BOARD OF REGENTS
BRIEFING PAPER

Agenda Item Title: FY17 Nevada Cloud Seeding Program Request to Submit to Interim Finance Committee

Meeting Date: March 3 and 4, 2016

2. BACKGROUND & POLICY CONTEXT OF ISSUE:

The moderate to extreme drought continues across most of Nevada as we enter the winter of 2015-2016. Cloud seeding can increase snowfall by about 10% when conducted properly. DRI has pioneered much of the science of cloud seeding over the last 40+ years, and has been conducting cloud seeding services to enhance snowpack and increase runoff in parts of Nevada for over 30 years. To expand on and improve the current Nevada cloud seeding programs, DRI has developed a plan based upon its experience that is designed to provide effective and cost efficient cloud seeding in selected mountains throughout the state.

3. SPECIFIC ACTIONS BEING RECOMMENDED OR REQUESTED:

DRI is requesting approval to submit a request to the Board of Examiners and the Interim Finance Committee for a renewed FY2017 Nevada State Cloud Seeding Program (see attached memorandum). The goal of this project is to enhance snowfall from winter storms and increase the snowpack and runoff water in several rivers across 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. The proposal is presented to include several of the major water production areas for Nevada and the cloud seeding programs that could be conducted from these mountains (see Figure 1 in attached memorandum).

The amount requested from the IFC for FY 2017 is $899,904 to support cloud seeding operations in the following watersheds: Humboldt River, Walker River, Carson River, and Spring Mountains of Southern Nevada. This request will be matched by continuation of the $310,000 provided by the Truckee Meadows Water Authority and Western Regional Water Commission for operations in the Tahoe-Truckee River region.

See attached memorandum for details on the proposed cloud seeding program.

Revised: June 2010

4. IMPETUS (WHY NOW?):

The proposed FY2017 Nevada State Cloud Seeding Program will address new water supply for several severely drought impacted rivers that serve the Nevada population. In order to prepare for cloud seed during the winter of 2016-17, the funds requested must be approved by the Interim Finance Committee during their March 2016 meeting. The extensive preparation time involves both installing and upgrading silver iodide generators in the selected mountain ranges, which can only be accomplished in the summer and fall of 2016.

5. BULLET POINTS TO SUPPORT REQUEST/RECOMMENDATION:

- The cloud seeding efforts will help improve severely drought-reduced 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, Walker, Humboldt and Spring Mountain areas. Increases of approximately 10% to the overall snowpack within a watershed can be expected.
- Based on the history of the State of Nevada Cloud Seeding Program from 1994-2009 and incorporating adjustments for the lower number of AgI generators and aircraft cloud seeding proposed here as well as greater efficiencies developed recently at DRI compared to operations under the prior state program, water augmentation yields should yield on average 43,300 acre-feet (14 billion gallons) of water at a cost of about $20 per acre-foot.
- This is by far the lowest priced water available. For comparison water produced through desalination plants run at $2,000 per acre-foot. Inter-watershed water transfers have multimillion dollar up-front costs, expensive environmental assessments with no guarantee of success. Trucking water for additional supply can on the order of $100.00 for 2,500 gallons or nearly $15,000 per acre-foot.

6. POTENTIAL ARGUMENTS AGAINST THE REQUEST/RECOMMENDATION:

None

7. ALTERNATIVE(S) TO WHAT IS BEING REQUESTED/RECOMMENDED:

Do not go forward with a request to renew the proposed FY2017 Nevada State Cloud Seeding Program, resulting in the State's ability to enhance the snowpack and thus obtain the lowest price water available during the current drought conditions. Lack of supporting the proposed cloud seeding plan could result in out-of-state entities providing less effective cloud seeding operations or ultimately the state seeking higher priced water derived from desalination plants, inter-watershed water transfers, or trucking water.

8. COMPLIANCE WITH BOARD POLICY:

- [x] Consistent With Current Board Policy: Title # __ Chapter # __Sections # __(Procedures Manual)
- [ ] Amends Current Board Policy: Title #_____ Chapter #_____ Section #_______
- [ ] Amends Current Procedures & Guidelines Manual: Chapter #_____ Section #_______
- [ ] Other:____
- [ ] Fiscal Impact: Yes_____ No √
  Explain:

Revised: June 2010

Desert Research Institute

1 February 2016

MEMORANDUM

To: Dr. Steve Wells, President of Desert Research Institute

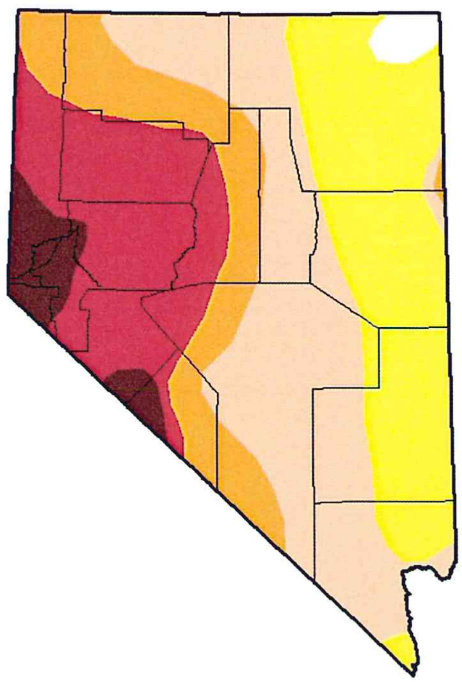
From: Frank McDonough, Program Manager, DRI Weather Modification Program

Subject: FY2017 Nevada Cloud Seeding Program

The materials need to support DRI's request to the Board of Examiners and the Interim Finance Committee for a renewed FY2017 Nevada State Cloud Seeding Program are attached. Included in the attachments is a copy of the Tahoe-Truckee WY2015 Final Report and a copy of the Walker Basin WY2015 Final Report. The DRI program budget for an expanded new Nevada State Program is included. The budget is described in two tables showing: 1) cost associated with each cloud seeding project area; 2) the major budget categories for the entire program.

The goal of this project is to enhance snowfall from winter storms and increase the snowpack and runoff water in several rivers across 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. The proposal is presented to include several of the moderate to exceptional drought impacted major water production areas for Nevada (Figure 1) and the cloud seeding programs that could be conducted from these mountains (Figure 2).

The cloud seeding efforts proposed here will help improve severely drought-reduced 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, Walker, Humboldt and Colorado River systems. Increases of approximately 10% to the overall snowpack within a watershed can be expected. Based on the history of the State of Nevada Cloud Seeding Program from 1994-2009 and incorporating adjustments for the lower number of AgI generators and aircraft cloud seeding proposed here as well as greater efficiencies developed recently at DRI compared to operations under the prior state program, water augmentation yields should yield on average 43,300 acre-feet at a cost of about $20 per acre-foot.



	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	1.35	98.65	71.74	40.76	25.48	4.80
Last Week 1/19/2016	1.35	98.65	73.26	40.76	25.48	4.80
3 Months Ago 10/27/2015	0.01	99.99	94.76	73.20	35.21	15.93
Start of Calendar Year 12/29/2015	1.34	98.66	93.08	65.49	31.74	9.35
Start of Water Year 9/29/2015	0.00	100.00	94.76	76.08	37.52	15.93
One Year Ago 1/27/2015	0.00	100.00	99.93	68.25	50.06	17.43

Figure 1. US Drought Monitor Map for Nevada, January 26, 2016.

This is by far the lowest priced water available. For comparison water produced through desalination plants run at $2,000 per acre-foot. Inter-watershed water transfers have multimillion dollar up front costs, expensive environmental assessments with no guarantee of success. Trucking water for additional supply can on the order of $100.00 for 2,500 gallons or nearly $15,000 per acre-foot.

If we spread the proposed labor cost equally across the six proposed project areas we can estimate the acre-foot costs per mountain range. Costs per acre-foot within a mountain range will decrease as additional generators are added to the range.

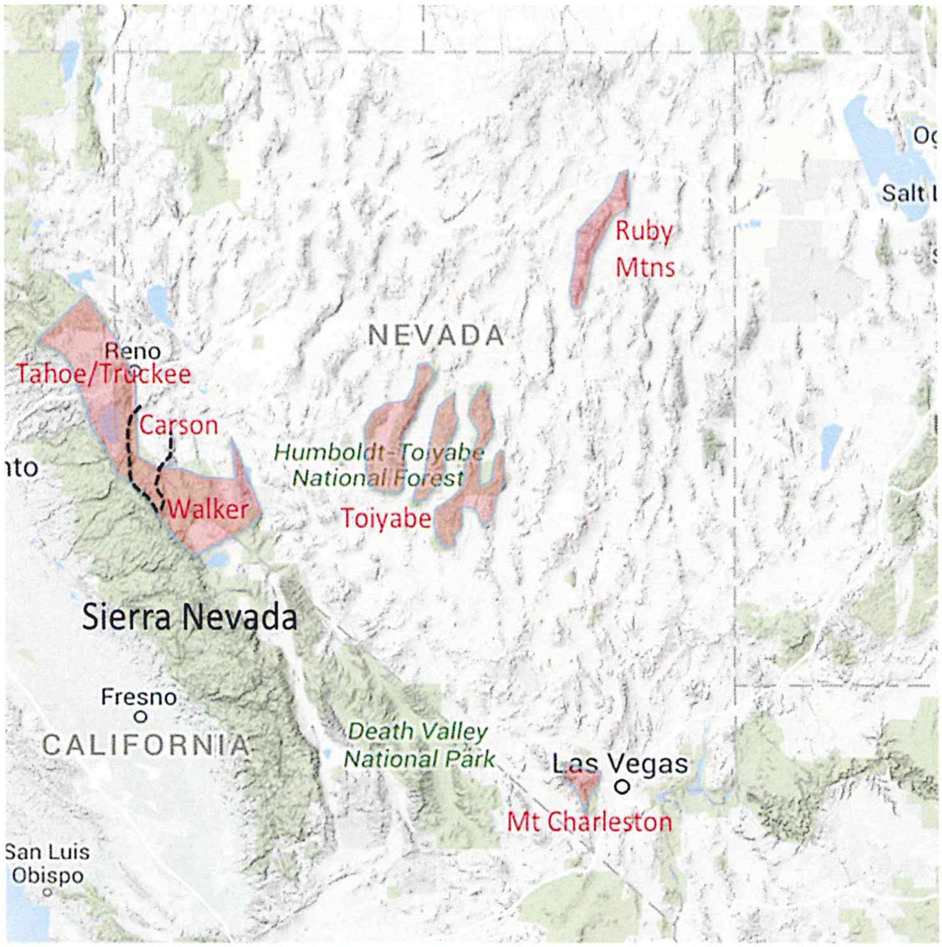


Figure 2. The locations of the proposed cloud seeding ranges for the new Nevada State Program.

