroll, Alexandra D. Lutz, Jeff Dean, Jeese W. Juchtzer, Arlen W. Huggins, Mike L. Kaplan

**Desert Research Institute**

**Reno, Nevada**

Ray DeLuna, Cameron Trembath

**TREC, Inc**

**Casper, Wyoming**

# Executive Summary

A Level III Siting and Design Study was conducted by the Desert Research Institute (DRI) to assess the potential for an operational cloud-seeding program in the Laramie Range of south-central Wyoming. The study was funded by the Wyoming State Legislature through the Wyoming Water Development Commission (WWDC). The goal of this project was to assess the potential to increase snowpack and the resulting runoff in streams of the Range that provide water to the North Platte River using a well-designed cloud seeding program. The executive summary summarizes the study but more detailed analysis can be found in the full report.

Winter cloud seeding has been conducted across the mountains of the western United States for more than six decades. Results of these studies suggest that a carefully planned and operated program can lead to snowfall increases of up to 10% for seeded storms compared to unseeded storms (Breed et al. 2015). The decreased snowfall in unseeded clouds is a result of inefficient ice crystal production in cloud layers with temperatures warmer than -15$^{o}$C (5$^{o}$F). Small aerosols that serve as the embryonic lattice structure for ice to begin to form often don't become active in natural clouds until cloud temperatures cool below these levels. The cloud particles remain as small droplets below freezing, stay within the cloud, evaporate downstream of the mountains, and don't fall to the surface as precipitation. Cloud seeding introduces embryonic ice crystals into these clouds at temperatures warmer than -15$^{o}$C, causing the small droplets to convert to ice, grow, and fall to the ground as snow.

Cloud seeding has been conducted in Wyoming for more than 50 years. The Eden Valley Irrigation and Drainage District program targets storms transporting clouds into the southern Wind River Mountains. The goal of this program is increased stream flow into Big Sandy Reservoir. The program history suggests annual snowpack increases of 7 to 10%. The State of Wyoming funded a long-term, multi-year weather modification feasibility study for the Medicine Bow/Sierra Madre and Wind River Ranges. The executive report from that study indicates a 5 to 15% increase in snowfall for seeded storms, but only 30% of storms had favorable conditions for cloud seeding (Ritzman et al. 2015).

Cloud seeding technology includes releasing small amounts of very small particles that have the proper structure to initiate ice formation, into the parts of clouds where they can have the desired effect. Most cloud seeding programs use the silver iodide molecule (AgI). Seeding can be conducted from the ground by burning a solution that contains the AgI or from aircraft using AgI flares. Aircraft allow direct application into the proper area of clouds, whereas ground-based generators require the plume to rise and enter the clouds. Aircraft operations require flight into often severe icing conditions and can be costly. An alternative method of creating the ice crystals is by forming a bubble of -40$^{o}$C air at the nozzle of a liquid propane (LP) dispenser. If this is done in clouds containing subfreezing liquid water droplets, the drops will freeze and end up freezing additional surrounding drops. These new ice crystals (frozen drops) then rise within the cloud, converting additional subfreezing drops to ice and eventually increase snowfall (Super and Heinbach 1989).

## Geography and Snowfall in the Laramie Range

The Laramie Range is a 130-mile long, relatively narrow (20–25 miles), mountain range located in south-central Wyoming extending south into northern Colorado. It is part of the eastern slopes of the Rocky Mountains, and the entirety of the range drains into the North Platte River. The northern half of the Laramie range is generally higher and steeper, with the highest peaks at 9,000 ft mean sea level (MSL), while further south near the state line the higher peaks are below 8,000 ft MSL. The highest point in the range is Laramie Peak in the central part of the range at 10,274 ft, with the lowest point along the North Platte River at 4,500 ft. The east side of the range has a peak-to-valley vertical aspect of approximately 3,000 to 4,000 ft, while the west side has a vertical aspect of approximately 1,500 ft (Fig. 1).

