Proposal and Scope of Work

Cloud Seeding Project for the State of Nevada for WY2016

Submitted to

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By

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Executive Summary

The goal of this project is to enhance snowfall from winter storms and increase the snowpack within the State of Nevada through the application of wintertime cloud-seeding technology. Two technological approaches are proposed with respect to wintertime cloud seeding: (1) ground-based silver iodide (AgI) generators, and (2) airborne cloud seeding. Technology (1) is considered essential to the proposal, whereas technology (2) is an option that can be employed to further extend the scope of seeding activities to several areas where ground-based silver iodide generators are not technically feasible or cost-effective.

With respect to technology (1), cloud seeding is proposed to be conducted from 27 ground-based AgI generators for winter 2015-2016 at a cost of $996,323. It is assumed that this cost will be shared in a 50/50 division between the State of Nevada and the Nevada State Consortium of Water Authority Managers with the Consortium determining internally the allocation of costs between its various members. Ground-based AgI generators will be situated in the higher elevations upwind of the Sierra Nevada, Ruby, Tuscarora/Owyhee, Toiyabe, and Schell Creek range crests, to target the Tahoe-Truckee-Carson, Walker and Humboldt Basins (including tributaries) as well as the Spring and Snake Valley areas in extreme east-central Nevada. Much of the ground AgI generator program is modeled after the former State of Nevada Cloud Seeding Program, with seven additional generators included compared to the scope of the former program.

With respect to technology (2), provided the Consortium elects to pursue this option, a subcontract will be issued to Weather Modification, Inc., based out of Fargo, ND, to provide supplemental aircraft seeding primarily to the Carson and Walker Basins and possibly to portions of the Humboldt Basin (specifically the Ruby Mountains as appropriate and resources allow) with an aircraft equipped with ejectable and burn-in-place (BIP) flares during a two-month period (most likely January-February 2016). The proposed budget for this component is $108,094 and allows for a range of 14-19 seeding flights to take place during the 2-month period.

The cloud seeding effort will help improve water storage supplies within the State of Nevada. The increased snowfall from cloud seeding is expected to enhance the water supply of the Truckee, Carson and Humboldt River systems as well as Spring/Snake Creeks. Historical research results from ground-based cloud seeding projects have documented the hourly increases in precipitation rate due to seeding to be in the range of a few hundredths to greater than 2 mm per hour. As a conservative estimate of the effect for the Tahoe-Truckee project, a value of 0.25 mm per hour will be used in the enhancement estimates. Such values lead to estimates of approximately 10% overall water augmentation. Based on the history of the State of Nevada Cloud Seeding Program from 1994-2009 and incorporating adjustments for the larger number of AgI generators proposed here as well as greater efficiencies developed recently at DRI compared to operations under the prior state program, water augmentation yields should range from an absolute minimum of 22,244 acre-feet to an absolute maximum of 131,027 acre-feet, with median and mean water augmentations between 81,600 and 82,800 acre-feet.

Trace chemical analyses of snow samples from the northern Carson Range in 2004 and 2005 showed that 34% to 52% of samples contained enhanced concentrations of silver (Huggins et al, 2006), indicative of snow frequently being created by cloud seeding with AgI. Such sampling provides one method of validation for the program. It can be included within the proposed program if desired but is currently not incorporated within any project budgets. All past environmental assessments have all indicated that no negative impacts to watersheds are produced by cloud seeding operations.

Project locations

Figures 1-6 shows proposed locations for the project, indicating current and potential sites for the AgI ground generators and aircraft program (aircraft used for the Carson-Walker project only). In each figure, the shaded regions approximately enclose the cloud seeding target area for the basin under considerations. Proposed DRI ground-based silver iodide cloud-seeding-generator (CSG) sites are shown either as yellow squares (Figure 1), blue pins (Figures 2-6) and red flags (Figures 2-6). Many of these sites have been utilized before, either within the former State of Nevada Cloud Seeding Program or within programs in the various basins that have been conducted under non-state funding. In particular, the initial focus of the silver iodide seeding program is to benefit the Tahoe-Truckee, Carson, Walker, Humboldt and Spring Creek drainages.

Some of these sites are on private property (thus no Federal/State permitting processes are required; DRI holds permits for some sites on public lands and could re-apply for permits for these sites where our permits have expired. If permits are required, we expect a relatively rapid process to obtain the required permits from the U.S. Forest Service, Bureau of Land Management, or other federal and state agencies (with the possible exception of the Schell Creek program). Previous experience with the Schell Creek project area has suggested that a more thorough process will be required for that program. If one or more EAs are required, DRI will submit a separate proposed budget to cover the costs for their preparation, which usually requires hiring an outside consultant to assist DRI in certain aspects of the assessment. Preparation of an EA costs between a few thousand dollars to as much as $60,000.

Project description

DRI typically separates its cloud seeding projects into three phases:

- Phase I: Site preparation, generator fabrication, generator pre-season setup and testing.
- Phase II: Forecasting, generator operations as well as mid-season and emergency generator maintenance
- Phase III: Data analysis (for purposes of evaluating effectiveness of seeding operations), reporting and post-season generator close-up and/or removal (if required by conditions of a USFS/BLM permit).

Followed by a general description of the conceptual model of cold-season glaciogenic cloud-seeding science and methodologies, a more detailed discussion of each of these phases will be provided.

Figure 7 provides a conceptual view of how DRI conducts cold-season glaciogenic cloud seeding. The key concept illustrated by Figure 7 is the ingestion of silver iodide aerosols (about 0.0001 mm in size) produced by ground generators or aircraft, that act as ice-forming nuclei (hereafter ice nuclei). In the case of ground-based generators, burning an acetone-based solution containing silver iodide at high temperatures (350-800C) generates the silver iodide. The ground-based silver iodide generators (hereafter, CSGs) are positioned a few miles upwind of the crest of the mountain range under consideration, and the microscopic AgI particles are transported downwind and dispersed into clouds over the mountains. Vertical dispersion up to at least 2000 feet above the surface is produced by the turbulence created by wind moving over the uneven terrain as well as the high temperatures producing the particulate plume. In the presence of cloud droplets existing at temperatures below -5^{o} C, the silver iodide particles act as ice-forming nuclei and enhance ice particle concentration in the natural clouds. In addition, because the silver iodide particle structure is similar to that of natural crystalline ice, deposition of water vapor also can occur directly onto the ice. Once initiated by silver iodide, the nascent ice particles grow in size and mass as they move downwind and begin falling to the surface when they have sufficient mass to overcome the upward motion in the clouds.

Numerous studies (e.g., Super and Huggins, 1992a,b; Heimbach et al. 1997; Super, 1999) conducted by a number of groups (including, but not limited to DRI) found that such high-altitude CSGs are more effective (compared to generators/flare trees at lower altitudes) at providing a substantive delivery of ice nuclei (the silver iodide) to the topographically-forced clouds accompanying wintertime storm systems. Only seeding by aircraft is more efficient, on a volume basis, in introducing ice nuclei into the cloud, but seeding by aircraft is two to three orders of magnitude more expensive per hour than ground-based seeding. The generators are positioned to take advantage of prevailing wind directions, associated with winter storms, at and just above mountain-top level. Generators are remotely activated by DRI staff (from Reno or any location with Internet access) when the proper weather and cloud conditions for seeding have been verified. A typical timeframe for snowfall enhancement to occur after seeding has been initiated is approximately 30 minutes. The “chain-of-events” in the cloud seeding process has been verified by numerous detailed experiments conducted in the Sierra Nevada and other mountainous regions of the western U.S. as well as studies in Australia.

Certain aspects of the conceptual model described in the preceding paragraphs also apply to aircraft-based silver iodide seeding. In the case of aircraft, the function of silver iodide within the cloud is the same as for ground-based seeding, supplementing the number of available ice nuclei in the cloud compared to what is available in nature. Differences arise from FAA restrictions about flying over complex terrain, and also because of concerns about aircraft icing. As a result aircraft-based cloud seeding is done from above cloud top or within the uppermost portion of the cloud. Either ejectable or burn-in-place flares containing silver iodide are used in aircraft-based seeding operations, which primarily target supercooled liquid water and water vapor in the upper portions of the cloud. Some seeding material can reach the lower portions of the cloud, but only if the upper portions of the cloud are not rich in supercooled liquid water. Because of the much greater expense of aircraft-based seeding in terms of cost-per-hour compared to ground-based seeding, aircraft-based seeding is proposed here as an optional add-on, for a two-month period for the Walker and Carson Basins as a continuation of a seeding program that is sunsetting in Spring 2015.

Forecasting and modeling in support of cloud-seeding operations

Output from high-resolution meteorological modeling using the Weather Research and Forecasting (WRF; Skamarock et al. 2008) system (run locally at DRI) will be used to generate forecasts for the generator locations. Such output is being produced for the current season (WY2015) for the Tahoe-Truckee and Walker Basin projects. These numerical model forecasts will be available at a resolution of 1.33 km (0.83 miles) and, as resources permit, can be used as input to plume dispersion models to better predict the track of the silver iodide plume, and thus seeding effectiveness. The WRF forecast input will be added to other observations and forecast products available routinely from national centers, including the National Weather Service's National Centers for Environmental Prediction. This information will aid in determining whether conditions are suitable for seeding operations. By considering the conditions affecting each generator separately (roughly according to the above criteria), this input will help in deciding when to turn on or off individual generators. Precipitation start and stop times from modeling results also can help in determining the initial timeout setting for the generators. This is the time set for the generators to shut down in the absence of additional operator instructions and is useful for periods, often during storms, when communications with the generators may be interrupted.