Humboldt River:

The Humboldt River is the major source of water for most of northern and central Nevada. It provides water for residential and irrigation uses as well as fisheries and recreation. As with the rest of the state, this area has been under an extreme drought over the past 4 years (Figure 2). This proposal includes cloud seeding in two of the major ranges that provide snowmelt to feed the Humboldt River.

The **Ruby Mountains** are one of the most important ranges for providing melt water to feed the Humboldt River. Cloud seeding in this range had been conducted for several decades but has not been conducted for the past 4 years due to lack of funding. Five cloud seeding generators, the remnants of the previous program are currently sited in the Ruby Mountains. The proposal in this first year plans to refurbish and operate 2 of these ground-based AgI generators and also initiate a new aircraft cloud seeding program based in Elko for this range. This would add a maximum of 12,575 acre-feet to the snowpack at an estimated cost of $15.50 per acre-foot. The goal in the second year of the program would be to add the 3 additional generators, which could add an additional 8000 acre-feet and potentially reduce the estimated costs to $12.58 per acre-foot.

The **Toiyabe Range** snowmelt feeds the Reese River, a tributary of the Humboldt. The water is used by the town of Austin, as well as ranchers and farmers in central Nevada for irrigation. The proposal introduces a new cloud seeding program to the Toiyabe range with a new AgI ground-based generator. This would add as much as 2800 acre-feet of water to the snowpack. The cost for this water is $40.22 per acre-foot. The reporting and weather forecasting services are generally fixed so adding additional cloud seeding generators would significantly reduce these costs.

Figure 3. The upstream side of the Rye Patch Dam and Rye Patch Reservoir on the Lower Humboldt River in August 2015.

Walker River:

The Walker River watershed is located along the eastern slopes of the central Sierra Nevada directly south of the Carson watershed. The winter snowfall provides most of the irrigation and residential water for the area. The water is stored in Bridgeport Reservoir and Topaz Lake and is used by the Walker River Irrigation District and towns along the river including Yerington.

A multi-year cloud seeding program, primarily funded by the US Bureau of Reclamation, with some funds from the Walker River Irrigation District, will end this year. The program included 4 ground-based generators and an aircraft cloud seeding program. This project will end in April 2016 so there would be no water augmentation for the Walker Basin by cloud seeding unless the new Nevada State Program in funded.

The budget for the new program will only allow DRI to maintain and operate 3 of the 4 ground-based AgI generators from their current locations. This would add up to 8,400 acre-feet to the snowpack at an estimated cost of $18.88 per acre-foot. The 4th generator would be added in the second year of the project.

Carson River:

The Carson River watershed is also located along the eastern slopes of the central Sierra Nevada directly south of the Tahoe-Truckee basin. The winter snowfall provides water for the Nevada cities of Gardnerville, Minden, Carson City, Dayton, and Fallon. It also provides irrigation water to the Lahontan Valley. There is currently no cloud seeding conducted in this watershed and the area is under severe drought. This Nevada State proposal plans to add an aircraft cloud seeding program to the Carson watershed. This would add as much as 6875 acre-feet to the snowpack. The cost for this augmentation is estimated to be $21.67 per acre-foot.

Tahoe-Truckee

The Lake Tahoe-Truckee River watershed is located along the eastern slopes of the central Sierra Nevada. The winter snowfall in the watershed provides water for the Lake Tahoe communities, Truckee Meadows cities, including Reno and Sparks, irrigation water to the Lahontan Valley, and recharges Pyramid Lake. The snowfall also generates significant economic activity through winter recreation, whitewater rafting, and fishing.

The Truckee Meadows Water Authority (TMWA) and the Western Regional Water Commission (WRWC) currently fund a $310,000 ground-based AgI cloud seeding program. This program uses a set of 5 remote controlled high altitude AgI generators sited along and west of the Sierra Crest to add snowfall to the watershed. The five generators on average add more than 14,000 acre-feet (4.5 billion gallons) to the snowpack per year.

This Nevada State proposal plans to add one additional generator to the northern part of the domain and also include aircraft operations. The estimated additional water added to the snowpack from this proposal would be 9775 acre-feet at a cost of $17.60 per acre-foot.

Southern Nevada:

Most of the water supply for southern Nevada originates in the mountains of Colorado. The DRI cloud seeding program is currently conducting a small cloud seeding program in Colorado using ground-based remote-controlled high-altitude AgI generators with funding from the Colorado Water Conservation Board. The proposal is for one of two options with the selection to be made after consultation with local officials. One option includes adding an additional DRI high-altitude remote controlled generator to one of the key locations in Colorado to produce additional Colorado River water for southern Nevada. A second option would be to install a ground-based cloud seeding generator in the Mt Charleston area to add snow to the area for additional water supply and recreational use. The additional water that could be produced by this generator is 2800 acre-feet at a cost of $40.22 per acre-foot. Adding a ground-based generator to an existing Colorado program could reduce the forecasting and some of the other labor costs. The reporting and weather forecasting services are generally fixed so adding new cloud seeding generators to this site in the future would significantly reduce these costs.

The FY2017 Nevada State Cloud Seeding Program addresses new water supply for several severely drought impacted rivers that serve the Nevada population. The proposal estimates that on average 43,225 acre-feet (14 billion gallons) of water can be produced at a cost of approximately $20 per acre-foot. This is by far the lowest cost method to add water supply to regions across the state. The summary table below shows the location, cloud seeding methods (ground and aircraft), the number of generators to be installed and operated by the program, the median yearly water supply increases expected, and the costs for the new Nevada State Cloud Seeding Program. Table 2 shows the total program cost by budget category.

Table 1. 2017 Cloud Seeding Program summary table with cost by project area.

Location	Number of proposed ground generators	Aircraft	Estimate median acre-feet* added	Cost ($)
Ruby Mtns.	2	Y	12,575	195,002
Walker Basin	3	N	8,400	158,624
Carson Basin	0	Y	6,875	149,010
Tahoe-Truckee	1**	Y	9,775	172,006
Toiyabe Range	1	N	2,800	112,631
Southern NV	1	N	2,800	112,631
Total	**8**	**3**	**43,225*** **	**899,904**

* An acre-foot is 325,851 gallons (An average metered Reno household uses 137,000 gallons per year)
** 5 existing operational cloud seeding generators, funded by the TMWA-WRWC program, are in place.
*** 14 billion gallons of water

Table 2. 2017 Cloud Seeding Program cost by budget category.

		2016-2017	
		Base Request	
		FTE	Amount
CloudSeeding	Professional Salary	0.50	43,502
CloudSeeding	Classified Salary	2.50	110,322
CloudSeeding	Grad Student Salary	0.65	19,731
CloudSeeding	Wages Salary		-
CloudSeeding	Fringe		84,234
	Subtotal Labor		*257,788*
CloudSeeding	Operating		129,102
CloudSeeding	Equipment Fabrication		170,460
CloudSeeding	Aircraft Seeding		125,000
CloudSeeding	Indirect Cost		217,554
	Total		899,904

Desert Research Institute

Annual Report

Cloud Seeding Project for Tahoe and Truckee Basins for WY2015: Status Update for Oct 2014 -June 2015

Submitted to

Mr. Jeff Tissier
Truckee Meadows Water Authority
1355 Capital Blvd
Reno, NV 89502

By

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Division of Atmospheric Sciences
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July 10, 2014

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1. Introduction

The goals of the DRI cloud seeding efforts in the Tahoe/Truckee Basin remain essentially the same from previous years: to enhance snowfall from winter storms and to increase the snowpack of the Tahoe and Truckee Basins through the application of wintertime cloud seeding technology. This report constitutes an update on project status for the first three quarters of the TMWA/WRWC grant period, covering 1 Oct 2014 -30 June 2015.

1.1. Brief Project Description

The project design and method of operation are the same as those used for the previous few seasons. Seeding is conducted from a line of five ground-based cloud seeding generators (CSGs) positioned on, or a few miles upwind of, the main Sierra Nevada crest to the west of Lake Tahoe (Fig. 1). The generators are positioned to take advantage of the generally westerly to southwesterly wind directions in winter storms in the Tahoe area, and are remotely activated by DRI staff when the proper weather and cloud conditions for seeding were verified. Forecasting for potential cloud seeding events during WY2015 began on November 1, 2014 and continued until May 28, 2015.