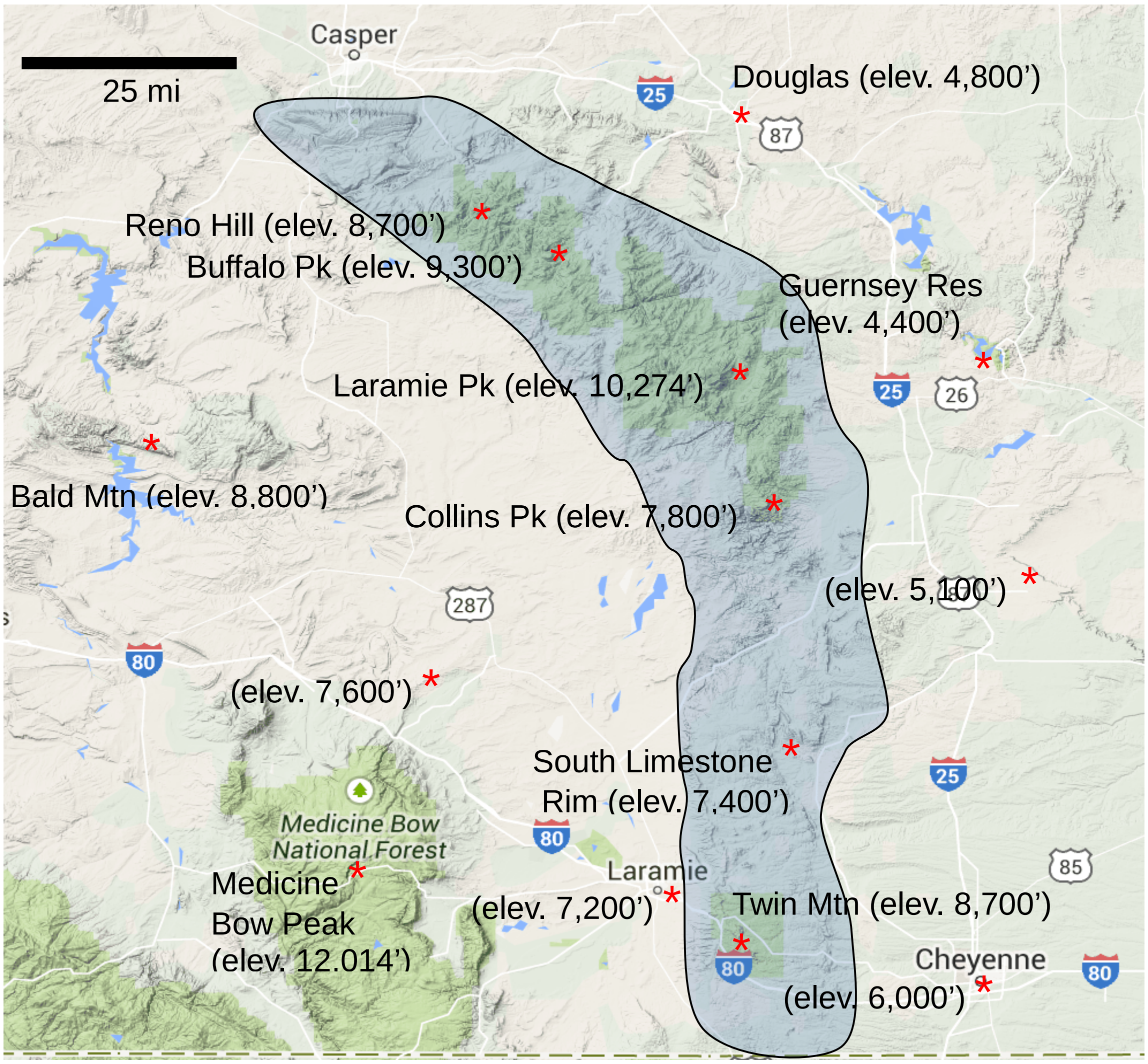


Figure 1. The Laramie Range (shaded) in south-central Wyoming. The Laramie Range target area is defined as the 621,000 acres over the northern part of the Range located above 8,000 ft. MSL

The annual snow water equivalent (SWE) in the mountains is measured by four Natural Resources Conservation Service (NRCS) instruments (SNOTEL). These are sited along the higher elevations of the northern part of the range (Fig. 2). The seasonal snowpack is maximized in early to mid-April with the highest amounts over the northwestern sites and significantly lower amounts over the central part of the range (see Table 1).

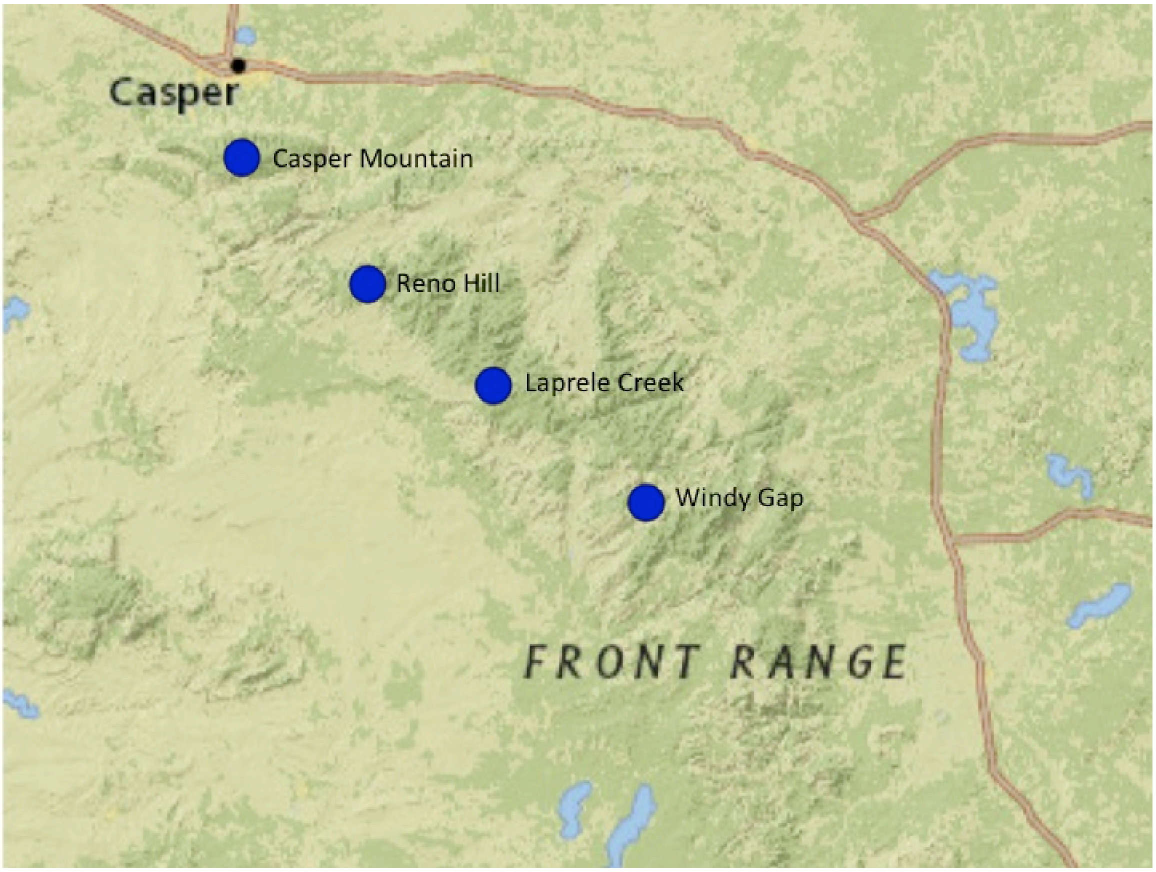


Figure 2. The NRCS SNOTEL observational locations in the Laramie Range. Among other measurements, these instruments measure the SWE as well as temperatures.

| 1.1.1.1 SNOTEL Site | 1.1.1.2 Elevation (ft) | 1.1.1.3 Median yearly maximum SWE (in) |
|---|---|---|
| Casper Mountain | 7,900 | 14.5 |
| Reno Hill | 8.400 | 14.2 |
| Laprele Creek | 8,375 | 9.4 |
| Windy Gap | 7,900 | 7.8 |

**Table 1.** Climatological snow water equivalent (SWE) for selected Laramie Range sites.

## Defining the Project Area

DRI and the Wyoming Water Development Office (WWDO) conducted two public meetings in the local area to inform the public and local stakeholders about the project. At these meetings, local stakeholders raised concerns about the impacts to winter ranching activities from increased snowfall. Information was gathered about the locations of the winter ranching activities and the nature of their primary concerns. We determined that all of the winter ranching activities occur below the 8,000 ft MSL elevation, where cloud seeding would have a minimal impact. The WWDO communicated to the DRI project team that the transportation corridors located in the southern end of the project area would not be considered part of the operational cloud-seeding program. Based on these recommendations, the final target area in the Laramie Range is defined as elevations above 8,000 ft. MSL, consisting of ~621,000 acres over the northern parts of the shaded terrain shown in Figure 1.