The DRI Weather Modification Program operates on a 24/7 basis through the months of November through April each winter, accomplished through two 12-hour shifts per day. Given that DRI staff (most notably the Project Manager) travel occasionally for conferences and other meetings during the winter months, 24/7 operations are maintained through advance scheduling and because DRI's ground-based seeding generators are designed to be operated from any computer with an Internet connection, anywhere in the world with sufficient bandwidth to connect back to our central facilities in Reno. More details on these forecast and operations processes can be found under the discussion of Phase 2 activities below.

Project phases

The following discussion describes project phases for a single project year. If this proposal leads to multi-year commitments from the State of Nevada and various Water Consortium partners, the discussion below can be applied to each project year. From a practical standpoint, there is usually some overlap in Phase 1 activities of the current project year and some Phase 3 activities from the previous project year. This overlap should be kept in mind while considering the material in the following paragraphs.

Phase 1 of the project will include the following activities:

- Preparation of the silver iodide generators at the locations shown in Figures 1-6. This includes reinstallation of any generators that are required to be removed in the late Spring as a condition of USFS/BLM permits, acquiring the necessary permits, deployment of generators to areas where they do not currently exist, conversion of any generators to be moved from lower- to higher-elevation sites (this involves fabricating a taller tower for the burn chamber to keep it out of the snowpack), and other minor maintenance and testing activities (e.g., refilling seeding solution and propane tanks, and testing all generator components and communications links). Generators will be filled with a minimum of 100 gallons of solution, which allows for about 250 hours of seeding per unit per season.
- Subcontracting to Weather Modification, Inc. or another aircraft-seeding vendor for aircraft-based seeding during a 2-month period in WY2016, if that option is desired.
- Preparation of an expanded numerical modeling/forecasting system from the current system that focuses primarily on the Tahoe-Truckee and Walker Basins, as well as modifications to the DRI Cloud Seeding Weather Information page to reflect these changes in program scope. The meteorological forecasts and observations needed to conduct the project are available either through the DRI Western Regional Climate Center or through public Web-based weather data links. These data links are combined on the DRI cloud seeding weather Web page (http://www.dri.edu/weather-information)

Phase 2

Phase 2 of the project will involve the forecasting and actual cloud seeding operations, beginning on 1 November. In Phase 2, the project manager and the DRI cloud seeding staff (consisting of a second meteorologist, one or more graduate students and field technicians) will begin monitoring the weather and making forecasts for seeding events to be expected within three to five days. The use of the varied number of staff ensures that 24/7 operations can be conducted. Routinely, DRI staff issue forecasts (see format in Figure 8) twice daily; these forecasts are distributed to all DRI cloud-seeding personnel. Although currently these forecasts are issued only for our two Sierra projects and our Colorado projects, we will expand the forecast scope to include all the proposed project areas. Key in these forecast statements are color-coded summary indicators (red, yellow, orange, green) of whether operations are in progress, likely to start within six hours, likely to start within three hours, or not likely to occur within at least 12 hours. As a storm begins to affect part or all of the region, cloud and weather conditions will be monitored more frequently (termed a Watch condition, or condition yellow in the color-coded scheme used in Figure 8) to determine when seeding criteria are satisfied and for which regions. When one of the meteorologists determines that conditions for conducting a seeding operation are satisfied, seeding will commence using the remotely controlled CSG communication network, and an operational update will be issued to DRI staff via e-mail. The communication links will be Internet-based (as is the case currently) and thus a generator can be started from any computer with Internet access. Seeding commences when all pre-established seeding criteria are met and continues until conditions in the storm fail to meet the criteria. Once conditions become unfavorable, generator operations are terminated, and DRI staff are notified. For our Colorado projects, various stakeholders and even members of the general public have asked to be notified of start/stop times of seeding events; we accomplish such notification via e-mail. If such notification is desired by any/all of the stakeholders of the proposed program, we can establish such e-mail notification lists.

Based on our experience during the last 13 years of the state program, the following number of seeding hours can be expected in the various silver iodide target regions, for the six-month seeding season (November-April):

- 886 seeding hours in the Tahoe-Truckee target area
- 728 seeding hours in the Walker/Carson Basins
- 1111 seeding hours in the Ruby Mountains
- 1357 seeding hours in the Schell Creek Range
- 125 seeding hours in the Toiyabe target area
- 374 seeding hours in the Owyhee/Tuscarora target area

The end date for Phase 2 could occur sooner than April 30 if generators run out of solution or other expendable supplies. The DRI technical staff will monitor and maintain seeding generators throughout the operational period. As part of the maintenance activities, a mid-season trip will be made to all generator sites to inspect equipment and, until supplies are exhausted, refilling the seeding solution tanks with what should be sufficient solution to carry each site to the end of the season. The propane distributor contracted by DRI will complete refilling of the propane tanks, if needed. Since DRI has changed some of its operational criteria and procedures since the end of the former Nevada state cloud seeding program, we have put forward our best estimate of consumable requirements in the proposed budget but recognize this may need to be adjusted in future years based on usage statistics during the initial year.

Phase 3

Phase 3 of the project will begin between May 1 and May 15 (depending on when operations end) and will include documentation of weather events to verify that seeding occurred during optimal time periods. Each period will be evaluated, and a seedability factor will be applied to quantify the fraction of time when seeding was potentially effective. The seedability factor is determined in different ways for ground- and aircraft-based seeding. For ground-based seeding, we examine in depth the weather conditions during the season using data plots similar to the one shown in Figure 9. We compare, on a detailed basis (hourly), the observed conditions to our cloud-seeding criteria for each target area. A simple ratio of hours seeded/hours possible (based on the seeding criteria being met) is used for the ground-based seeding seedability factor. For aircraft-based seeding, the seedability factor is assigned a value between 0.5 and 1 based on the severity of icing conditions encountered (on takeoff, in transit, on station and on landing) by the seeding aircraft during a seeding flight. DRI staff do not typically authorize seeding flights unless there is strong evidence (from radar, satellite, other aircraft and model data) that supercooled water is present in the cloud systems under consideration. Thus, the minimum seedability factor for a seeding flight is 0.5, corresponding to light icing conditions.

The seedability factor is directly utilized in our estimates of snow water augmentation (discussed in detail in the following subsection), which are included, along with a detailed weather analysis (including multiple charts of the type in Figure 9) and discussion of operational issues and their resolution during the project year, in a final report to the stakeholders. In addition, the final report will discuss two case studies in detail to illustrate the performance of our forecasting and seeding operations as well as relevant operational issues that may require attention for future years. We propose to produce such a final report for delivery to the Consortium by 31 July of the initial year (WY2016) and each year thereafter that the program is in place. We also propose to produce a semi-annual report, delivered to the Consortium by 28 February of each year, summarizing the work done in Phase I and the first three months (November-January) of Phase 2 operations.

Phase 3 also includes the removal of seeding units as dictated by Forest Service special use permits and/or Bureau of Land Management Right-of-Way agreements. Removal of generators is only possible after snow has melted and roads to the sites become useable. In some years this can be as late as mid to late July (as occurred in 2011 for the Tahoe-Truckee basin generators). Phase 3 will end on 30 September 2014 to allow time for all generators to be checked for problems and repaired as needed either in the field or at DRI's Weather Modification Fabrication and Maintenance Facility located at the Reno-Stead airport. Based on the amount of expendable supplies used during the season, a new order for cloud-seeding chemicals will be placed in early summer to prepare for operations during the following winter season.

Expected water augmentation results

DRI and other cloud seeding operators that utilize high-altitude silver iodide generators have found that the average expected benefit from ground-based silver iodide cloud seeding from high elevation sites is an increase in the liquid equivalent precipitation rate of 0.25 mm (~0.01 inch) per hour. Translated to snowfall rates, this average is a 1/10 inch per hour increase in the snowfall rate. Past studies of seeding plume dispersion over mountainous target areas, and documentation of the fallout area (of snow) within a seeding plume, have shown that the average area affected by one seeding generator is approximately 35 square miles. This area of effect will vary as cloud conditions and wind speed vary and can also change as the dimension of the mountain barrier along the wind direction changes. Because all the parameters affecting area cannot be precisely evaluated on a case-by-case basis due to lack of a dense enough observational network (a major undertaking of its own), we utilize this 35 square mile areal figure and account for multiple generators in a network by summing together all the operational hours of all generators in a network.

To better illustrate how our water augmentation estimates are computed, the seeding operations during WY2014 for the Tahoe-Truckee network serve as an example. The estimate of the amount of snow water produced by seeding (W_s) is provided by multiplying the total time of generator operation (T_s = 916.7 hours) by the precipitation rate increase (P_s = 0.25 mm per hour). This product is then multiplied by the area of effect (A_s = 35 sq. miles), and then by SF (0.89). To obtain the estimate in units of acre-feet the following conversions are needed:

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

So, for the WY2014 winter season, the estimated snow water increase from seeding in the Tahoe-Truckee target area was:

W_s = 916.7 h x 0.25 mm/h x 0.00328 ft/mm x 35 sq mi x 640 acres/sq mi x 0.89

$\underline{W_s \approx 15{,}032 \text{ acre-feet}}$.

A comparison of this water augmentation estimate with those from 16 prior years is shown in Figures 10a-b. The comparison includes the Nevada state-funded program water years 1998 to 2009, and the years of Truckee River Fund/TMWA/WRWC sponsorship that followed. The top panel also shows the number of seeding generators used in each season. Snow water augmentation estimates were computed using the same method for all seasons except the first three shown, when the seedability factor was not used. Seeding hours tend to reflect the frequency of storms in a given year, thus a lower number of hours during the drier years from 2007 through 2009. However, lower seeding hours also can occur in very wet years like 2000 when seeding was suspended during flooding events. WY2011 is also an anomaly since seeding hours were about 72% of the 16-year average (due to the snowpack suspension in April and May), but the storm frequency was well above average. The WY2014 snow water augmentation estimate was about 102% of the 16-year average of 14,643 acre-feet, reflecting improved forecasting.