2. Summary of Phase 1 Activity

Activity under Phase 1 of the project was concluded during the first quarter and included preparation of the five seeding generators at the locations shown in Fig. 1. This work required several weeks, and included re-installation of the Barker generator as required by USFS permits for use of the site. Additional Phase 1 tasks included refilling the seeding solution tanks, refilling propane tanks, and testing all generator components and communications links.

3. Summary of Phase 2 Activity

Phase 2 of the project includes the actual cloud seeding operations and supporting work such as forecasting and real time monitoring of weather over the Tahoe target area. The project meteorologists monitor the weather and make forecasts for seeding events that are expected within one to five days. Throughout Phase 2 the cloud seeding field technicians and project meteorologists made at least weekly checks of cloud seeding equipment by logging into the data loggers, briefly activating the units and monitoring key operating parameters such as flame temperature and solution flow.

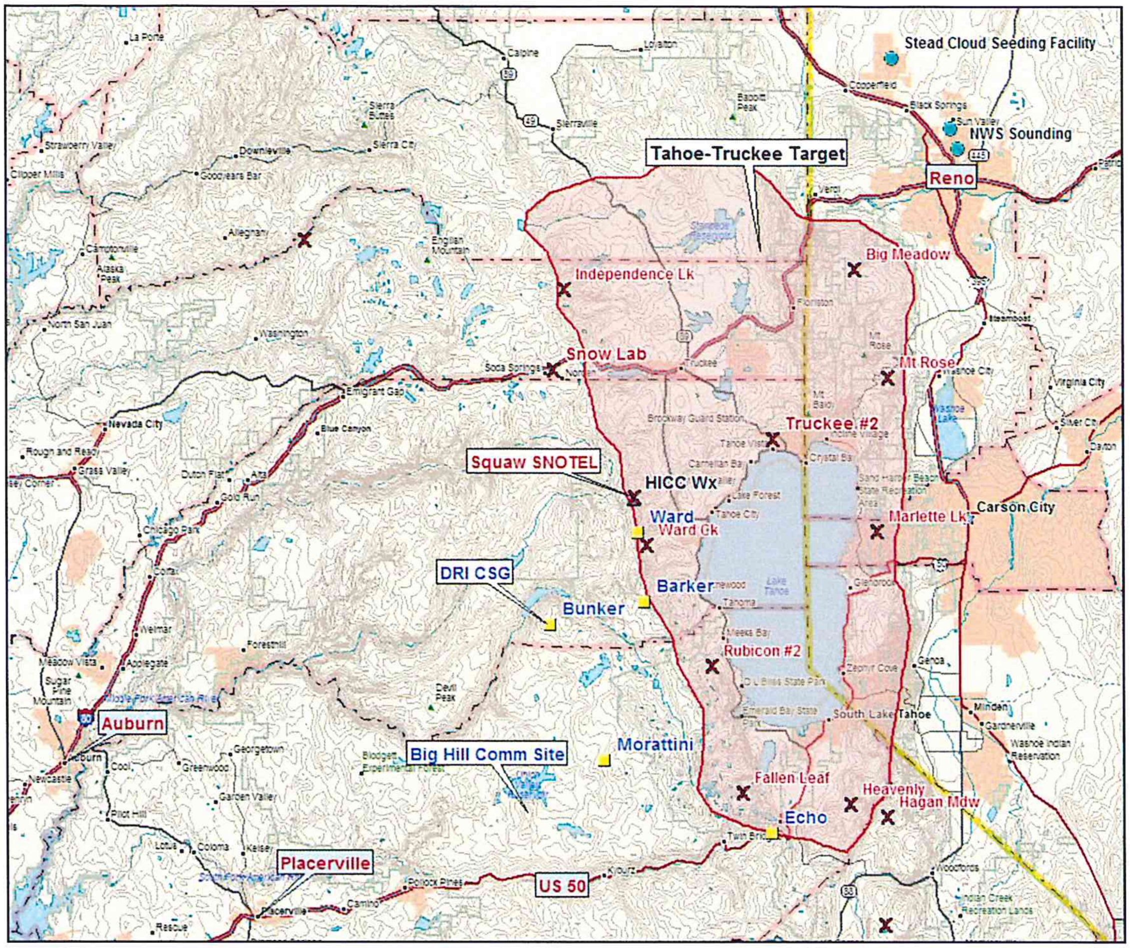

Figure 1. Map showing the Tahoe-Truckee cloud seeding target area (red shading) and instrument sites in and around the target area. NRCS SNOTEL sites, which measure precipitation and snow water equivalent (SWE) are indicated by red Xs. Ground seeding sites are shown as yellow squares. Reno facilities are shown in the upper right as cyan-colored circles. Weather data shown in Section 4 of this report were collected near the sites labeled Snow Lab, Squaw SNOTEL, and NWS Sounding.

3.1. Summary of Tahoe-Truckee Cloud Seeding Operations

The cloud seeding activity during Phase 2 that occurred through the winter season are presented in this report. By the end of May a total of 20 seeding operations had been conducted, with the final seeding operation of Phase 2 on 24-25 April 2015. Figure 2 shows the monthly totals for seeding hours and seeding events for all of WY2015. For the season there were a total of 681 seeding hours conducted over 20 separate events. The details of all operations are given in Appendix A. The record warm and dry winter led to lower total seeding hours than the previous seasons that the project has been funded by TMWA and WRWC. An analysis of generator operating efficiency (*ratio of actual seeding hours to total hours possible if all CSGs had operated correctly throughout all events*) for the season produced a value of 90%, which is significantly improved from last season. Poor communication to the Bunker Hill site caused the biggest loss of seeding hours. A few other problems, such as ignition failures, low flow, and depleted solution were also encountered, but were typically dealt with quickly and lead to fewer lost hours compared to the communication problem.

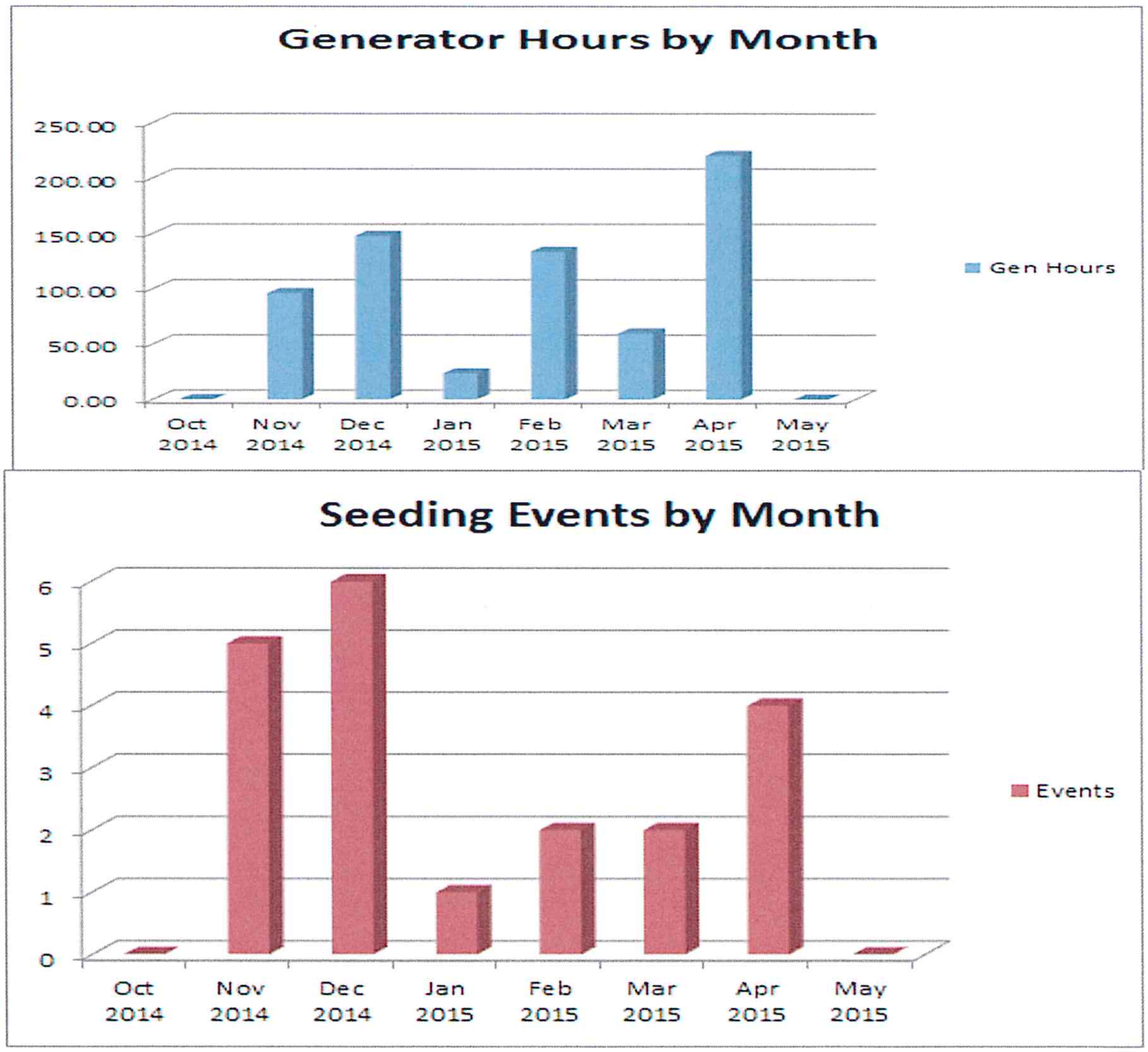

Figure 2. Monthly summaries for Tahoe-Truckee area cloud seeding operations in WY2015. Top panel shows CSG seeding hours by month and bottom panel shows the number of seeding events by month.