## Climatology of the Laramie Range

This feasibility study assessed the frequency of winter storms in the area, characterizing their temperatures, cloud structures, winds, and atmospheric stability. We implemented two approaches to assess these storms' characteristics: (1) an 11-year purely model-based approach and (2) a 10-year combined observational and numerical model based approach. These data sets covered the 2004-2015 and 2005-2015 winter seasons respectively over the Laramie Range (Fig. 3).

For the purely model-based climatology we ran a nested Weather Research and Forecasting (WRF) (Skamarock and Klemp 2008) numerical model simulation over the area with 1 km horizontal resolution over the Laramie Range. The model results suggested that favorable AgI cloud-seeding conditions (temperatures between -6°C and -16°C and modeled supercooled liquid water (SLW) greater than 0.001 g $m^{-3}$) were present up to 12% of the time between November and April over the higher peaks of the Laramie Range (Fig. 3). Seeding conditions are confined to clouds at altitudes lower than 12,000 ft. MSL and over the peaks of the Range (Fig. 4). The majority of favorable cloud-seeding conditions were associated with modeled precipitation in the Range.

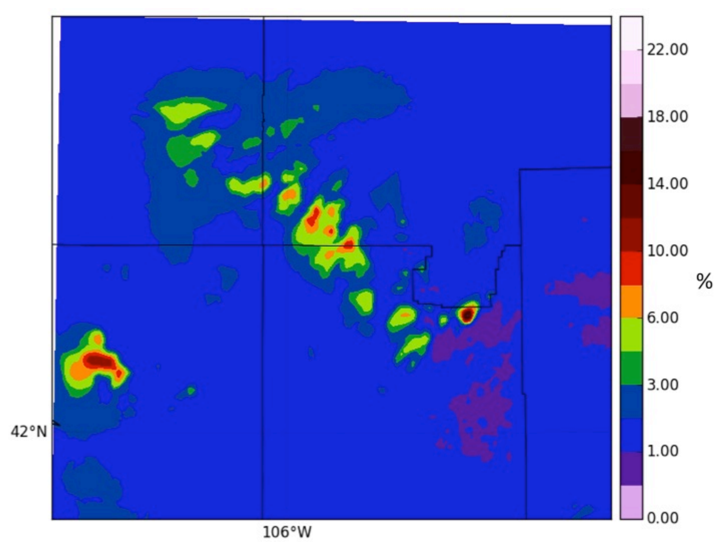


Figure 3. Horizontal projection of the percent of time when AgI cloud-seeding potential is present in the column over the WRF 11-year winter-season climatology. Favorable cloud-seeding conditions exist when temperatures are between -6°C and -16°C and supercooled liquid water (above 0.001 g/kg) is present.

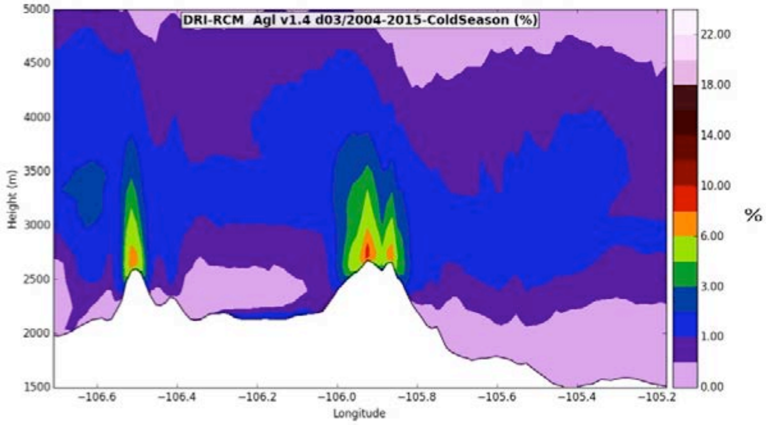


Figure 4. Vertical cross section at 1 km for the percent of time when AgI cloud seeding potential is present using the WRF 11-year climatology. Crest of Laramie Range is shown in the center of image.

The observational data used in the observational climatology included geostationary satellite (GOES), National Weather Service (NWS) radar, surface observations, SNOTEL observations, aircraft icing reports, hourly model initialization winds, and model soundings from the high resolution WRF simulations. There were 447 precipitation events identified during the 11-year period. Working from the observational climatology, two primary storm flow regimes were identified: a northwesterly flow regime (Scenario 1) with 249 cases and a north-northeasterly flow regime (Scenario 2) with 97 cases.

Based on temperature, wind, cloud presence, and atmospheric stability, the Scenario 1 cases were found to be favorable for ground-based AgI seeding 63% of the time, aircraft AgI cloud-seeding conditions were favorable approximately 92% of the time, and 29% of the time when ground based seeding was not favorable aircraft cloud seeding was possible (Table 2). LP cloud seeding was not feasible under northwesterly flow due to the potential of the propane plume to descend at times and exit the cloud.

For Scenario 2 (Table 3), 77% of the cases were seedable from the ground, 86% from aircraft, and 39% from LP – when the cloud base observed at the valley airport in Casper is below 8,000 ft MSL. Orographic lifting during storms often produces cloud bases, which are lower than the cloud base height over valley locations, therefore the year average 72.1 hour frequency for LP seeding is likely an underestimate.

| SCENARIO 1 | Seeding Hours | % Scenario Hours | Yearly Avg. hrs |
|---|---|---|---|
| Ground-based AgI | 2479 | 63.05 | 247.9 |
| Aircraft AgI | 3605 (1126) | 91.68 (28.63) | 360.5 (112.6) |

**Table 2**: Scenario 1 (west though north-northwest wind direction at 700 millibars (mb)) potential seeding hours. The aircraft only hours and percentages are shown in parentheses.

| SCENARIO 2 | Potential Seeding Hours | % of Scenario 2 Storm Hours | Winter Avg. (hrs) |
|---|---|---|---|
| Ground-based AgI | 1274 | 77.17 | 127.4 |
| Aircraft AgI | 1439 (165) | 87.16 (10) | 143.9 (16) |
| Propane (all) | 1580 | 95.70 | 158.0 |
| Propane (< 10000') | 1094 | 66.26 | 109.4 |
| Propane (< 9000') | 866 | 52.45 | 86.6 |
| Propane (< 8000') | 721 | 43.67 | 72.1 |

**Table 3**: Scenario 2 (north though east-northeast wind direction at 700 millibars (mb)) storms and seeding methods potential hours. Row 5 is for Casper observed cloud bases below 9,000 ft MSL and row 6 is for Casper cloud bases below 8,000 ft MSL. The aircraft only hours and percentages are shown in parentheses.