Figures 11a-b provide similar statistics for the Ruby Mountain project up until its termination in WY2013. The top figure shows the entire history of the DRI Ruby Mountain program in terms of seeding hours and water augmentation (the latter beginning later after the current general method of water augmentation estimation was adopted). The lower figure focuses on the period encompassing Water Years 2004-2013, for which the generator numbers and locations in the Ruby Mountains were more stable; the lower figure thus provides a good estimate of the variability in water augmentation that can occur due to climatic factors alone, as opposed to considerations of having more or fewer generators utilized for seeding.

Figures 10 and 11 both indicate substantial variability in water augmentation during the periods, both from the standpoint of climatic factors as well as number of generators utilized. As a means of estimating the potential water augmentation from the ground-based silver iodide seeding program proposed in this document, we examine the statistics compiled for the former Nevada State Cloud Seeding Program from 1994 to 2009 as well as compare these statistics to the water augmentation estimates from the projects that remained after the end of the state program. These statistics, presented in Table 1, are relevant for the program proposed here because the same regions were targeted for silver iodide seeding in the state program as are proposed here, and the post-state program projects cover a subset of those regions. Discussion of augmentation from the optional aircraft-based seeding will be given separately subsequent to the discussion of silver iodide program water augmentation.

As is clear from Table 1, there is considerable variability in the estimated water augmentation from DRI's Nevada cloud seeding programs during the past 20 years, the first fifteen of which involved a state program comprised of 19 or 20 CSGs distributed over the Tahoe-Truckee, Walker, Carson, and Humboldt River basins (the latter basin covered by multiple projects). Indeed, both the high and low figures (86,418 acre-feet versus 14,671 acre-feet) for estimated water augmentation occurred under the state program, with a factor of six separating these values. Median and mean values are both near water augmentation of 54,000 acre-feet.

A key result that can be found by reviewing the state program reports is the realization that greater cost-effectiveness occurs with the use of more high-altitude generators rather than fewer for a target area, even though there is a somewhat greater absolute cost involved for more generators. The greater cost effectiveness comes about through two different avenues: (1) greater saturation of the cloud systems with silver iodide due to multiple plumes emanating from ground-based generators; and (2) economies of scale given that the amount of effort involved in forecasting and operating generators does not scale upward in a 1:1 linear manner with the number of generators. Indeed, the forecasting effort for an increased number of generators in a given target area is basically the same, and only increases when different target areas in significantly different geographic zones (such as, for example, the Walker and Upper Humboldt Basins) must be considered at the same time. Even so, there is still much forecast information that translates across the differing target areas, and the time expended in forecasting still scales less than linearly with the number of areas for which forecasting is done. Operational effort, from a practical standpoint, scales upward with more generators per target area and more target areas. Given that DRI cloud seeding operations staff are generally 40 hr/week salaried employees and not billing by the hour, those costs are already built into the budget in advance. Thus, the only direct linear increase in costs with more generators/target areas lies in consumable expenses. Thus, overall, a greater number of generators per target area, and even (to some extent) a greater number of target areas, does not result in a 1:1 proportionately larger cost, but rather, somewhat less, providing the economy of scale.

Given this, here we propose a total of 27 generators split amongst the project areas shown in Figures 1-6, with six Tahoe-Truckee/Carson Basin generators, five Walker Basin generators (one of which may also double as a Carson Basin generator), six generators in the Ruby Mountains, six generators in the Schell Creek Range, two generators in the Toiyabe Range and two generators in the Tuscarora/Owyhee area. Assuming that the 19-20 generator water augmentation estimates discussed above scale upward linearly with the number of generators (a conservative assumption but expected to be easily valid), a 27-generator program covering the above areas could be expected to produce a **median water augmentation of nearly 82,000 acre-feet**, with a **maximum of 131,000 acre-feet possible**. Cost-effectiveness, expressed in terms of cost/acre-foot, is addressed in the next section.

Based on DRI experience with aircraft seeding projects, we estimate that the **aircraft seeding option in this proposal will deliver a median of 6,840 acre-foot water augmentation** with a **maximum of more than 13,100 acre-feet**. The bulk of this aircraft seeding occurred for the Walker/Carson and Tahoe Basins, and most recently only for the Walker Basin due to high public concern over aircraft-based seeding in the Tahoe Basin. For the purposes of this proposal, we limit the coverage of the aircraft program to the Walker/Carson Basins and assume that we can reproduce this range of results with a proposed budget similar to that utilized for the WY2014 Walker Basin project.

Expected cost-effectiveness

Tables 2 and 3 provide budget breakdowns for the proposed program. For the purposes of this section, we note that the proposed cost of the silver iodide ground-based generator program is $996,323. The proposed cost of the two-month, 20 flight aircraft-based seeding program is $108,094

From a practical standpoint, we estimate cost effectiveness in terms of the median and maximum water augmentation values put forward in the preceding subsection. Of course, for a year where the climatic factors provide little to no seeding opportunities, cost-effectiveness for any cloud-seeding program operated by any entity would be poor. From a planning standpoint, the median water augmentation estimates are the logical place upon which to build an argument, and considering the case of maximum augmentation gives a sense of the range of cost-effectiveness that is potentially attainable. Using the budgetary and water augmentation figures above, we find the following estimates on cost of each component per acre-foot, both in total and the share that the Consortium would have to provide assuming a 50/50 cost share with the State of Nevada:

- Median water augmentation scenario, *Total Cost*
  - Silver iodide generators: $12.15 per acre-foot
  - Optional Walker/Carson aircraft seeding: $15.80 per acre-foot
- Median water augmentation scenario, *Cost to Consortium*
  - Silver iodide generators: $6.08 per acre-foot
  - Optional Walker/Carson aircraft seeding: $7.90 per acre-foot
- Maximum water augmentation scenario, *Total Cost*
  - Silver iodide generators: $7.61 per acre-foot
  - Optimal Walker/Carson aircraft seeding: $8.25 per acre-foot
- Maximum water augmentation scenario, *Cost to Consortium*
  - Silver iodide generators, $3.81 per acre-foot
  - Optimal Walker/Carson aircraft seeding, $4.13 per acre-foot

Principals involved

Dr. Marc Pitchford assumed the position of Interim Director of Weather Modification at DRI in November 2014 upon the resignation of the previous Director. A well-qualified permanent replacement will be selected prior to the start of this program. During late April 2014, a new meteorologist was hired to assist in forecasting, operations, data analysis and numerical modeling. In addition, a half-time graduate student assists in operations, forecasting and data analysis. Note that neither the project manager nor the second meteorologist's time is fully covered under this proposal, and other supplemental funding will be sought for these individuals. Field operations and maintenance support will be provided by two full-time field technicians assisted by a part-time

(33% FTE) technician.

Schedule

The following schedule is for illustrative purposes only, and assumes that funding is in place prior to the start of the Water Year 2016 winter season, specifically by 1 June 2016 because of the need for fabrication and preparation time. Dependent upon actual funding dates, the start and end dates for some phases may shift; alternatively, partial deployment of some systems may be an alternative solution if funding arrives later than this date. If funding is available earlier than 1 June, an earlier start to the seeding season may be pursued; alternatively, if funding starts before the end of the 2015-2016 Winter Season, work under Phase 1 will start when possible and thus allow for completion of Phase I well before the end of September 2016.

Start Phase 1: 1 June 2016. Order consumables and spare parts. Convert lower-altitude silver iodide generators as needed for use at higher altitude sites (primarily extending the burn chamber tower on each unit).

End Phase 1: 1 Nov 2016. All seeding generators are installed, tested and ready for use. Bad weather could produce delays, but testing and other work can be done if units have been installed. All Web-based computer products are prepared for use in Phase 2.

Start Phase 2: 2 Nov 2016. Cloud-seeding occurs as storm conditions dictate. Cloud-seeding equipment is monitored and maintained as needed. A log of seeding operations is maintained and the weather data needed to assess operations are archived. The cloud seeding update page is revised on a weekly basis.

End Phase 2: 30 April 2017. This is the approximate end of the operational cloud-seeding period. If need be, this date will be modified according to whether solution is exhausted or seedable storms persist into May 2017

Start Phase 3: 1 May 2017. Weather data are analyzed to assess the seeding operations. Estimates of water augmentation from seeding operations are made. Meet with Consortium and State representatives to discuss modifications for the next water year.

End Phase 3: 30 Sept 2017. The Final report on operations is completed by 30 July 2017. All seeding equipment has been checked and repaired as needed. Final invoices for the year will be submitted to the State and Consortium.

Budget discussion:

As noted earlier, Tables 2-5 provide the budget breakdowns for the proposed program. The proposed cost of the silver iodide ground-based generator program is $996,323. The proposed cost of the two-month, 20 flight aircraft-based seeding program is $108,094.

Costs for the silver iodide ground-based generator, and aircraft seeding operations all include salary time for the meteorologists and technical staff at fully loaded rates[1]. The majority of the budgeted time for seeding operations, such as forecast support is found in the silver iodide seeding budget, with supplementary amounts in the aircraft operations budget. The ground-based silver

[1] Fully loaded labor rates include fringe and overhead. No overhead is being charged on non-salary items.

iodide generator budgets also include a variety of standard operational costs, estimated based upon our experience in recent Tahoe-Truckee, Walker and Ruby Mountain projects.

The aircraft seeding components cover per diem and lodging in Sacramento for a pilot dedicated full-time to the project, as well as hanger rental at McClellan Executive airport (usually the best choice for flights targeting the Walker/Carson basins), fuel, maintenance and consumables (burn-in-place and ejectable flares). This option likely will be serviced via a subcontract from DRI to Weather Modification, Inc. based in Fargo, ND. This company has been conducting airborne cloud seeding for many years with an excellent safety record, and they have been DRI's contractor for aircraft seeding operations for more than a decade.