3.2. Water Year Summary

Figure 3 documents the history of snowwater liquid equivalent (SWE) accumulations (relative to 30-year median values) in the Tahoe and Lower Truckee Basins for WY2015. The winter season was again dry, with the snowpack's SWE only briefly reaching 50% of the median in late December.

Snowfall was minimal through much of the late fall. A set of warm storms in early December increased the snowpack somewhat, but SWE in both the Tahoe and the lower Truckee basins were at about 30% of the median values by the end of a very dry January. SWE remained exceptionally low as a set of very and wet warm rainstorms moved through area in early February. Storms in early February only increased the SWE in the highest elevations of the Tahoe Basin and lower Truckee Basin. Only a few additional storms occurred though the second half of the calendar winter and a very warm early spring in March allowed the low SWE values to go to near zero. A few spring storms added a bit of snow in April but only minimally added to the SWE.

The winter snowfall history at specific SNOTEL sites in the Truckee Basin is documented in Fig. 4. The sites shown vary in location (see Fig. 1) and altitude. The Central Sierra Snow Lab (CSSC) is the lowest site (6255 ft.) located upwind (west) of the main Sierra Nevada crest. Squaw is just above 8000 ft. and located slightly downwind (east) of the Sierra crest, and Big Meadow the highest site at 8250 ft. is in the Carson Range on the east side of Lake Tahoe. The warm early December storm seemed to only impact the Sierra Crest (Big Meadow showed no increase in SWE) is shown in Fig. 4, as is the extended dry period that encompassed most of January 2015. The second big warm storm occurred in early February, with Squaw SWE increasing by 5 inches. A storm in late February added slightly to the SWE at all three sites. By the end of March the snow was gone from both CSSL and Big Meadow, and less than 2-inches at Squaw. The 30-year median SWE at Squaw on March 31 is just under 50-inches. A late April storms briefly increased the snowpack at all three sites.

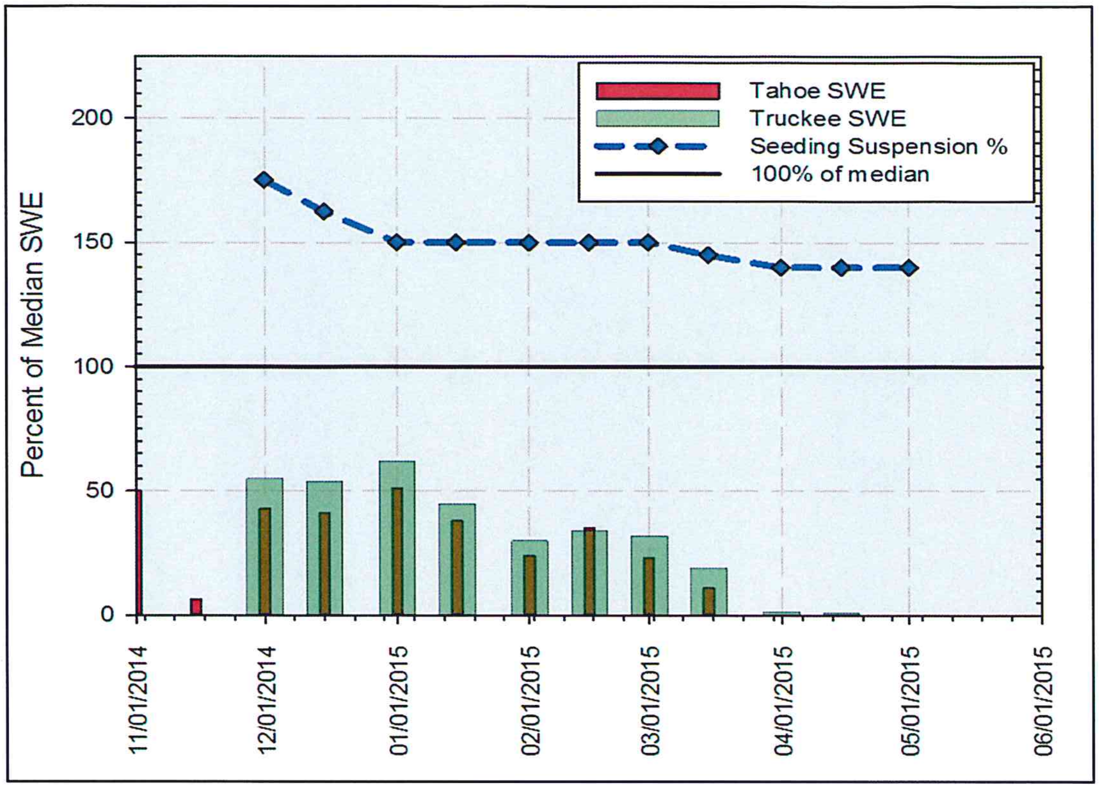

Figure 3. Snow water equivalent (SWE) percentages relative to 30-year median values for the Lower Truckee and Tahoe Basin for WY2015. Black line highlights 100% of the median. Blue dashed line shows SWE percentage thresholds at which cloud seeding is suspended due to above normal snowpack. Wide green bars show Truckee Basin SWE and thin red bars show Tahoe Basin

4. Summary of Phase 3 Activity

The phase 3 work typically begins in late May after the end of all seeding operations and includes the analysis of weather data during cloud seeding periods, an estimate of snow water augmentation from the season's seeding, and final postseason maintenance work on the CSG network. Maintenance includes removal of the Barker CSG because of its accessibility to the public during the summer. This was done in June this year. The ordering of expendable supplies for future operations also generally occurs as part of Phase 3, and this will be done during the final quarter of the contract period.

All of the significant storm systems in WY 2015 were warmer than normal and thus seeding conditions were not always optimal. In addition, some of these storms were characterized by relatively low atmospheric stability, such that the associated clouds were often more of a convective nature than the stratiform clouds observed in many wintertime storms in the Sierra Nevada range. With such convective clouds, updrafts of up to 10 m/s are possible, allowing seeding material to reach greater altitudes and colder temperature than is possible with stratiform cloud systems. Thus, it is quite possible that even when temperatures are warmer than -5°C at 700 mb (10,000'), the seeding material can be taken to somewhat higher altitudes within the clouds where supercooled liquid water at temperatures less than -5°C are present. Because of this, seeding strategies were modified somewhat for this period. The strategy allows seeding to commence for 700 mb. temperatures between 0°C and -5°C if it was determined that either convective clouds were already present over generator sites or that sufficient atmospheric instability (as determined from observed and model forecast temperature and moisture profiles) was present to promote convective cloud development.

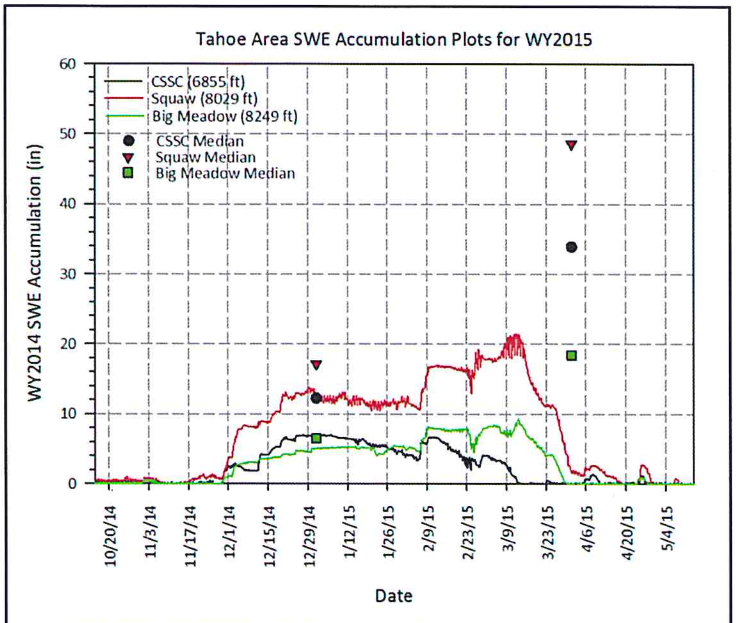

Figure 4. SWE accumulation plots for three SNOTEL sites in the Tahoe-Truckee River Basin. Note the locations in Fig. 1.

A complete assessment of weather conditions during seeding events is part of the Phase 3 analyses. The weather data and seeding periods for November 2014 are shown in Fig. 5. The season started quickly with a seeding event on November 1st. The next 3 weeks were too warm for operations. A complex set of storms moved through the area late in the month. These storms were not that cold, but the periods with 10,000' MSL temperatures colder than -5°C and the more unstable periods were seeded.

In early December (Fig. 6) a very wet but warm storm ('Pineapple Express') moved across the Sierra under southwesterly flow. This system was much to warm to seed. By December 12 at 10,000' MSL temperatures cooled below -5°C and several seeding events were conducted though the middle of the month. A cold storm ('Inside Slider') moved just east of the area on December 24-25 but winds were from the east throughout this event. January 2015 was quite dry and much warmer than the climatological normal (Fig. 7). There was only one seeding event in an unstable atmosphere at the end of the month with light precipitation.