## Preliminary Project Design

The preliminary project design and potential cloud seeding generator placement, was initially created from results gleaned from the numerical model based, and the observed climatology (Fig. 5). During times when cloud seeding was favorable in the numerical model simulations, modeled cloud seeding plume trajectories were run backward in time from the seeding target area to see where the air originated. We completed this for all the cloud seeding periods identified in the model climatology. A broad area of plume initiation points were identified to the west through north-northwest of the target area for Scenario 1, and a second area of initiation points to the north through east-northeast of the target area for Scenario 2. Based on experience, we placed the preliminary project design generators in favorable sites within the model-defined locations.

We then tested the preliminary project design generator sites using forward trajectories from the plume-tracking software for all of the seedable periods identified, as in Figure 6. This ensured that the seeding plumes would successfully reach the target areas.

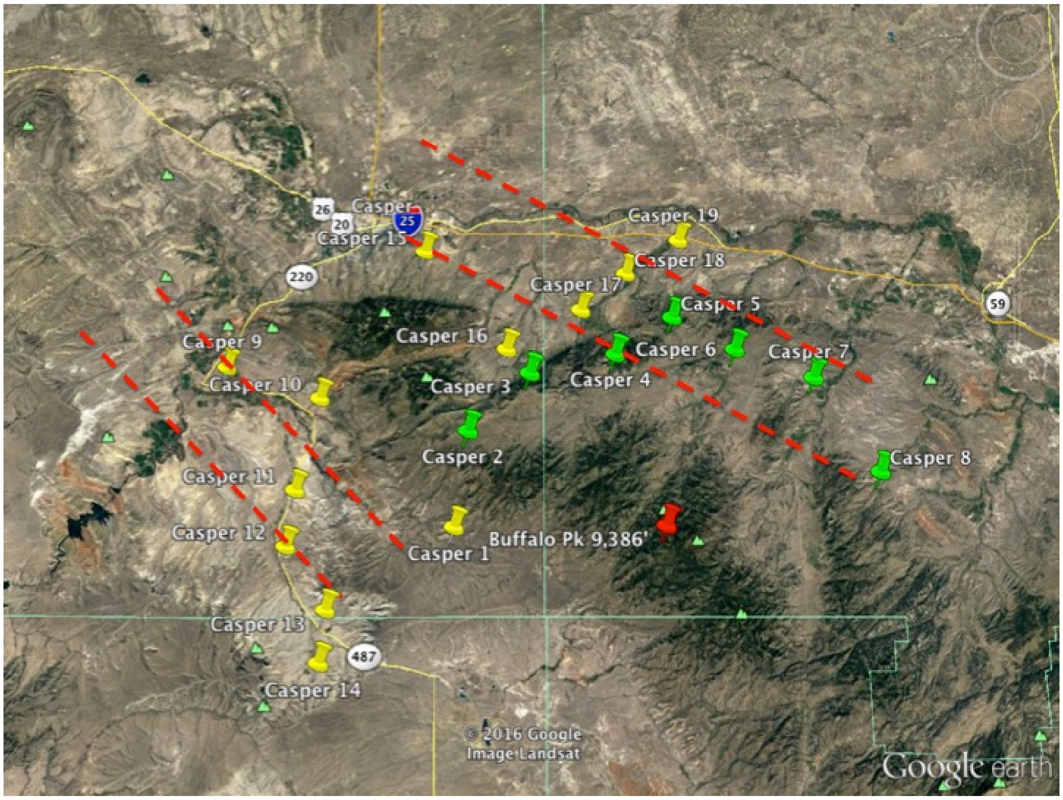

Figure 5. The preliminary design for generators and flight tracks. Yellow pins indicate ground based AgI generator locations; green pins indicate LP or AgI generator locations; and red dashed lines show potential aircraft flight tracks.

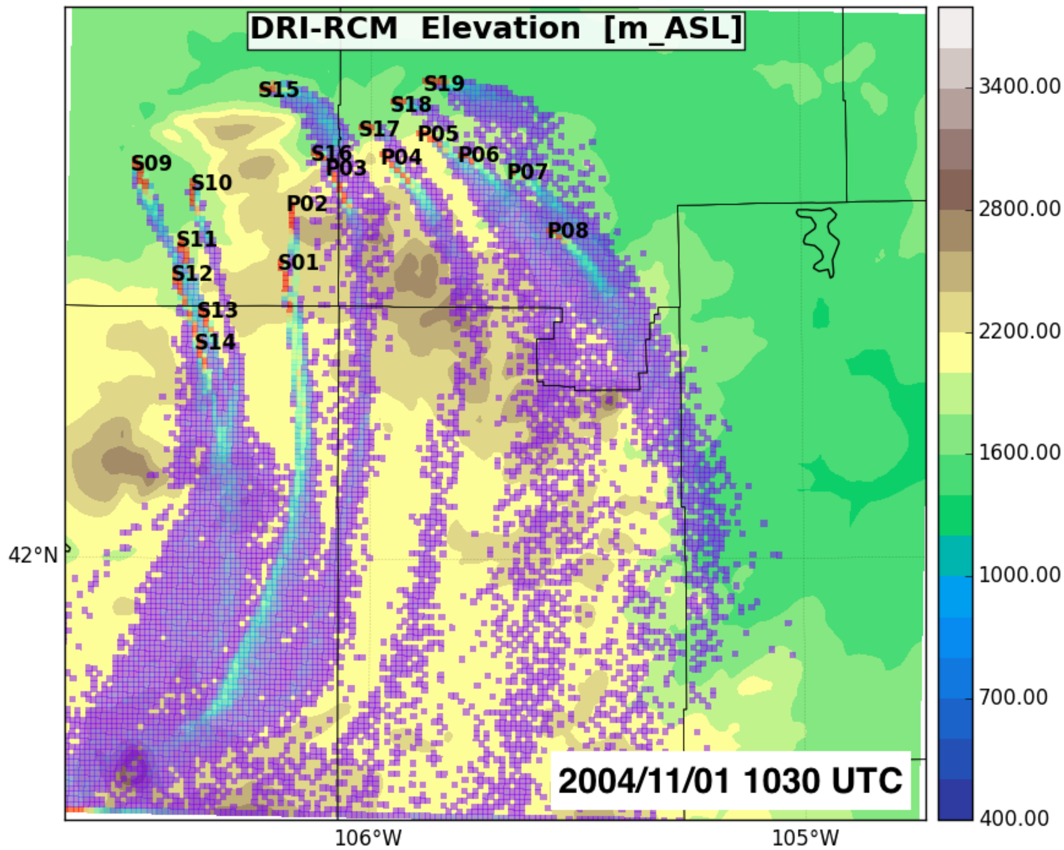


Figure 6. This figure shows a simulated release of seeding particles from the generators at the locations of the preliminary project design generators sites during one of the seedable storm periods.