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Super, A. B., and A. W. Huggins, 1992b: Investigations of the Targeting of Ground-Released Silver Iodide in Utah---Part II: Aircraft Observations. *J. Wea. Mod.,* **24,** 35-48.

Super, A. B., 1999: Summary of the NOAA/Utah Atmospheric Modification Program: 1990-1998. *J. Wea. Mod*., **37**, 35-66.

Table 1. Water Augmentation Statistics for the 15 years of the Nevada State Cloud Seeding Program, as well as Statistics for Water Augmentation for the combined post-State Program Tahoe-Truckee, Walker and Ruby Mountain Cloud Seeding Projects operated by DRI.

Year by Year Water Augmentation Totals (Acre-Feet), Silver Iodide Generators Only	
Nevada State Cloud Seeding Program	
1994	53879
1995	55712
1996	61922
1997	14671
1998	84098
1999	49240
2000	82765
2001	79490
2002	79095
2003	86418
2004	64012
2005	58593
2006	54170
2007	46123
2008	43463
2009	26820
Post-State Program Projects	
2010	45767
2011	37740
2012	48266
2013	48973
2014	25255

Table 2. Proposed budget for the Silver Iodide Ground-Based Component of the Proposed Program.

Desert Research Institute				
Sponsor: State of Nevada and Consortium				
Project: Cloud Seeding for the State of Nevada for WY2016				
Project Period: 12 months				
Option 1: Use of silver iodide solution with ground-based cloud seeding generators				
Labor	Rate	Hours	Amount	
Program Director	$181.68	1320	$239,818	
Project Meterologist	$107.00	1520	$162,640	
Instrument Field Tech 1	$109.41	1760	$192,562	
Instrument Field Tech 2	$79.70	1760	$140,272	
Graduate Student	$45.86	1200	$55,032	
Subtotal Labor			$790,323	
Operating	Rate	Units	Amount	
Cloud seeding solution (100 gallons)	$5,800	28	$162,400	
Propane and nitrogen	$600	28	$16,800	
Supplies			$5,000	
Generator replacement parts	$1,000	14	$14,000	
Data/communications lines (monthly ra	$150	12	$1,800	
Vechicle usage (4x4 truck) (daily rate)	$112	45	$5,040	
Snowmobile usage (2)	$60	16	$960	
Subtotal Operating			$206,000	
Total Project Costs			$996,323	

Table 3. Proposed budget for the Walker/Carson Aircraft Component of the Proposed Program.

Desert Research Institute				
Sponsor: State of Nevada and Consortium				
Project: Cloud Seeding for the State of Nevada for WY2016				
Project Period: 12 months				
Option 2: Use of Aircraft for cloud seeding for the Walker/Carson (aircraft only)				
Labor	Rate	Hours	Amount	
Program Director	$181.68	80	$14,534	
Project Meterologist	$107.00	80	$8,560	
Instrument Field Tech 1	$109.41		$0	
Instrument Field Tech 2	$79.70		$0	
Graduate Student	$45.86		$0	
Subtotal Labor			$23,094	
Operating				
Subcontract to Weather Modification Inc.			$85,000	
Subtotal Operating			$85,000	
Total Project Costs			$108,094	

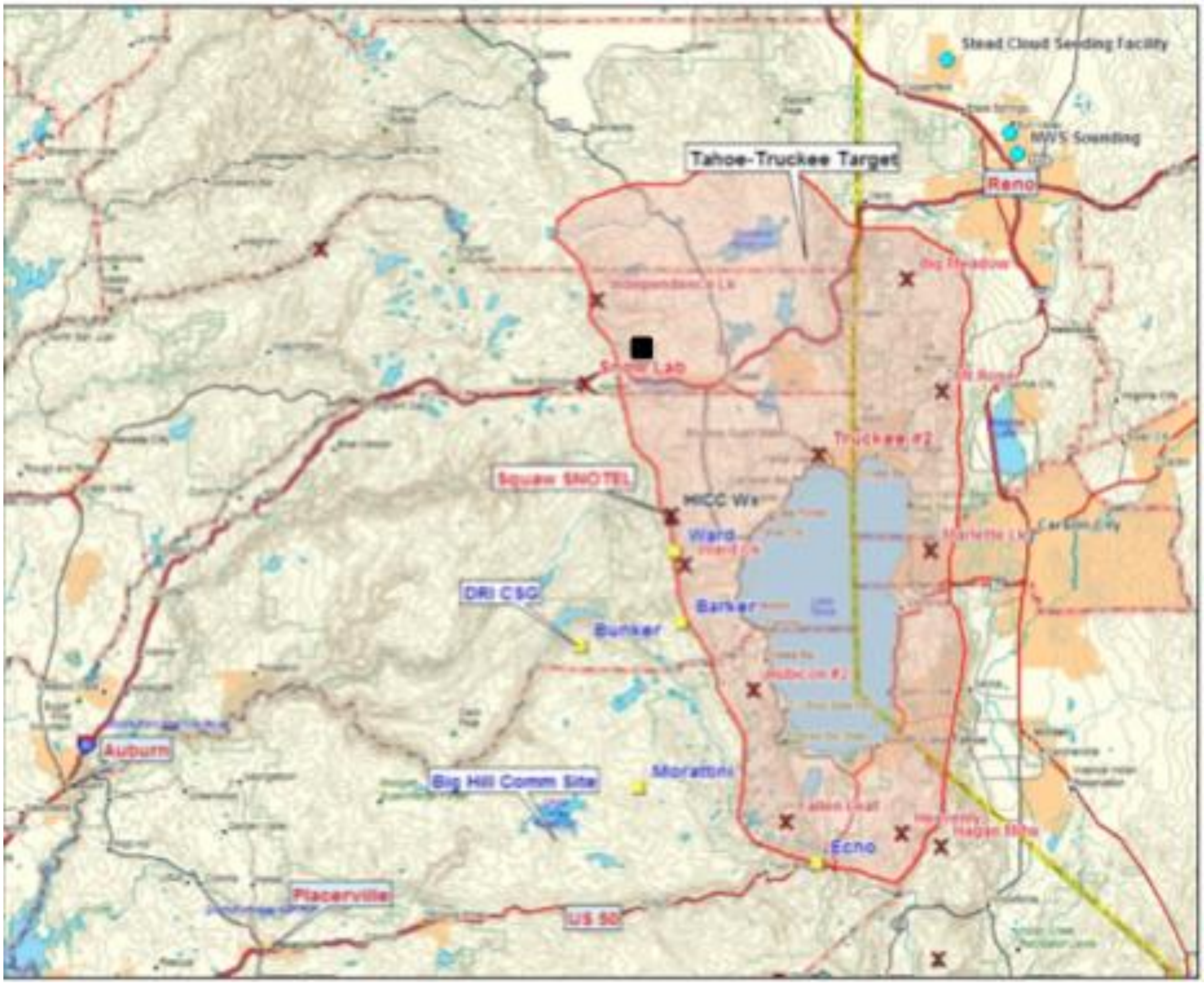


Figure 1. Proposed Tahoe-Truckee cloud seeding project area. The target area, shaded in red, is the same as in previous years. Newly proposed this year is the addition of a sixth ground-based silver iodide generator site located near Interstate 80 in the general vicinity of the Boreal and Tahoe-Donner ski areas, as a means of better impacting the northern portion of this target area. Yellow pins with blue labels represent current DRI cloud seeding generators; the Black square represents an approximate location for the newly proposed generator. Red X's denote SNOTEL stations and other geographic features are as labeled.