At the end of first week of February 2015 (Fig. 8) a pair of warm and very wet 'Pineapple Express' storms moved across the area under southwesterly flow aloft. Most of the precipitation fell as rain, even across the highest elevations of the Sierra Crest. The end of the second event was seeded as the temperatures cooled and winds became more westerly. At the end of the month a colder Gulf of Alaska storm moved across the area. This entire event was seeded. March 2015 (Fig. 9) was also quite warm and dry. A brief event was seeded on March 2 and second stronger event on March 22. April 2015 (Fig. 10) was somewhat more active than earlier in the season with 4 events in the month. The first two storms of the month were cold with winds from the northwest and ideal cloud seeding conditions. A short event occurred as a cold front crossed the Sierra on April 14. Late in the month a cold front again crossed the area, which allowed an extended period of cloud seeding with 10,000' MSL temperatures colder than -5°C, low clouds, and winds generally from the northwest.

The WY2015 seeding events are summarized in Fig. 11 where several weather variables are averaged or totaled over each seeding period. An hour was added to the end of each analysis period to account for any continued effects from seeding after CSGs were shut down. The data from the Tahoe City Snotel has replaced the Squaw Valley base data set, since that data set has been shown to be unavailable for extended periods of time in previous seasons. These two sites are close to each other and at about the same elevation. Figure 11 indicates that the 20 seeding events generally met all project seeding criteria. Exceptions were Events 4, 12 and 13, which had 700 mb. temperatures slightly higher than the -5° C seeding threshold. The events 12 and 13 both were under unstable conditions where the seeding material would be expected to mix higher than the normal threshold and to colder levels of the clouds. Seventeen of the 20 events had measureable precipitation, although four events had less than 0.2 in. The differences in precipitation amounts between the observation stations were significant this winter. CSSL or the Squaw SNOTEL in the main Sierra Nevada range typically record the most precipitation, although Mt Rose in the Carson Range recorded more than Squaw during four events. The most precipitation (2.2 in) during any single seeding event was recorded at Squaw in late April.

There were several different 700 mb. wind direction regimes during seeding events in WY2015. Seven events had a more west to northwesterly flow pattern. All but one (event 12) of these 7 events had temperatures below the 5° C seeding threshold. The remainder of the events had more typical south to southwesterly flow including all of the unseeded Pineapple Express storms.

In estimating the effect of seeding on snow water equivalent in the following section, the data in Figs. 11 and the data plots like Fig. 5 were first used to determine a seedability factor (SF) for each seeding period. The SF semi-quantitatively estimates how well the project seeding criteria were satisfied for each event. If cloud cover, wind and temperature criteria are all satisfied, then SF is one. If the wind criterion is only satisfied during half of an event then SF drops to 0.5. For the temperature criterion SF is reduced if the 700mb temperature is above -5° C; from 0.9 for the first degree above -5°, down to 0.2 at -1°, and 0 at or above freezing. This reduction in SF was applied to stratiform atmospheric cloud structures. For convective cloud structures the temperature threshold (SF = .95) was increased to -3.5°C with the SF linearly decreasing and set to 0 at the freezing level. To estimate snow water augmentation for the season an event duration-weighted value of SF was computed and found to be 0.92.

The 2 new TMWA/WRWC high-resolution snow gauges (one in Hope Valley and one above Incline Village) will help reassess the weather and resulting impacts from cloud seeding.

WY2015 Snow Water Augmentation Estimate

The analysis of weather events and seeding criteria in the previous section and from other analysis indicated that the project seeding criteria were identified in realtime a high percentage of the time during the winter of 2014-15. As noted in the previous section the estimate of snow water increase from seeding is factored according to the percent of time that criteria are met. As indicated above the seedability factor (SF) was computed to be 0.92. Our original proposal indicates that the expected benefit from cloud seeding is an increase in the precipitation rate of 0.25 mm per hour (~0.01 inch per hour). 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 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. For simplicity (and because all the parameters affecting area cannot be precisely evaluated) the area is taken as a constant.

Following previous years, 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 = 681.35 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 (0.92). 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 2014-15 winter season the estimated snow water increase from seeding is:

W_s = 681.35 h x 0.25 mm/h x 0.00328 ft/mm x 35 sq mi x 640 acres/sq mi x 0.92

$W_s \approx$ 11,513 acre-feet.

A comparison of seeding operations in the current water year with those from 18 prior years is shown in Fig. 12. The comparison includes Nevada state-funded program water years 1998 to 2009, and the years of TRF and TMWA/WRWC sponsorship. 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 the lower number of hours during the drier years from 2007 through 2009. However, lower seeding hours can also occur in very wet years like 2000 when seeding was suspended during flooding events. WY2011 is also something of 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 WY2015 snow water augmentation estimate was about 78% of the 16-year average of 14,643 acre-feet.

5. Budget and Expenditures

The project has gone as planned and is on budget. A final expenditures spreadsheet will be submitted to the sponsor in the fourth quarter of WY2015.

Reference

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, and J. G. Powers, 2007: A description of the Advanced Research WRF Version 2. NCAR Tech. Note NCAR/TN-4681STR, 88 pp.

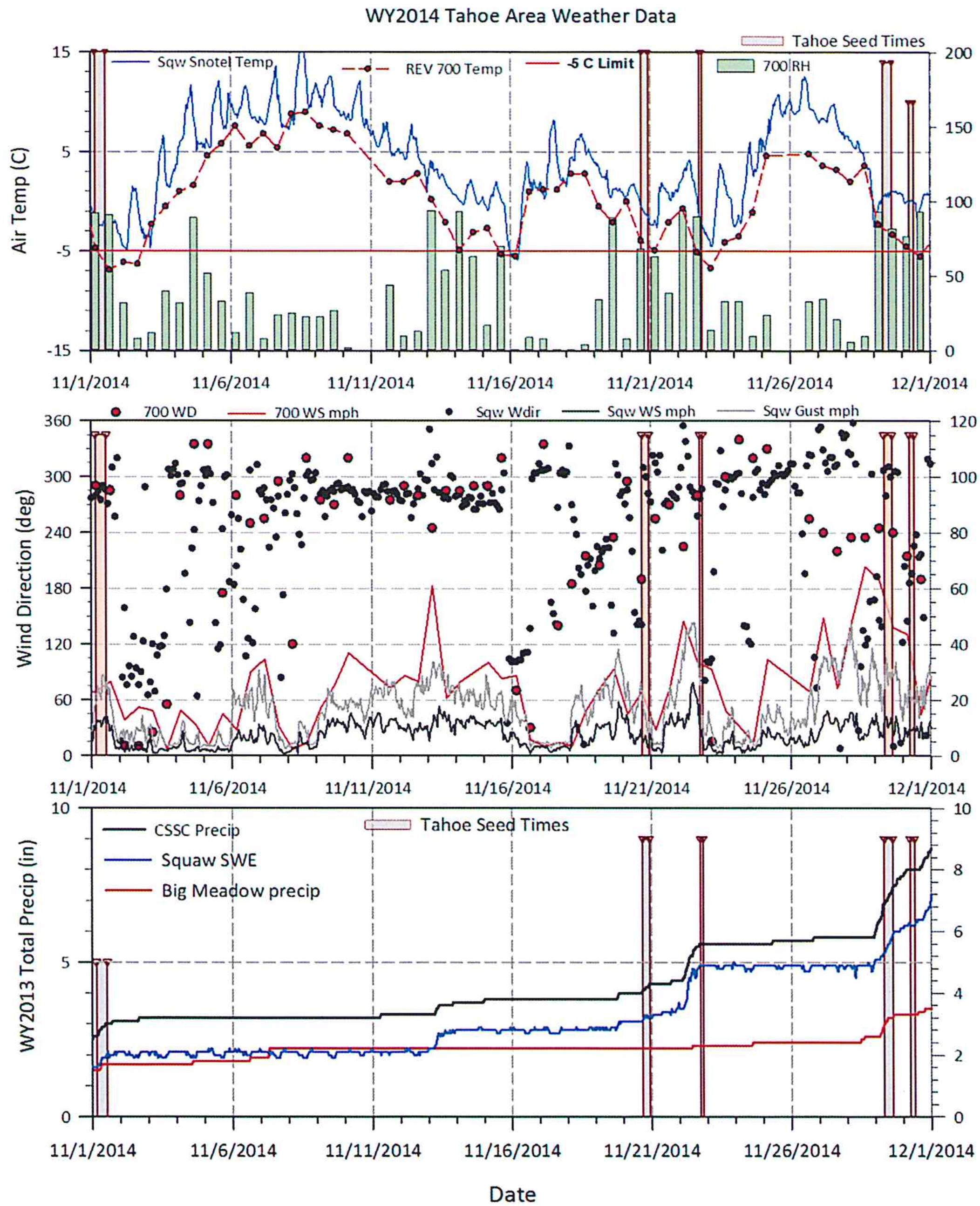

Figure 5. Tahoe area weather data and cloud seeding periods (shaded regions) for November 2014. Top panel shows 700 mb. temperature and relative humidity, and Squaw SNOTEL temperature. Middle panel shows wind data at 700 mb. and Squaw, and bottom panel presents precipitation or SWE accumulation at CSSL, and Squaw and Big Meadow SNOTEL sites.