Once the preliminary project design was completed, a DRI technician and local environmental consultant from TREC Inc., of Casper, Wyoming visited the potential generator sites. TREC was hired as a local consultant to aid with several aspects of this project. A few of the potential LP sites could not be accessed due to muddy conditions. Several of the sites were slightly relocated to place generators on hilltops or at other more favorable locations (relative to road access, specific terrain features, vegetation, etc.). The latitudes and longitudes of the potential generator locations were recorded and given to TREC Inc. to assess access and easement requirements and identify any local, state, and federal requirements necessary to place and operate the project generators and other ancillary equipment.

## Development of an Operational Design

An operational project design was developed to outline how the proposed project could be conducted. Initially, the project meteorologist reviews the project operational cloud seeding suspension criteria and determines whether or not cloud-seeding operations can commence. The suspension criteria are a set of rules developed to ensure cloud seeding is not conducted during periods of abnormally high snowpack or periods with a potential flood threat. A detailed collection of observational and model data sets has been defined to identify the presence of cloud-seeding opportunities. Analysis of these data sets is used to test whether cloud-seeding conditions are present. If the correct meteorological conditions are present, then the generators will be started and appropriate stakeholders informed about operations. Seeding criteria for the Laramie Range project are based on specific means of identifying SLW clouds with favorable winds and temperatures.

## Identification of SLW clouds

The presence of SLW in targeted clouds can be inferred using the data sets discussed above:

1. Clouds need to be present in the target area
   (and)
2. Cloud top temperatures in the cloud layer over the target area and at target altitudes should be warmer than -25°C, although strongly forced clouds with high vertical velocities can contain SLW when cloud tops are colder than -25°C
   (or)
3. Numerical model cloud simulations should show SLW in the target area
   (or)
4. Positive pilot icing reports are present (direct indicators of SLW in the clouds)
   (and)
5. Cloud base heights should be below ridge top and be warmer than -10°C.

| **Ground-based AgI Cloud Seeding** |
|---|
| Clouds present over the area |
| Supercooled liquid water present (SLW_FCAST) |
| 10,000 ft MSL winds from 270° (west) clockwise through 60° (east-northeast) |
| 10,000 ft MSL winds speeds <50 MPH and >10 MPH |
| Low-level stability suitable to vertically transport seeding plume |
| Temperatures in seeding target clouds <-6°C and >-16°C |
| Cloud bases below 10,000 ft MSL |

| **Ground-based LP Cloud Seeding** |
|---|
| Clouds present over the area |
| Supercooled liquid water present (SLW_FCAST) |
| 10,000 ft MSL winds from 360° (north) clockwise through 60°(east-northeast) |
| 10,000 ft MSL winds speeds <40 MPH and >5 MPH |
| Temperatures in seeding target clouds < -2°C and >-16°C |
| Cloud bases at or below generator height |

| Aircraft cloud seeding |
| --- |
| Clouds present over the area |
| Supercooled liquid present (SLW_FCAST) at flight level |
| Flight level winds from 250$^o$ (west-southwest) clockwise through 60$^o$ (east-northeast) |
| Winds speeds >10 MPH |
| Temperatures in seeding target clouds <-6$^o$C and >-16$^o$C |
| Cloud bases at or below 10,000 ft MSL |

## Environmental Considerations and Cloud Seeding Concerns

We completed a thorough review of available published literature regarding the safety of cloud seeding material to confirm the safety of these methods of precipitation enhancement. All of these studies, including a statement from the Weather Modification Association (WMA), indicate that silver iodide used in cloud seeding remains as an uncharged solid in the environment and does not bio-accumulate. The studies all agree that there is no evidence of adverse effects on human health or the environment from silver iodide used for cloud seeding (e.g., Williams and Denholm (2009)).

A common question posed by people unfamiliar with cloud seeding is whether cloud seeding in one location reduces precipitation in downstream locations. A detailed water budget analysis shows that less than 1% of the available water vapor in the atmosphere is removed due to cloud seeding (Breed et al. 2015).

## Evaluation Methodology

Evaluating the success of a cloud-seeding program can be approached through statistical methods, detecting the physical evidence of successful seeding, and numerical modeling Ritzman et al. (2015). Statistical analysis, physical observations, and numerical modeling validation should all be planned for this potential project. An economical cloud-seeding validation plan, a target-control statistical assessment for both snowfall and stream flow, as well as numerical model validation are proposed recommendations for a potential Laramie Range Cloud Seeding Project.

Our proposed cloud seeding validation plan is as follows:

1) Install an ice detector and heated weather station at the top of Hogadon Mountain Ski area at 7,900 ft MSL on the northwest end of the Range to determine the approximate mountain temperatures and winds as well as when and how much SLW is present.
2) Install Web cams pointing at the highest terrain on one of the Scenario 1 generators, and on one of the Scenario 2 generators, to determine cloud presence and cloud base heights over the target area.
3) Collect NWS operational data as outlined in the observational climatology.

4) Collect snowfall in real time during seeding events both within, and outside the seeding plume during one or two storms
5) Dig snow pits and collect snow samples from various layers late in the winter. Conduct trace chemical analysis on the layers to determine successful targeting.
6) Conduct snow chemical trace analysis in real time (i.e. elevated AgI found in the fresh snow)
7) Define target and control statistics for stream flow at Deer Creek (within the target area) and at Sybillie Creek (outside the target area in the southern Laramie Range).
8) Create target and control regression analyses for Scenario 1 and Scenario 2 storms for the northern Laramie Range SNOTEL site and the Cow Creek site in the southern Laramie Range.
9) Run the high resolution WRF model that was used in the climatology, but add cloud-seeding cloud physics parameterizations.