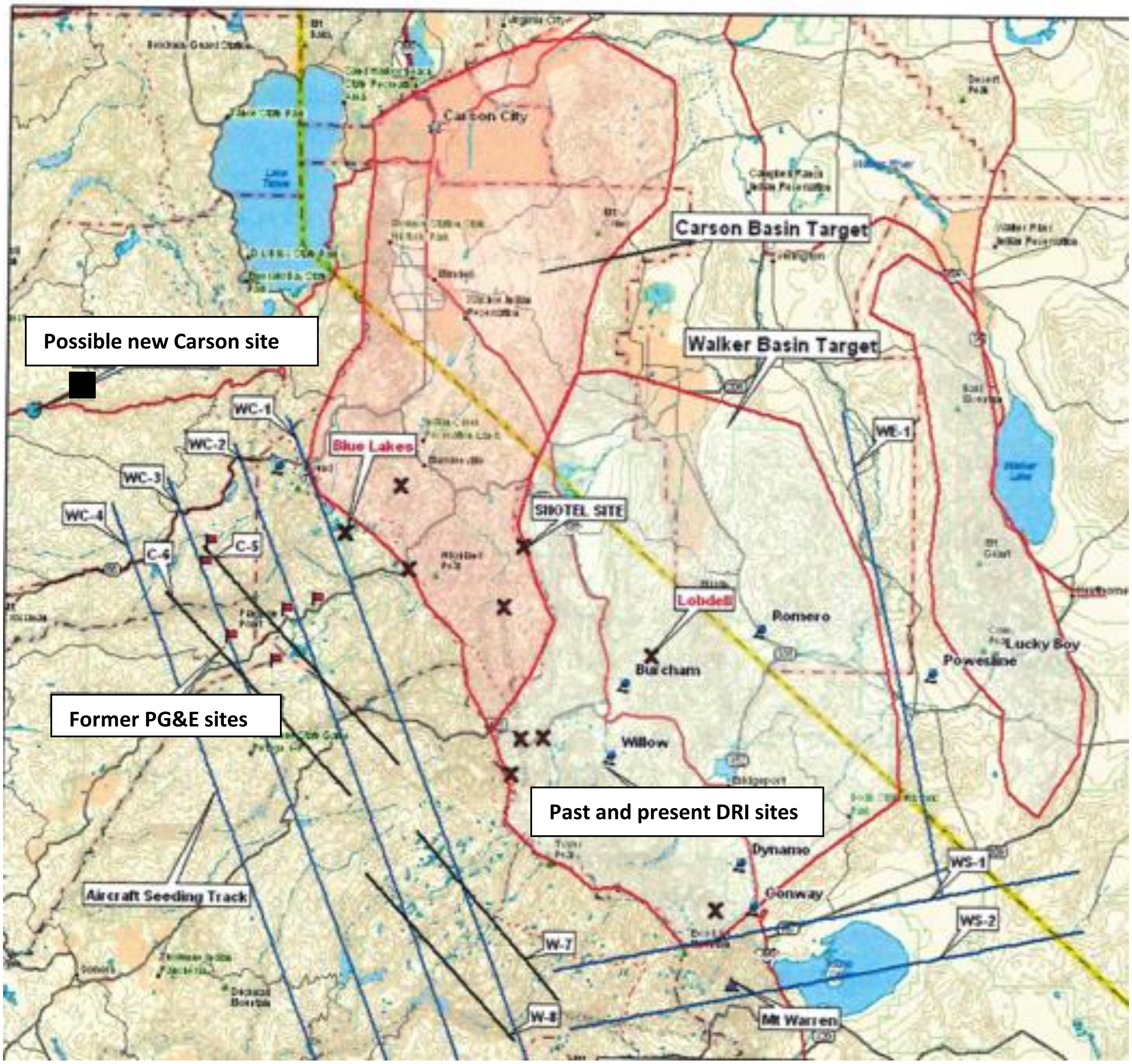


Figure 2. Proposed Carson and Walker cloud seeding project areas, with the Carson area shaded red and the Walker area with a transparent white shading, as indicated. Currently, the Romero, Dynamo and Conway sites are active for the Walker Basin, as is a 4th site on the east side of Highway 395 near Conway Summit (not shown). Black square indicates a potential new seeding site for the Carson Basin north of US Highway 50 that could potentially be added, while red flags indicate past ground generator sites utilized by Pacific Gas and Electric that could be reactivated; blue pins outside of the generator sites mentioned above could also be re-activated if desired.

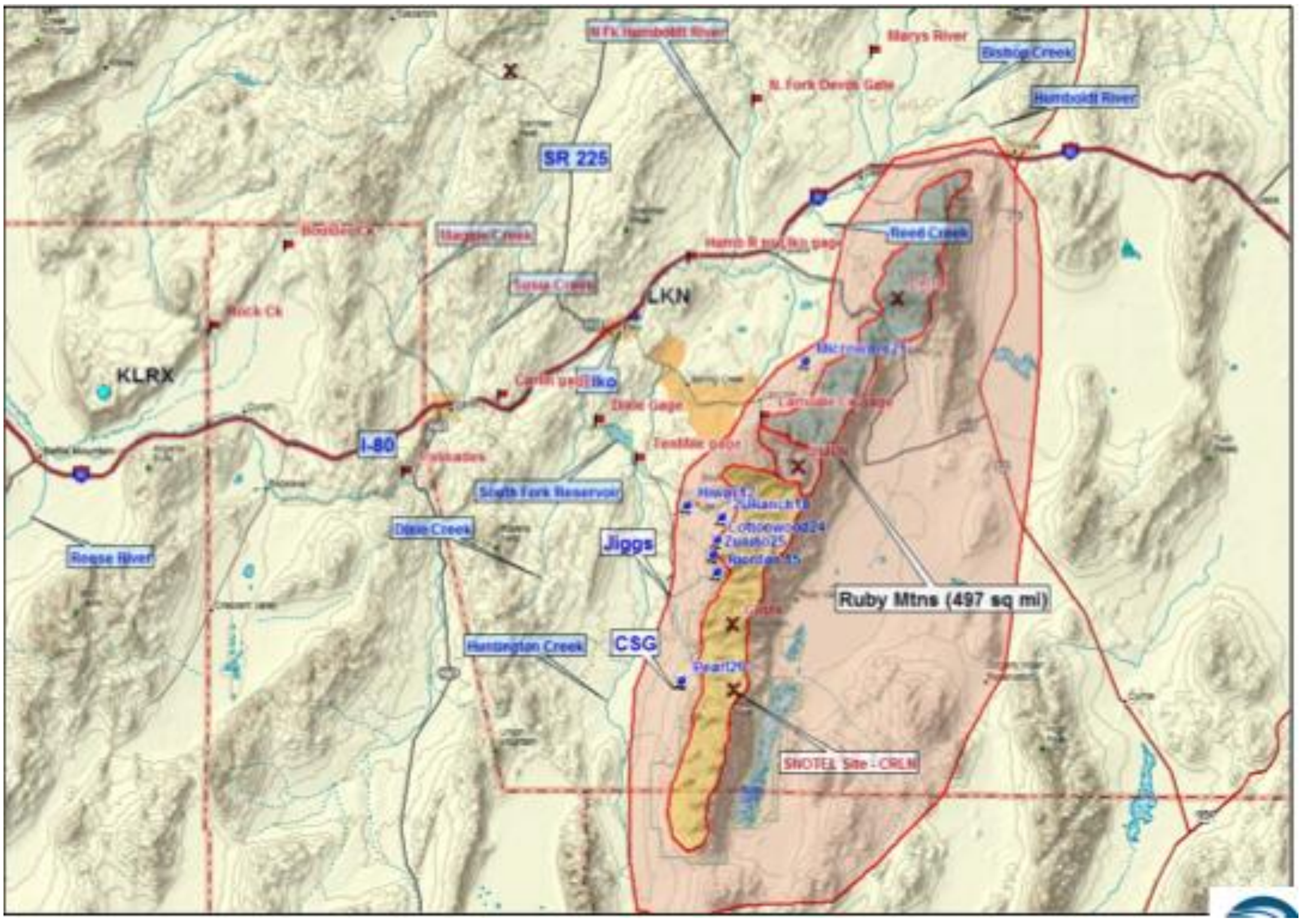


Figure 3. Proposed Ruby Mountain cloud seeding project area (shaded red) along with subareas represented by individual SNOTEL sites (tan, grey and red shading with Xs). Under the proposed program, the generator site Highway12 would be redeployed to a different part of Nevada, given that this particular low-level generator site has proven less effective than the other sites, which are all at altitudes.

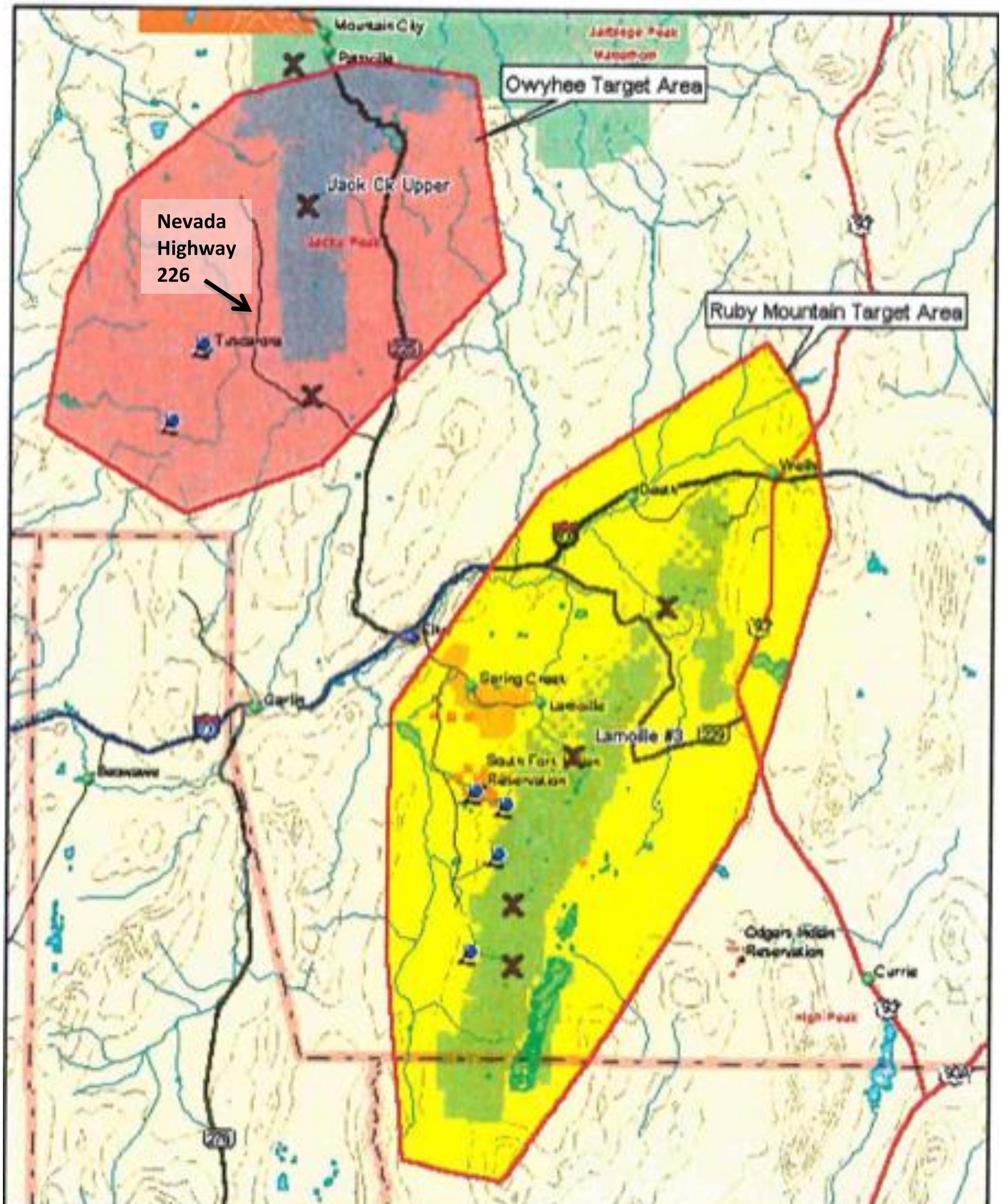


Figure 4. Proposed Owyhee cloud seeding project area (shaded red) and its relationship to the Ruby Mountain project area (shaded yellow). Under the proposed program, the Tuscarora generator site would be reactivated, probably with the Highway12 generator previously upstream of the Ruby Mountains. DRI would seek to obtain a second silver iodide generator site located close to Nevada highway 226 (indicated on the plot) north of Tuscarora. The other DRI generator site indicated SW of Tuscarora would not be utilized as a silver iodide site given the prevailing wind directions for the majority of winter storms are unfavorable to seed the mountains to the north and the location is too far SW to effectively seed the mountains located to the east of Nevada highway 226.