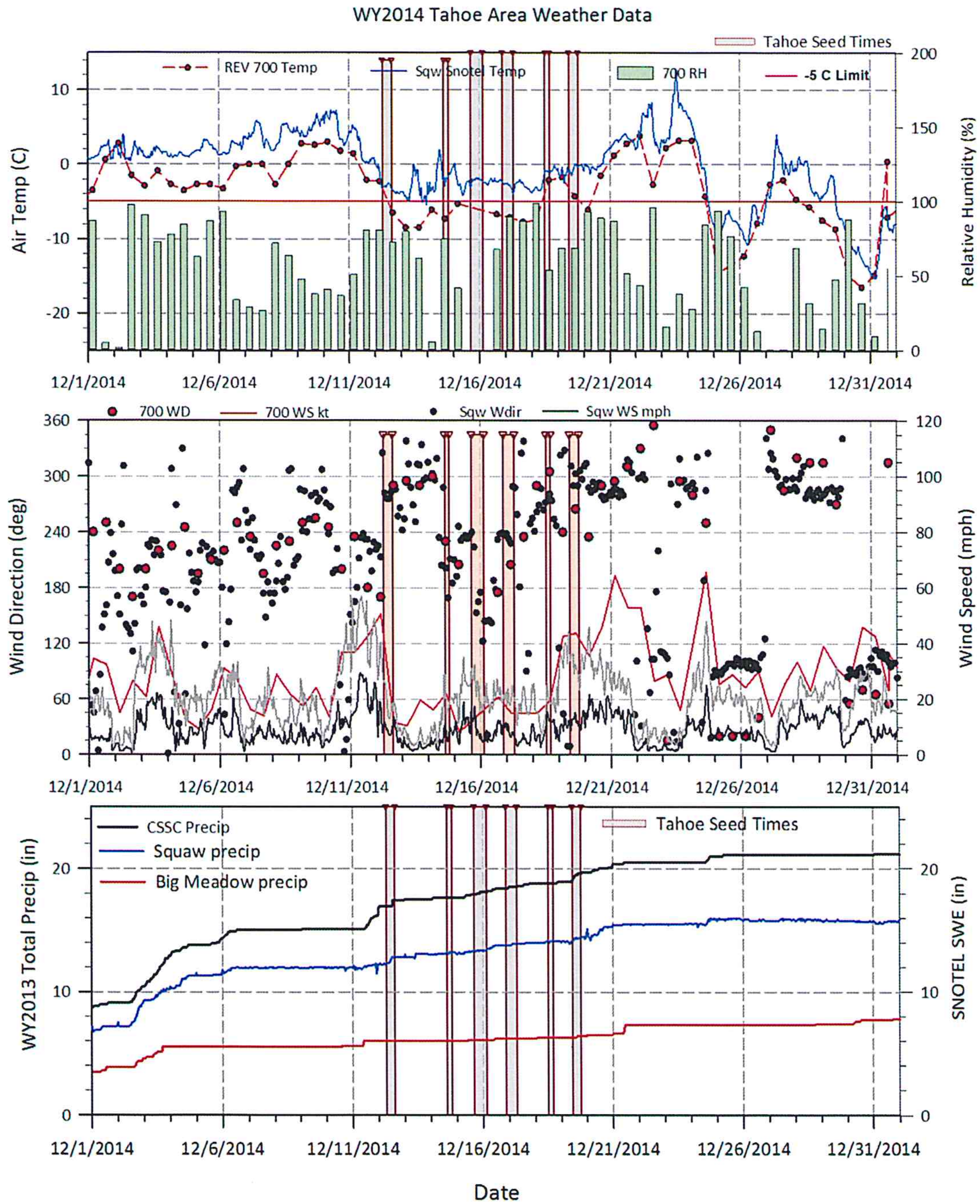

Figure 6. As in figure 5 but for the month of December 2014.

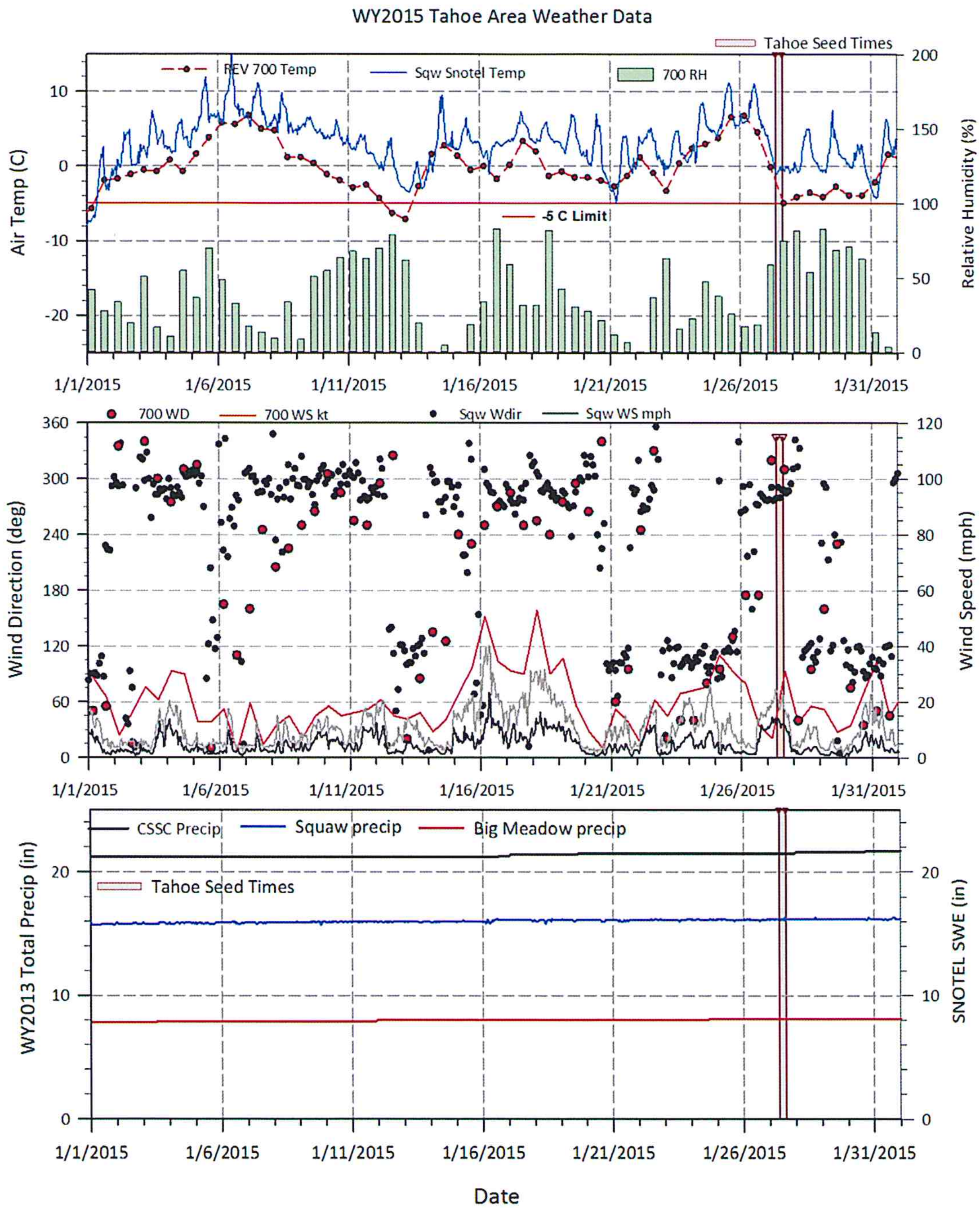

Figure 7. As in figure 5 but for the month of January 2015.