## Potential Benefits/Hydrologic Assessment

Complex hydrologic models were selected to assess potential runoff increases due to the cloud seeding program, and a simple linear regression approach was completed. The regression was built to develop a relationship between SNOTEL observations and stream flow gauge data for a majority of the drainages in northern sections of the Laramie Range (Fig. 7). Following development of the relationship, incremental increases were added to the SNOTEL values to estimate additional runoff (Fig. 8). Our results suggest that larger increases in runoff will be realized in wetter years. Each stream can be individually summed to estimate the increase in stream flow at Glendo Reservior (Fig. 9).

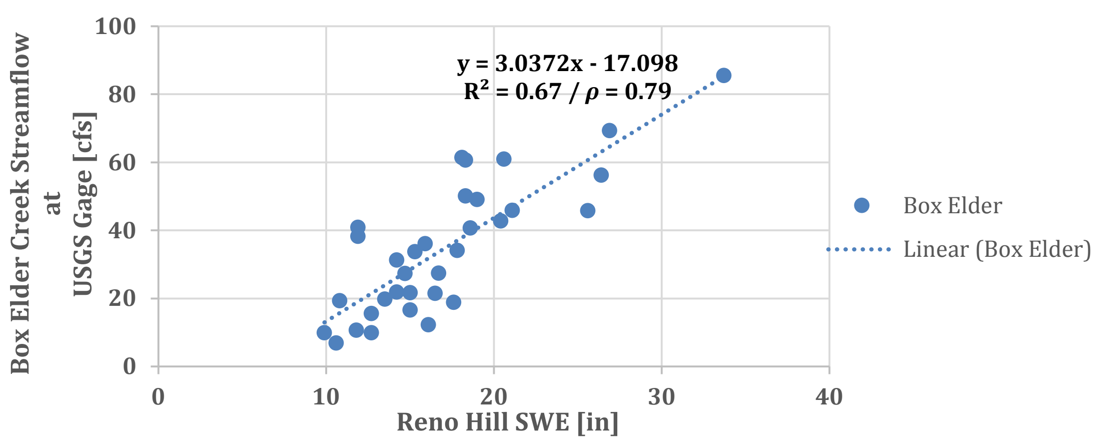


Figure 7. Development of linear relationship between the maximum Reno Hill SWE and the runoff observed at the gauge in Box Elder Creek.

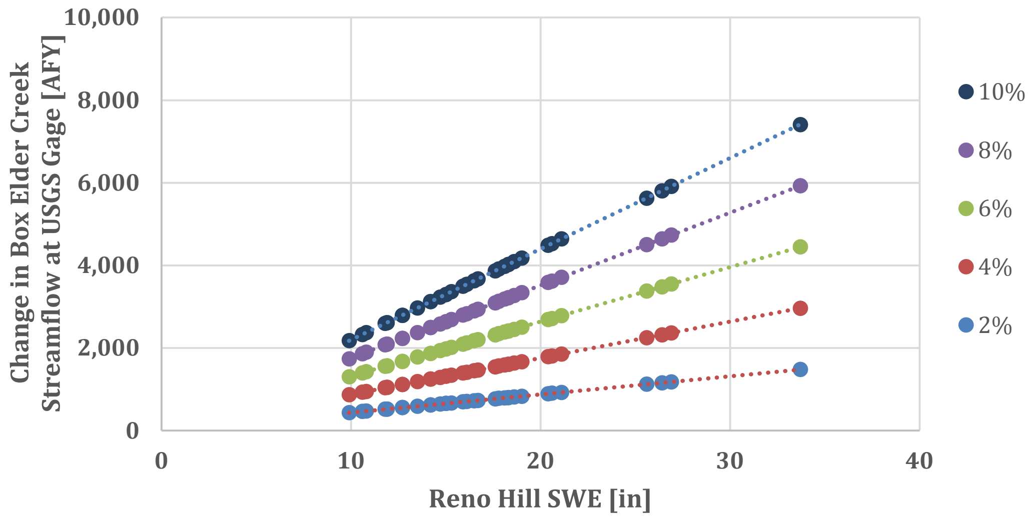


Figure 8. Estimated acre-feet per year (AFY) increases in runoff for all of the observed Reno Hill SWE and Box Elder Creek years with observations. Increases in SWE by (2%, 4%, 6%, 8%, and 10%) and expected increases in Box Elder streamflow.

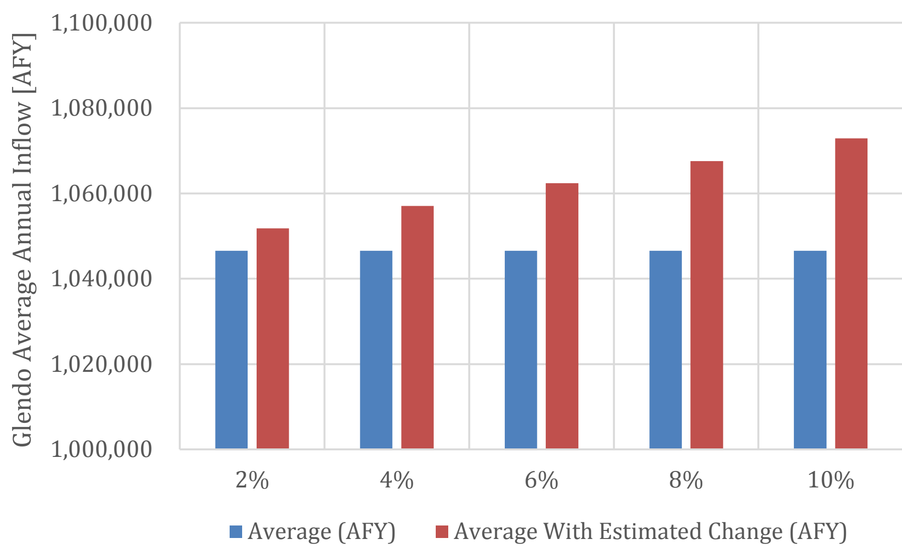


Figure 9. Estimated increase over average annual inflow at Glendo. Average annual inflow is 1,046,543 AFY and is calculated by the Bureau of Reclamation (http://www.usbr.gov/gp-bin/arcweb_gler.pl).