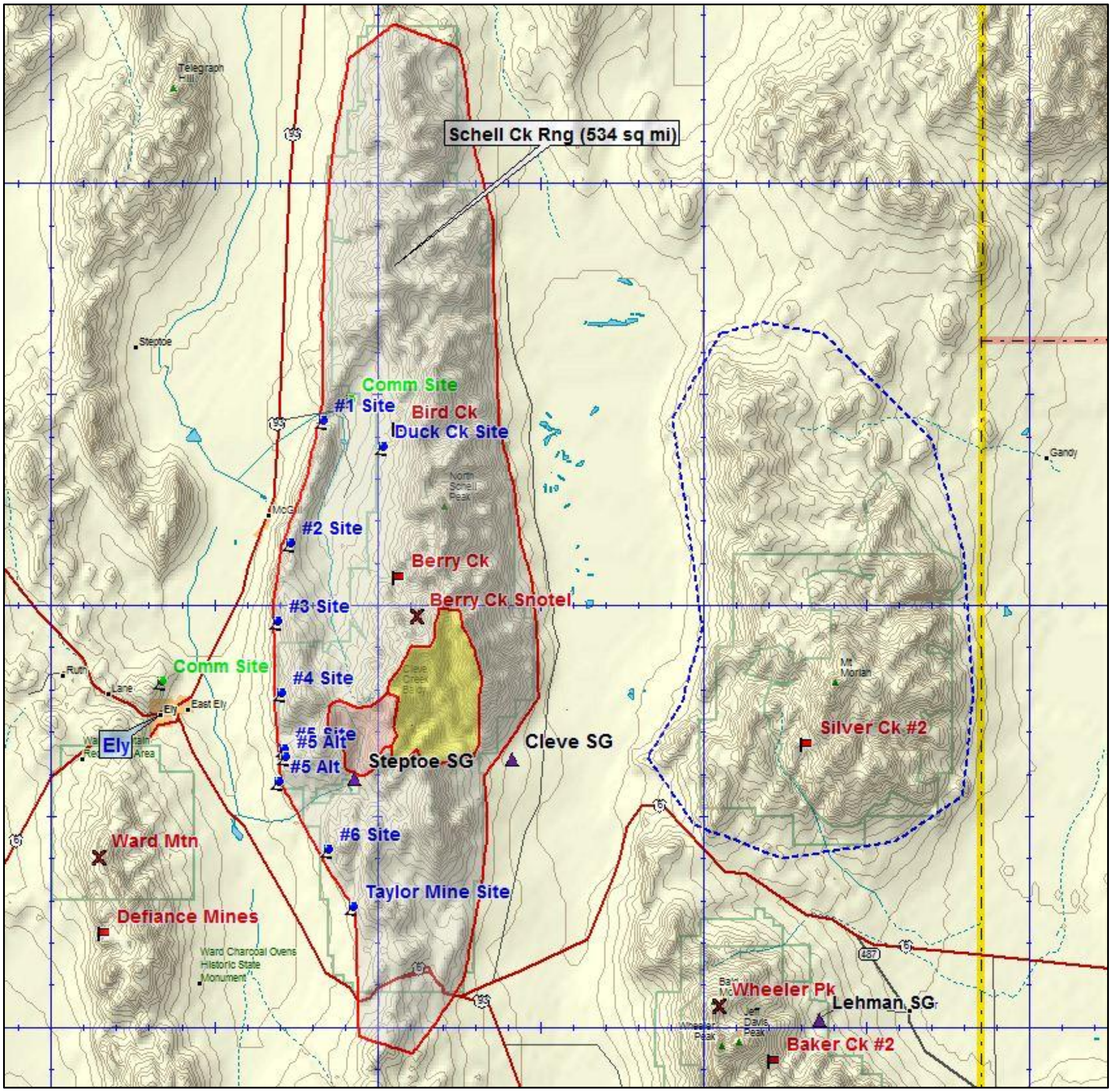


Figure 5. Proposed Schell Creek/Snake cloud seeding area (shaded gray) as well as schematic of current proposed generator locations for this seeding area (blue pins). Six locations of those schematically illustrated here would be utilized for the proposed statewide program; the sites listed as “Duck Creek Site” and “Taylor Mine Site” would be omitted. Multiple locations are possible for Site #5, hence the listing as “Site 5” and two “5Alts” in the figure.

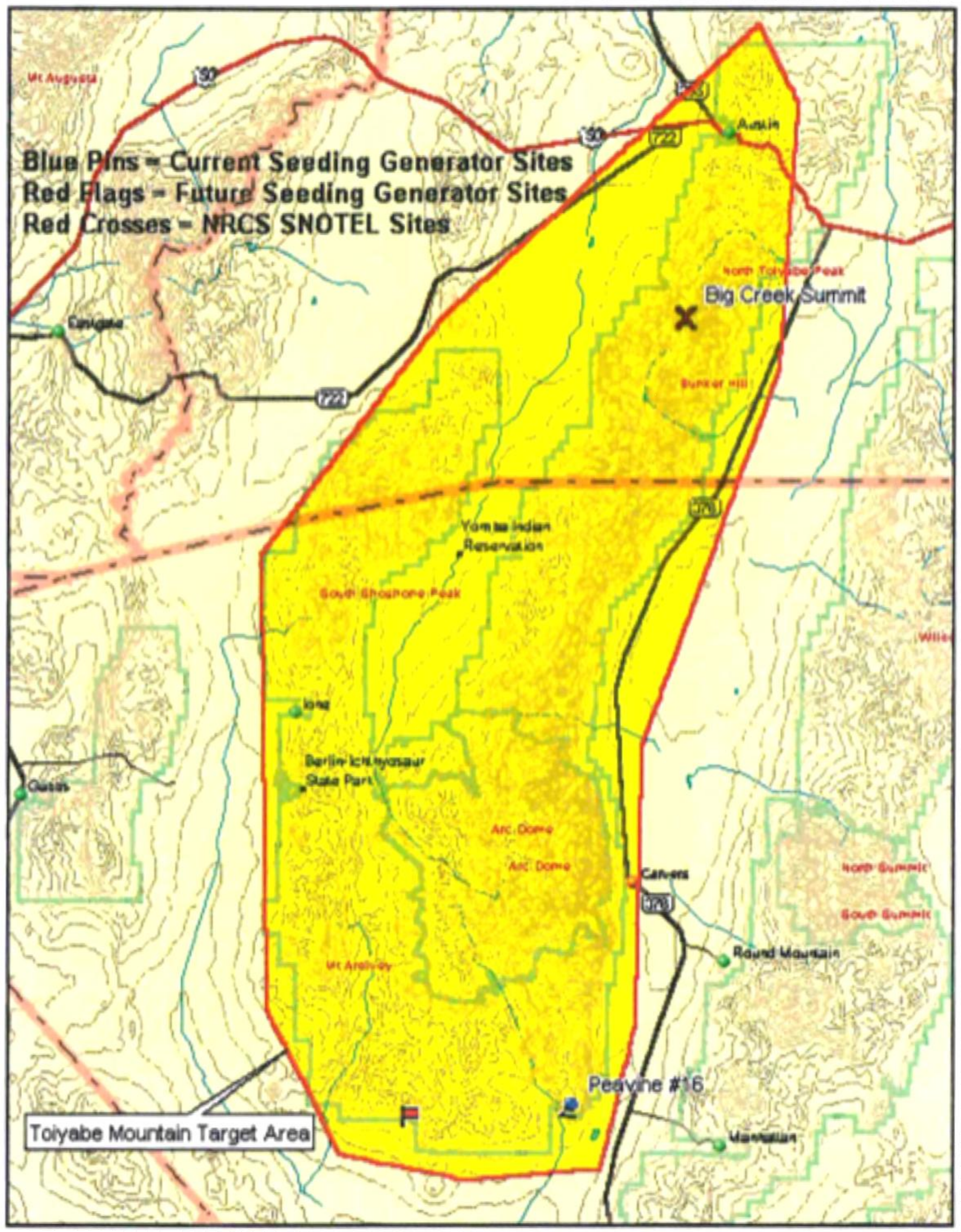


Figure 6. Proposed Toiyabe cloud seeding project area (shaded yellow). Although the former Peavine #6 generator site (blue pin) in Nye County was useful for targeting storms with significant S to SSW winds, the Nye County site indicated by the red flag would be more optimal for those storms and allow a larger range of wind directions and speeds to be acceptable as seeding criteria. Under the proposed program we would work to establish the site with a red flag as well as find a second acceptable seeding site either in Lander County north of the Yomba Indian reservation or along Highway 722, or a second site in Nye County south of the Yomba Indian Reservation and northeast of Berlin-Ichthyosaur State Park.