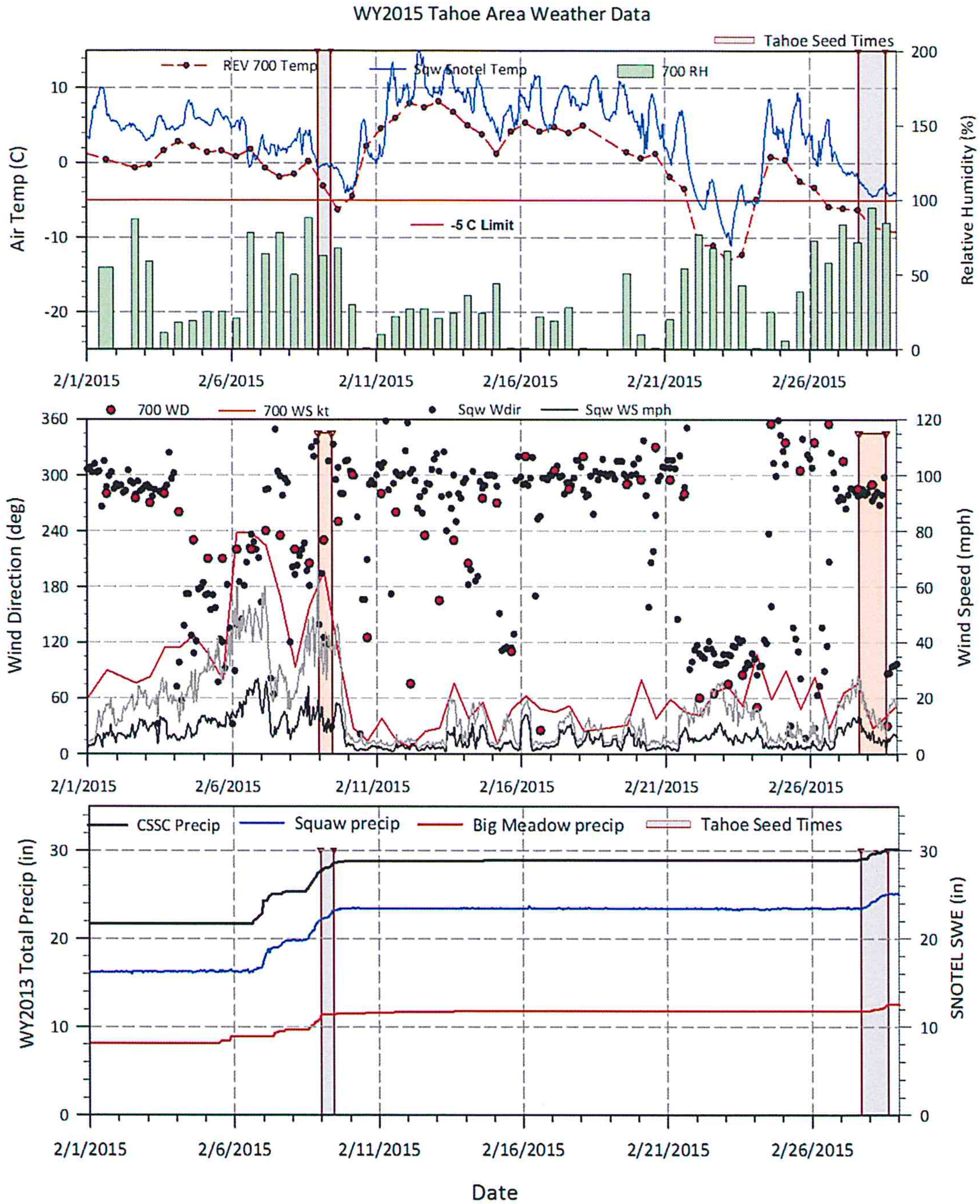

Figure 8. As in figure 5 but for the month of February 2015.

2215 Raggio Parkway, Reno, Nevada 89512-1095
Phone (775) 673-7300 Fax (775) 673-7397

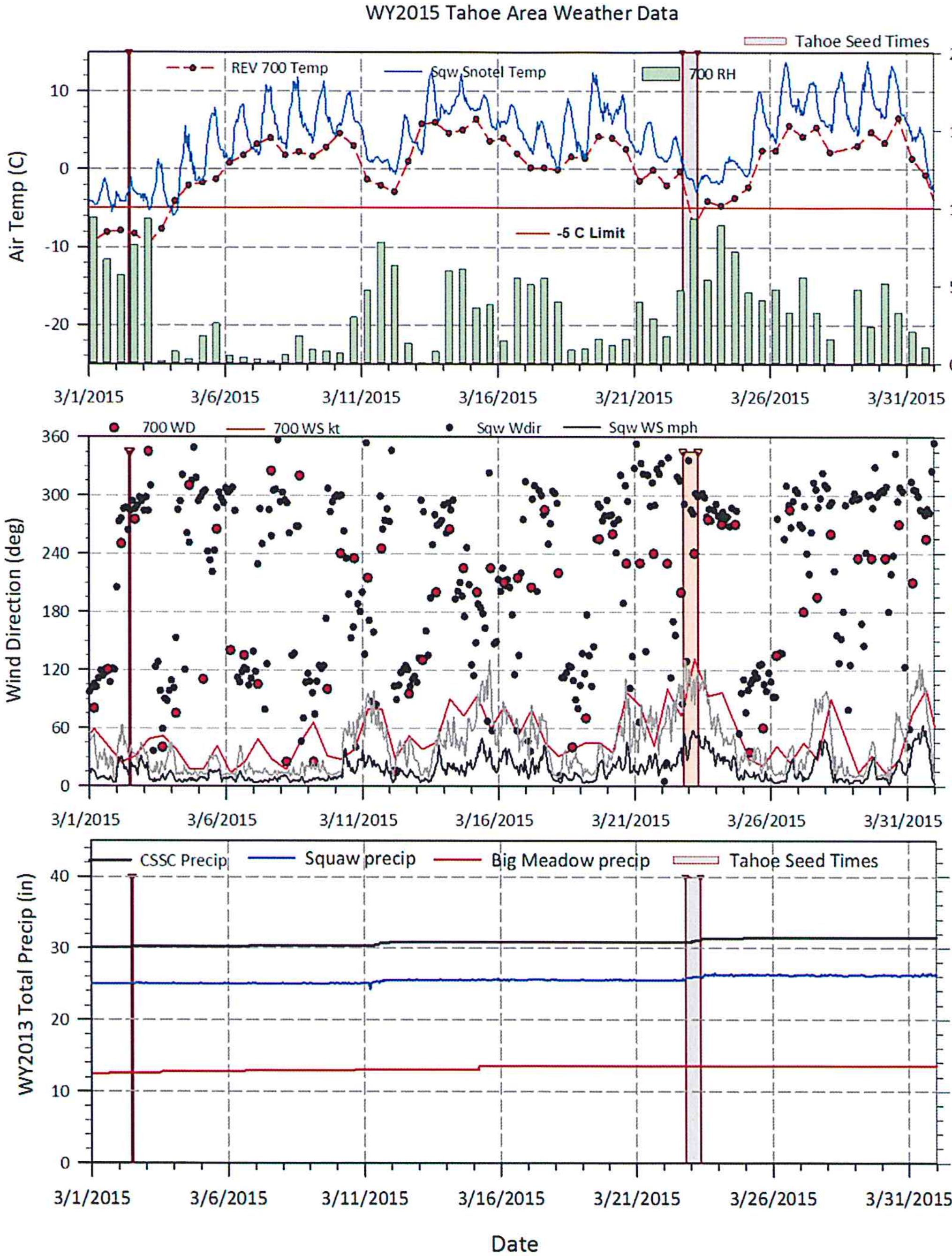

Figure 9. As in figure 5 but for the month of March 2015.

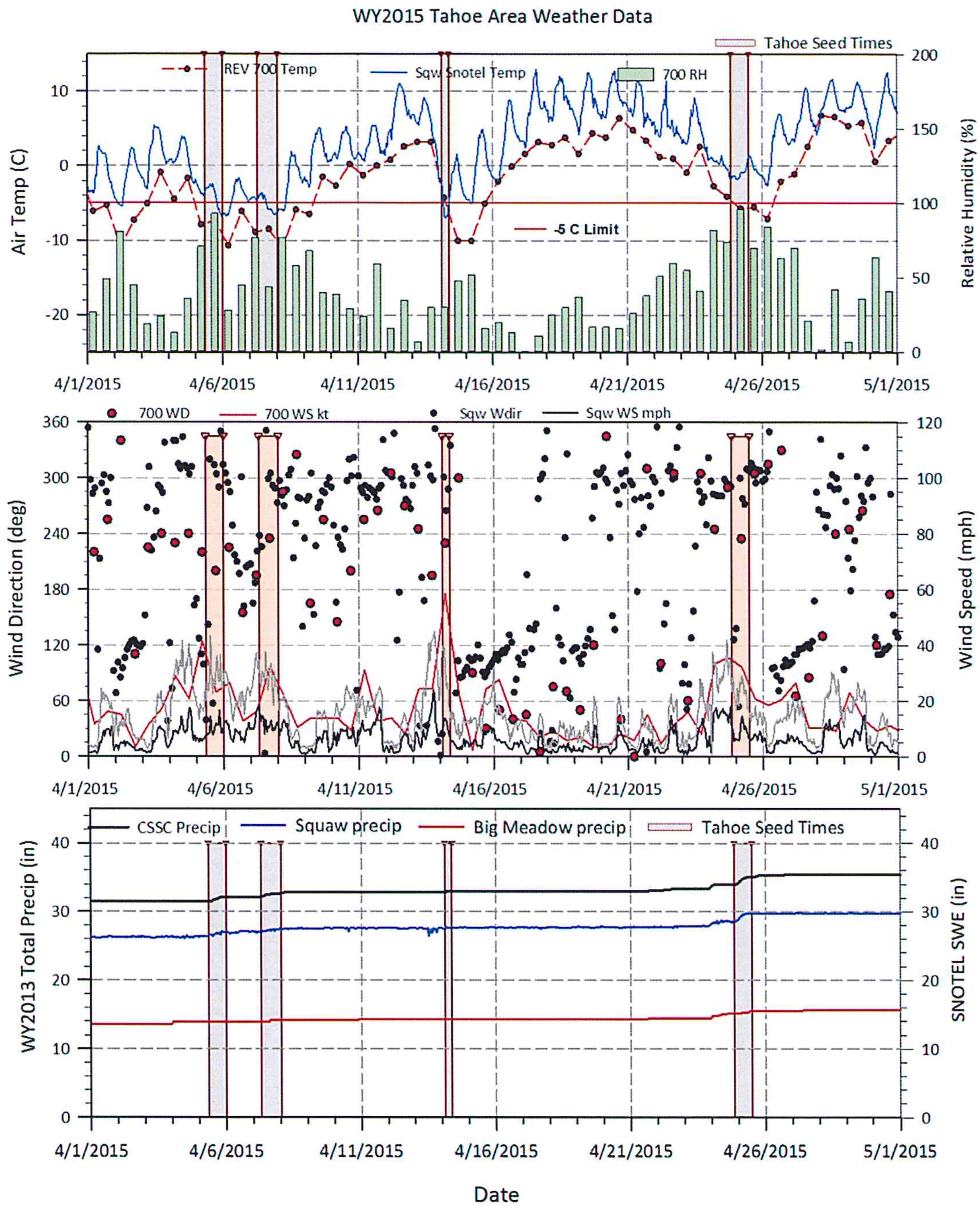

Figure 10. As in figure 5 but for the month of April 2015.