A more advanced model (PRMS) also was selected and tested over the Box Elder and Deer Creek drainages in the northeastern Laramie Range. The PRMS model is complex and includes numerous environmental parameters that model runoff (Fig. 10). Our preliminary results suggest non-linear increases in stream flow from cloud seeding during wetter years (Fig 11).

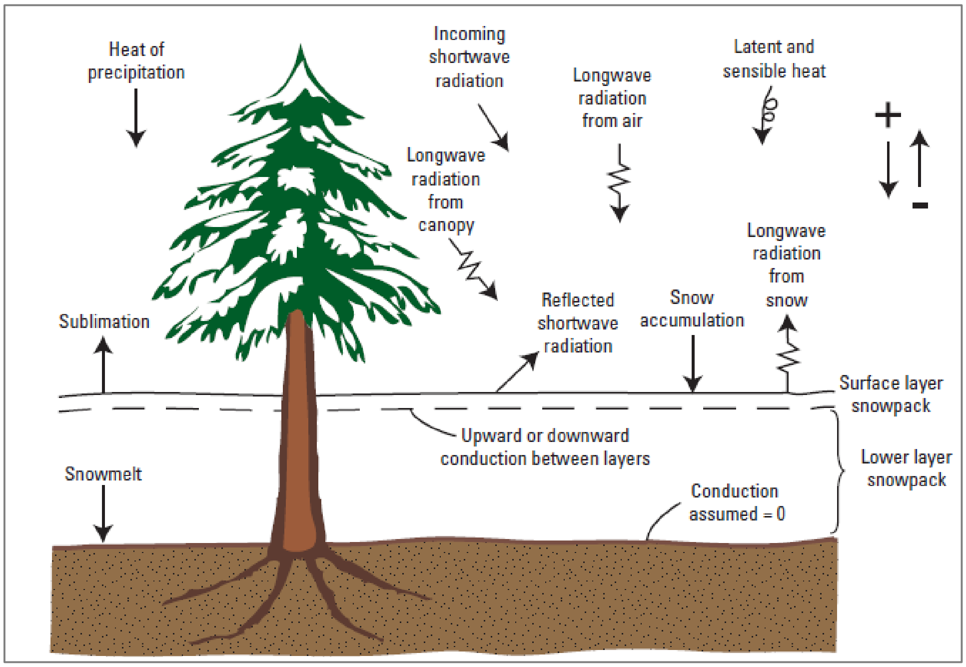


Figure 10. Components of the snowpack energy balance, accumulation, snowmelt, and sublimation.

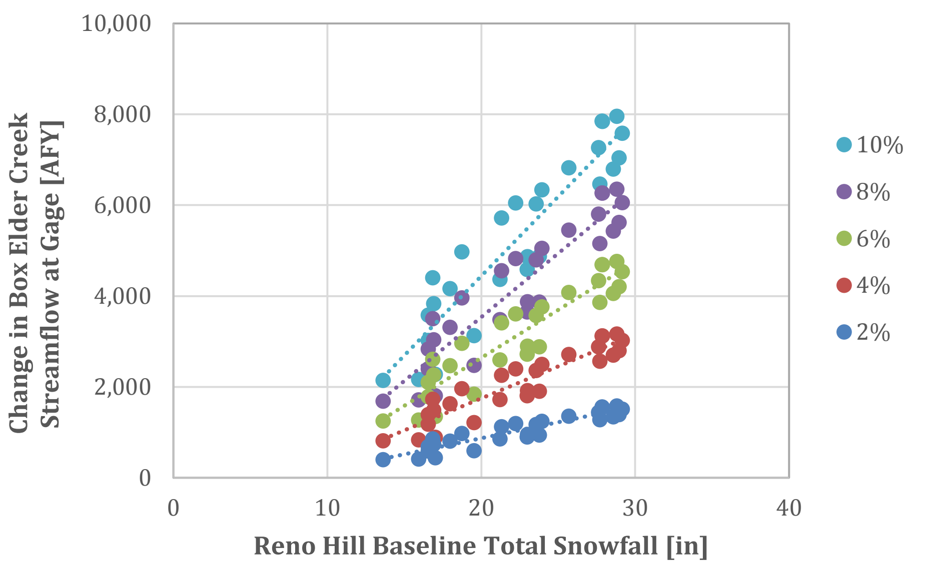


Figure 11. As in Fig 8 except for PRMS model estimates of cloud seeding increases in streamflow (AFY) at the Box Elder USGS gage from cloud seeding as a function of change (2%, 4%, 6%, 8%, 10%) in total observed precipitation.

## Cost estimates and cost benefits

The approximate costs to operate the outlined cloud seeding program includes expenses for equipment, consumables, transportation, and labor. We estimate that the labor (program management, daily forecasting, operation of the generators, reporting, and travel) to conduct a project in the Laramie Range would be approximately $100,000 annually.   Shown in Table

4 are estimates of additional project costs based on DRI's experience operating on-going cloud seeding operations and equipment.

| Type of equipment | Cost per unit |
|---|---|
| Ground-based AgI (per generator) | $30,000 |
| Aircraft (single plane) | $1,000 (ferry to location), $2,000 flight time). This does not include stand by time. |
| Liquid propane (per generator) | $15,000 |

**Table 4.** Approximate unit costs for equipment for winter operations (does not include forecasting, operations, or reporting).

If the entire recommended ground based-design were implemented (12 AgI generators and 7 LP generators), the total project cost would be $565,000. If the number of AgI generators were to be reduced by half, the cost for the project would be reduced to $385,000. Fifty hours of aircraft seeding would cost approximately $75,000, not including standby time.

Cost estimates, as a function of runoff, are presented in Table 5. For a full program (12 AgI and 7 LP generators). At a low estimate of only 2% increased runoff, the projected costs are more than $100 per acre-ft (AF). Based on the climatology results, we estimate that a well-targeted, operational project could produce an additional 16,000 to 20,000 AF of water on an annual average for $25 to $30/AFY.

| Increases in SWE | 2% | 4% | 6% | 8% | 10% |
|---|---|---|---|---|---|
| Average Seeding Increases (AFY) at Glendo | 5,297 | 10,535 | 15,833 | 21,072 | 26,368 |
| Cost Acre-Ft (12 AgI and 7 LP) | $106 | $54 | $36 | $27 | $21 |

**Table 5.** Cost benefit estimates at Glendo inflow as a function of increases in SWE in the Laramie Range.

An initial trial project, the first year, could be accomplished using only two AgI cloud seeding generators as an alternative to the larger project presented above. The increases in precipitation are estimated following the Huggins (2012) report on the Winter Park, CO cloud seeding project. The smaller potential project would only use the Casper 1 and Casper 10 AgI cloud seeding generators (see Fig 5).