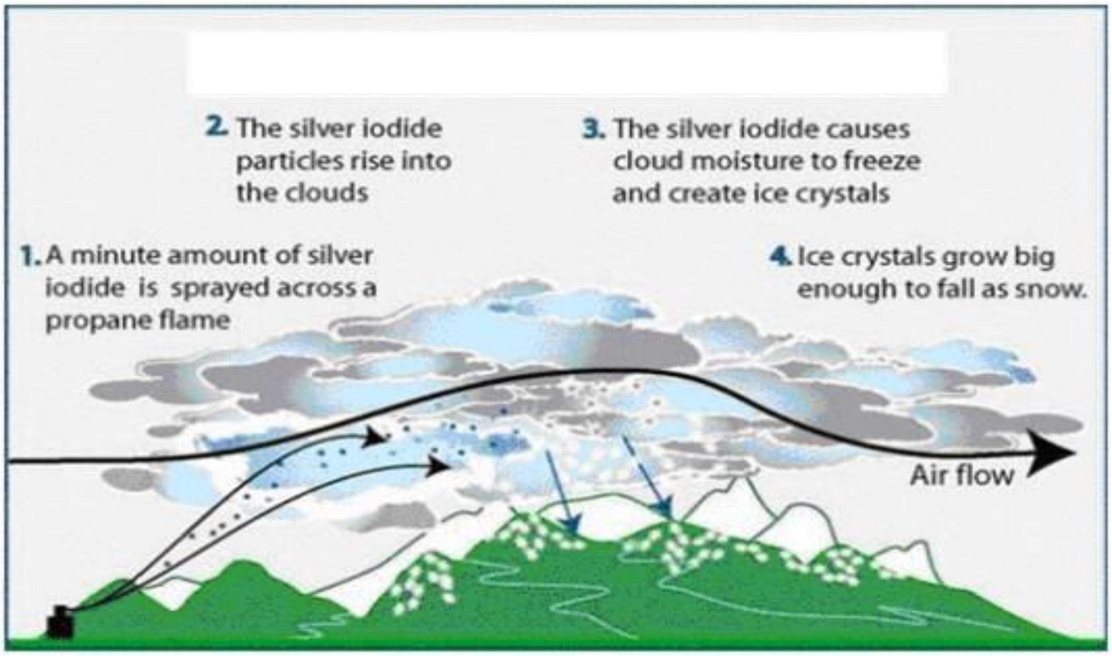


Figure 7. Schematic diagram of the key steps involved in ground-based glaciogenic cloud seeding with silver iodide. Diagram also applies to aircraft seeding with the proviso that the aircraft flights above cloud top or in the upper portion of the cloud system under consideration.

Date and Time: 03/03/2014 1900 PST
Current Situation and Synopsis:
The next system is now well onshore under conditions of nearly zonal flow at midlevels, leading to a rapid progression eastward. The moisture plume represents another atmospheric river of tropical moisture that can be seen extending southwest of Hawaii on satellite imagery (see attached image). Thermal characteristics of this system are unfortunately, reflecting this tropical heritage with relatively little modification as it has traversed the subtropics. The bulk of the colder air with this system, however, is far north of our target areas, sitting at the US/Canada border and this has prohibited ground seeding efforts thus far. Forecasts do not suggest a lot of change in this thermal structure overnight.

Nowcast (0-6 hrs):
The moisture plume will remain over the area through the nowcast period but thermal advection looks to be near zero at mid-levels through the period, thus 700 mb temperatures are likely to stay close to -3C overnight and ground seeding probabilities are low. Probabilities for Walker aircraft seeding, however, are rapidly increasing and I have notified the flight crew to mobilize for ops. The best window appears to be between now and 11 pm- midnight, after which time winds will begin a more decided shift from SW-WSW to W.

Short-Term Forecast (6-12 hrs;);
The moisture plume is forecast to exit most of northern California save the Central Sierra by 12 hours. Thermal advection at mid-levels, if any, becomes positive during this period thus there is little chance of ground ops overnight. Aircraft ops are unlikely after 1 a.m. due to unfavorable wind direction.

Medium Forecast (12-24 hrs);
Skies should begin to clear during the day Tuesday though the next impulse tapping the atmospheric river is forecast by the NAM to enter California by the end of the 24 hour period. The bulk of the moisture will not have entered the Central Valley by 7 pm tomorrow, so no ops are expected for the daytime tomorrow. Also, if anything, the next impulse looks to be slightly warmer than the current one.

Long Range (> 24 hrs;);
The atmospheric river feed is cutoff by the approach of a stronger wave, the third in the series, during Wednesday. This wave is accompanied by colder air and phases with the cutoff low from wave #2 which has migrated northward and tapped another reservoir of colder air. It is still not clear in the models yet whether enough cold air will be tapped to allow for ground seeding ops. Upstream ridging effectively stalls the progress of the moisture save moving it northward of the target areas by late Thursday afternoon. The impact of this system will become clearer in the next several model cycles.

Green===All Clear, No Operations Foreseen in Forecast Period
Yellow===Watch; Possible operations within Forecast Period; weather should be monitored at 6 hr intervals with new ops statements at this interval.
Orange===Close Watch: Operations likely to start within next 6 hr Window; weather should be monitored at 3 hr intervals with new ops statements at this interval.
Red===Operations Imminent within next 3 hrs or In Progress and should continue: If Generators not being turned on immediately, weather should be checked at hourly intervals; new ops statement issued to wiki westerly flow hen operations begin.

Tahoe/Truckee: Probability for ops is low but an intermediate update will be provided at midnight.
Walker Ground:
Walker Air: A Walker aircraft op has been authorized as soon as they can get crew

Figure 8. Sample of Twice-Daily Weather Discussion produced by DRI meteorologists for the evening of 3 March 2014. Operation areas discussed at this time were limited to the Tahoe-Truckee and Walker Basin projects but, as can be seen, discussed of both Walker Basin ground and airborne seeding prospects are included. Forecasts focus on the 0-24 hr time periods but also consider a more extended range outlook. Color coding is as follows: Green: no operations foreseen in the forecast period; yellow; operations possible during the forecast period; red: operations in progress or imminent.

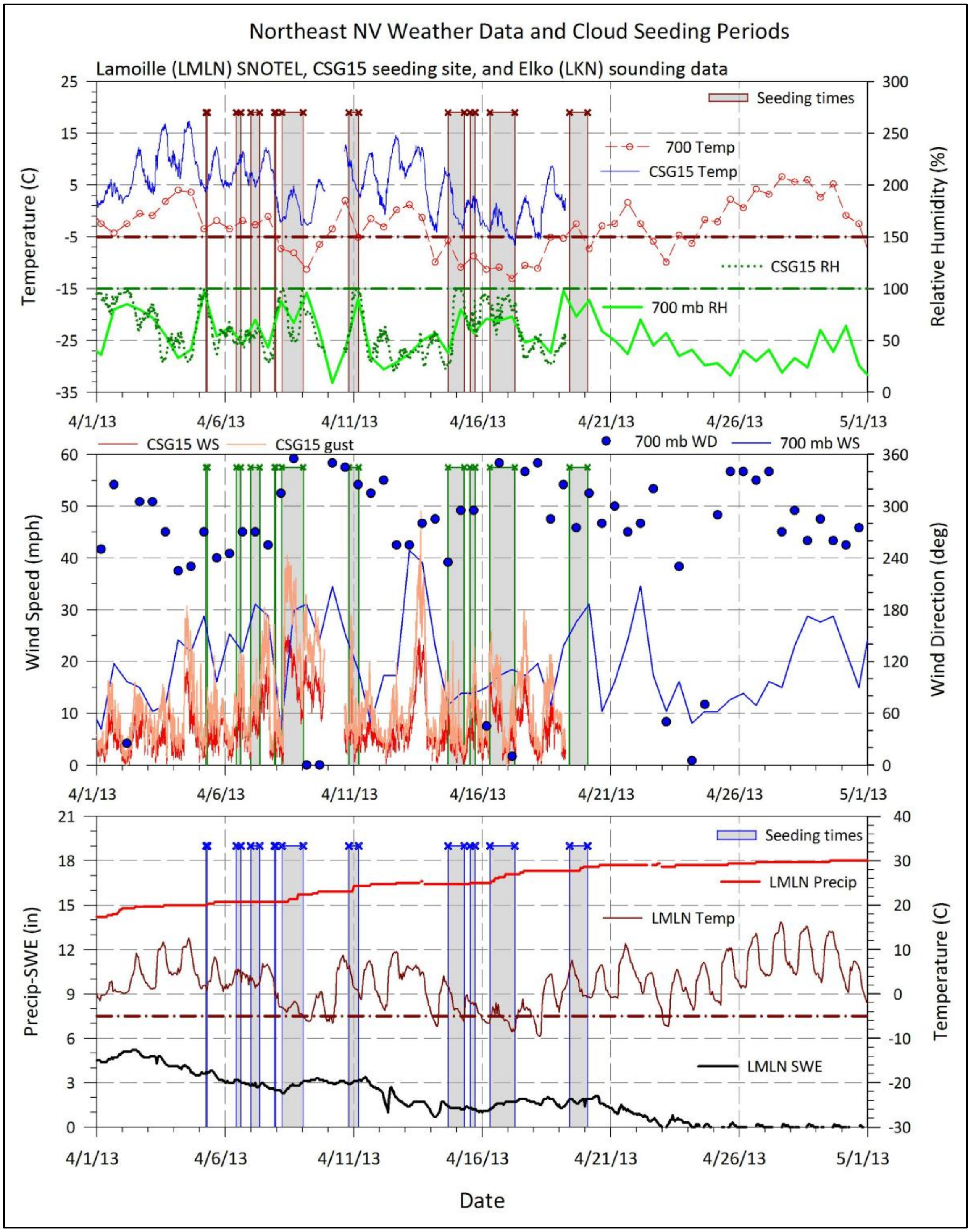


Figure 9. Weather and seeding data for April 2013 for the DRI Ruby Mountains cloud seeding network. Top: Air temperature and relative humidity at Riordan (CSG15) and LKN 700 mb level. Red dot-dashed line marks -5° C and dark dot-dash green line marks 100% relative humidity. Middle: 700 mb wind speed and direction and CSG15 wind and gust speeds. Bottom: LMLN precipitation and SWE accumulation since 1 October 2012 and LMLN temperature. In all panels seeding time periods are indicated by gray shaded regions.

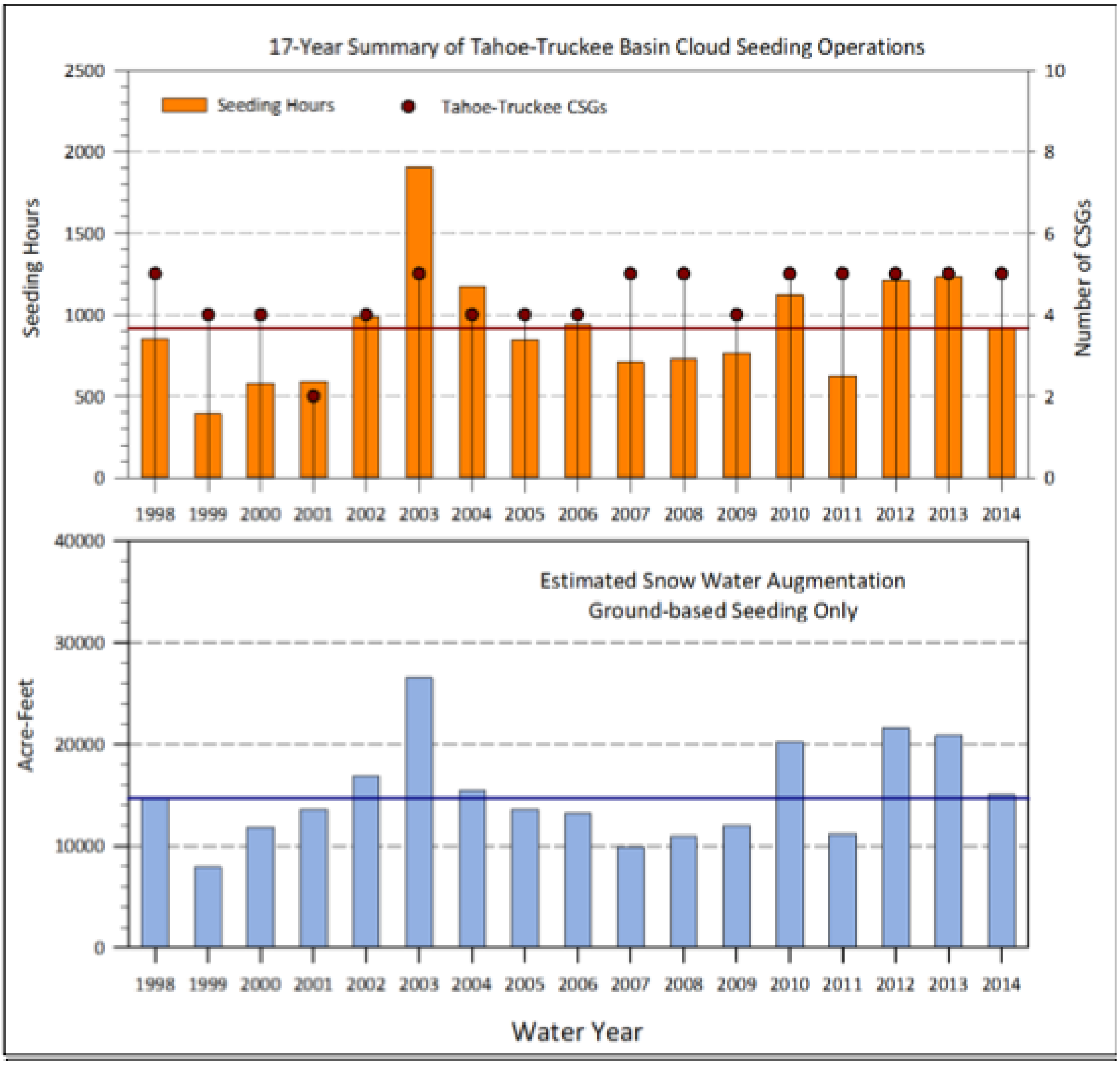
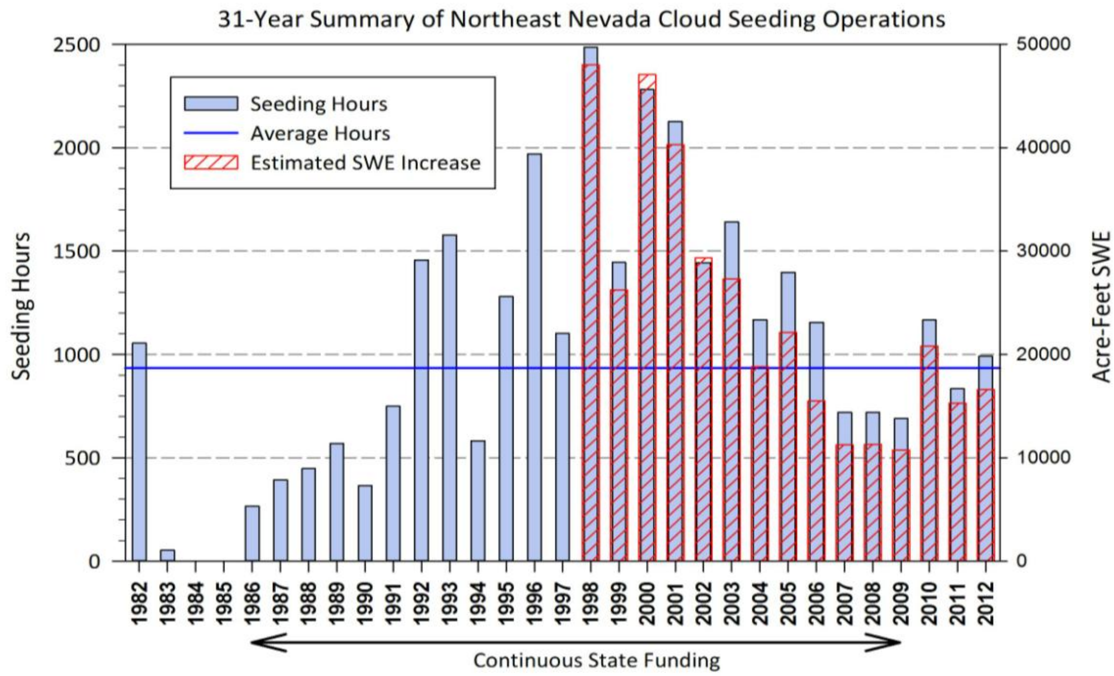


Figure 10. (Top) Summary of operational seeding hours and number of CSGs used per season for the Tahoe-Truckee project over the period encompassing Water Years 1998-2014. (Bottom) Estimated water augmentation, in acre-feet, over the same period in the top figure. Red line in the top figure indicates the average number of seeding hours (~ 915) over the period, while the blue line in the bottom figure indicates the average estimated water augmentation (~15000 acre-feet) over the same period.



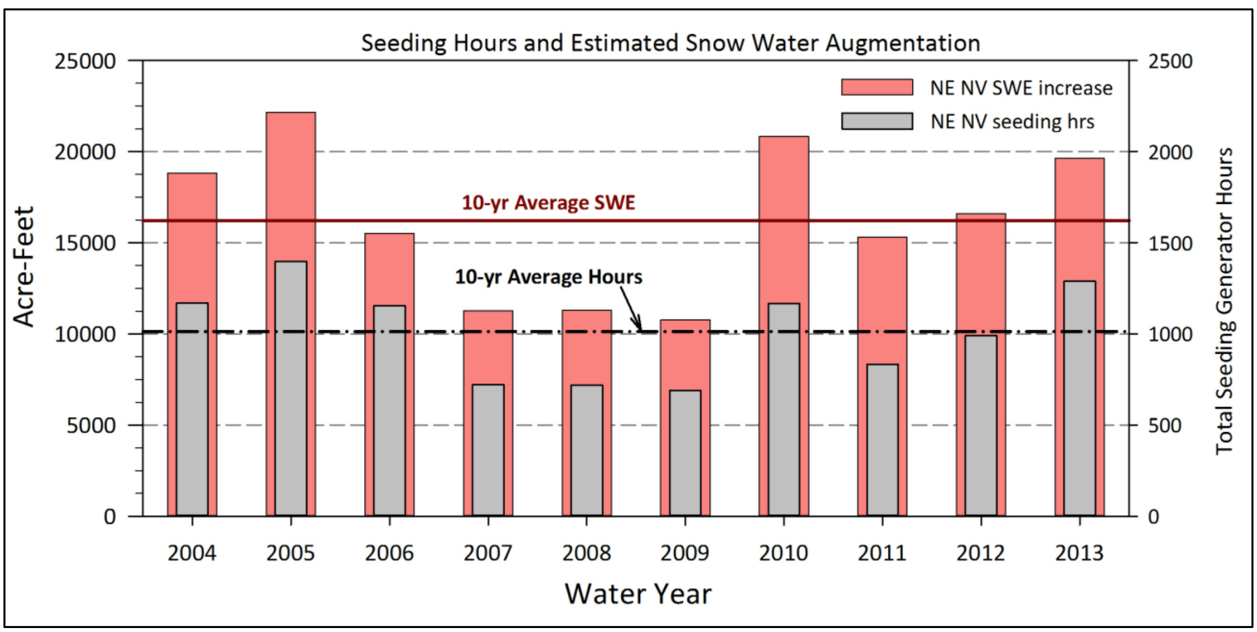


Figure 11. (Top) Summary of operational seeding hours and estimated water augmentation, in acre-feet, per season for the Ruby Mountain seeding project over the period encompassing Water Years 1982-2012. (Bottom) Same as top but for the period encompassing Water Years 2004-2013, for which the number of Ruby Mountain generators was largely stable.