The estimate of the amount of SWE produced by seeding ($W_S$) during the winter period for the Laramie Range is provided by multiplying the total expected time of generator operation for Scenario 1 storms (Table 2 - maximum 247 hours/year). The maximum total generator time $T_S$ is 247 hrs X 2 generators ($T_S$ = 494 hours). Multiplying by the conservative cloud seeding precipitation rate increase (0.25 mm (0.01") per generator hour). This product is then multiplied by the area of effect (~35 sq. miles). To obtain the estimate in units of acre-feet the following conversions are also needed:

0.25 mm = 0.00328 ft.
1 sq. mile = 640 acres.

So, for the initial winter season using the 2 AgI generators the maximum estimated snow water increases from seeding would be:

$$W_s = 494 \text{ h} \times 0.25 \text{ mm/h} \times 0.00328 \text{ ft/mm} \times 35 \text{ sq mi} \times 640 \text{ acres/sq mi}$$

$$\mathbf{W_s \approx 9{,}073 \text{ acre-ft of SWE.}}$$

The total cost for this 2 AgI cloud seeding generator project, including the initial set up, would be ~$150,000. This includes $80,000 for labor for the smaller project, $10,000 for the one time delivery and installation of the cloud seeding generators, and $60,000 for the generator leasing and cloud seeding solution. The project's initial year, which would help create the necessary forecast and validation tools for the project, could be evaluated and allow the project mangers operational results to decide whether to expand or cancel the project beyond the initial year.

**The cost for this SWE from the 2 AgI generators is estimated at $150,000/9,073 acre-ft = $16.50/acre-ft.**

## Climatological Monitoring

A set of monitoring tasks were completed during the winter November 1, 2015- April 30. 2016. A radiometer, used to measure periods of SLW, was sited in the Box Elder Creek area of the Laramie Range in early November 2015. This instrument operated almost continually until it was removed in early May 2016. A large observational data set was collected for the target area during the winter (November 1, 2015 – April 30, 2016). Daily Laramie Range cloud seeding forecasts were generated throughout the winter season. An example of the daily cloud seeding forecast is provided in Figure 11.

> ***Laramie Range: Jan 25, 2016 04 UTC***: *A deep cloud layer resides over the Laramie Range. Cloud top temperatures are -55C and bases have risen to 11,000' MSL at this time. Temperatures at Reno Hill are -6C with ridge top winds from the north-northwest. 8" of fresh snow has fallen today with 0.7" of SWE. Some light icing was reported by aircraft at Casper 12,000' MSL at 2:40 UTC. Low-level radar coverage is poor, no echos observed across the area at this time. The forecast calls for the deep well-mixed cloud layer to remain over the area this evening and cloud bases may again drop below the mountain-top level, especially as cloud top temperatures warm. Cloud seeding may become possible by both ground based generators and aircraft flares from the northwest side of the range once the cloud bases drop below 9,000' MSL. Conditions should be closely monitored.*

Figure 11. Laramie Range forecast discussion for Jan 25, 2015

## Recommendations

The climatology study suggests that winter storms over the Laramie Range peaks have supercooled liquid water present up to 12% of the winter period and are therefore often "seedable'." Our project analysis suggested that the primary flow regime is from the northwest, which is parallel to the high peaks of the Range. This can make ground-based targeting challenging. The operational storm periods must be closely monitored; and generators brought online and offline within storm periods as winds, temperatures, and cloud conditions will change suddenly. For the defined full project the preliminary estimated average increases in stream flow is 5,297 AFY for a 2% increase in snowfall from cloud seeding. As much as 26,368 AFY is estimated for a 10% increase in snowpack. The costs for the 10% increase in snowfall is $21 an acre-foot. The preliminary PRMS hydrological assessment suggested even more runoff was possible for modest increases in precipitation.

The small-scale two generator initial project is estimated to yield an average maximum of 247 seeding hours and 9,083 AFY.

These results suggest that although the Laramie Range receives on average less than 20 inches of SWE per year, a well conducted and expertly targeted program could produce increases in North Platte River flows.

Specific recommendations are as follows:

- Start with the 2 AgI generator proposed project and expand from there.
- Install an ice detector at Hogadon Ski Area.
  Obtain baseline stream and soil samples for AgI trace chemical analysis prior to start of program.
- Install two Web cams on generators: one for the Scenario 1 area and one for the Scenario 2 area.
- Conduct snow chemical analysis early in the initial winter during operations to ensure proper targeting.
- Use high resolution numerical modeling for forecasting guidance and as an evaluation tool.
- Aircraft cloud seeding should not be conducted the first year of a potential project but its feasibility should be discussed in the yearly report. Aircraft seeding should be reevaluated after 1 or 2 winters.

## References

Breed, D., D. Axisa, C. Liu, X. Feng, 2015: An Evaluation of Seeding Effectiveness in the Central Colorado Mountains River Basin Weather Modification Program. Submitted to and available from the Wilson Water Group and the Colorado Water Conservation Board.

Huggins, A. 2012: Winter Park Resort Colorado, Water Year 2012 Report. Submitted to Winter Park Resort and the Colorado Water Conservation Board.

Ritzman, J. M., Terry Deshler, Kyoko Ikeda, and Roy Rasmussen, 2015: Estimating the Fraction of Winter Orographic Precipitation Produced under Conditions Meeting the Seeding Criteria for the Wyoming Weather Modification Pilot Project. J. Appl. Meteor. Climatol., 54, 1202–1215. doi: http://dx.doi.org/10.1175/JAMC-D-14-0163.1

Skamarock, W. C., and J. B. Klemp, 2008: A Time-Split Nonhydrostatic Atmospheric Model for Weather and Forecasting Applications. J. Comp. Phys., 227, 3465-3485, doi:10.1016/j.jcp.2007.01.037.

Super A. B., J. A. Heimback Jr. 1989: Feasibility of Snowpack Enhancement from Colorado Winter Mountain Clouds: Emphasis on Supercooled Liquid Water and Seeding with Silver Iodide and Propane report submitted to CWCB.

Williams, B. D. and J. A. Denholm, 2009: An assessment of the environmental toxicity of silver iodide – with reference to a cloud seeding trial in the Snowy Mountains of Australia. J. Weather Mod.,41, 75-96.