2215 Raggio Parkway, Reno, Nevada 89512-1095
Phone (775) 673-7300 Fax (775) 673-7397

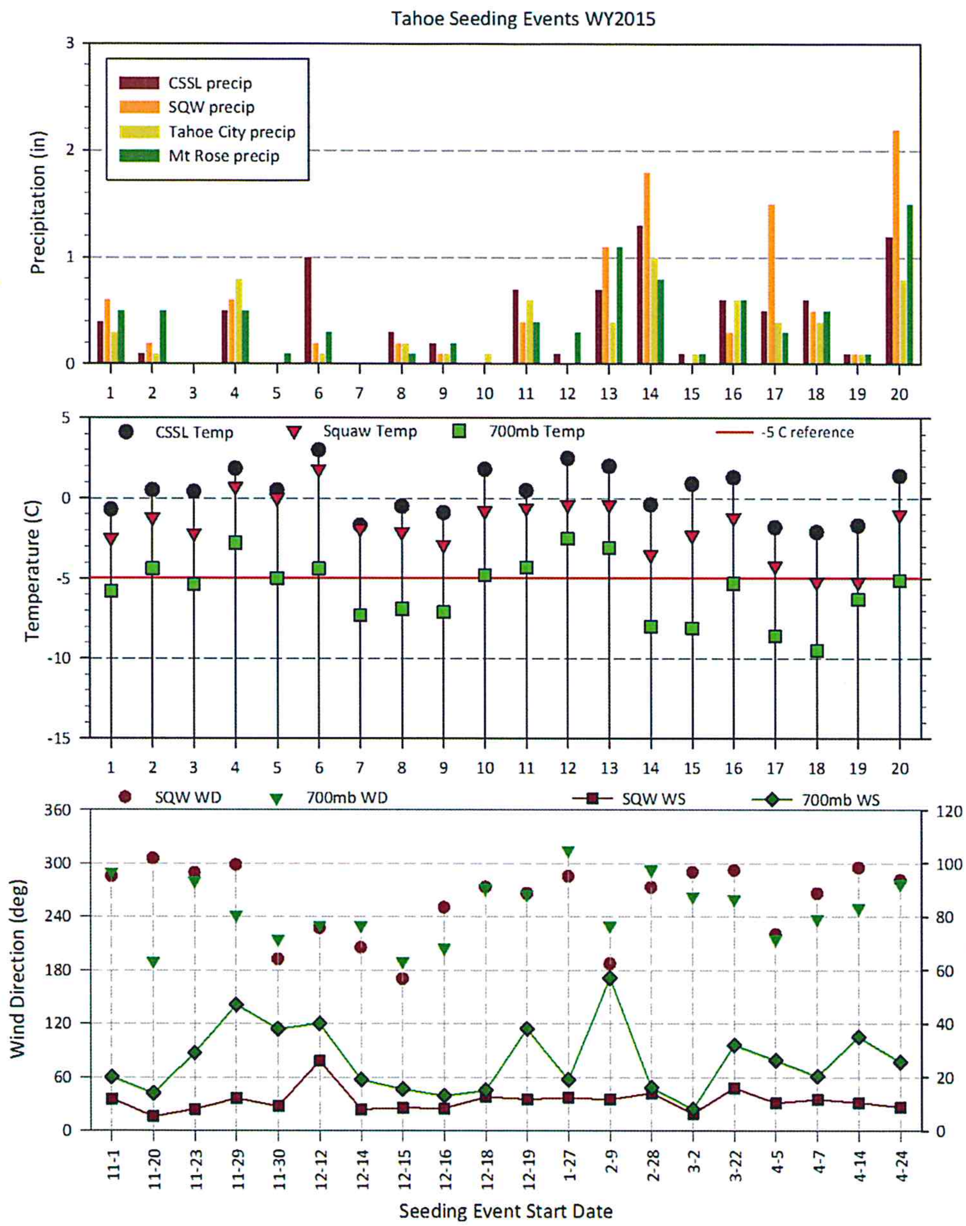

Figure 11. Weather variables for cloud seeding periods in the Tahoe area during November 2014 through May 2015. Top panel shows precipitation accumulation at the Central Sierra Snow Lab (CSSL), Squaw Valley (SQW), Tahoe City, and Mt. Rose SNOTEL sites. Middle panel presents the average temperature at CSSL and the Squaw SNOTEL, and the 700 mb. temperature interpolated to the midpoint of each seeding period. Bottom panel shows the average wind direction and speed at the Squaw SNOTEL, and the midpoint values at 700 mb. The bottom panel scale is annotated with the start date of each seeding period.

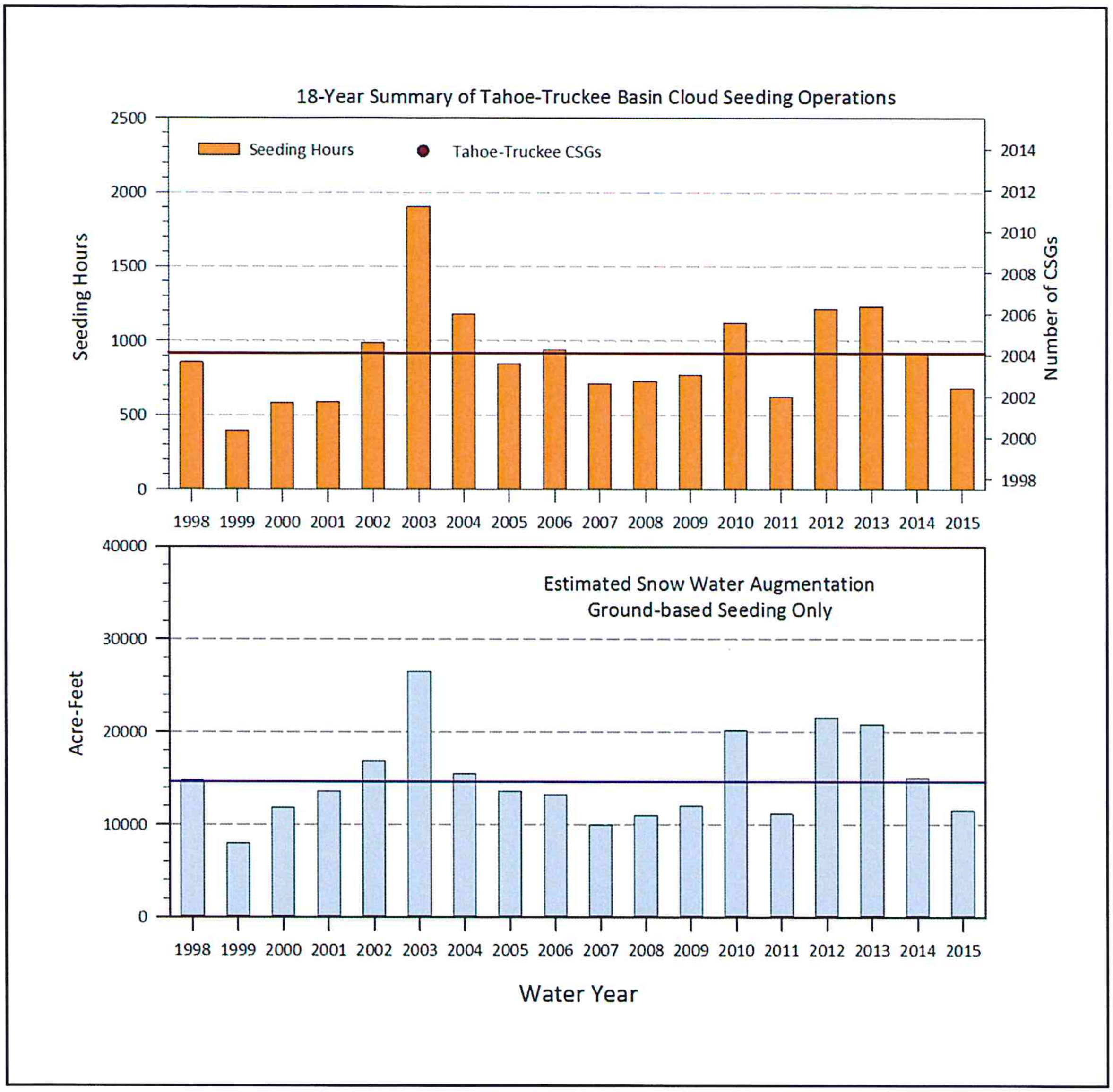

Figure 12. History of cloud seeding hours and snow water augmentation estimates in the Tahoe-Truckee Basin for Water Years 1998 to 2015. The Nevada state-funded project ran from 1998 to 2009. Solid line on each graph represents the 16-year average.

Appendix A. Tahoe Seeding Operations: 1 November 2014 to 14 December 2014

Operation #	Location	Generator	Start Date-Time	TC1	TC2	Flow at On (V)	End Date-Time	TC1	TC2	Flow at Off (V)	Generator Time (hh:mm)	Generator Hours	AgI Release (g)	Event Hours	Event AgI Release (g)	Season Total (hours)	Season Total AgI (g)
1	Barker Pass	6	11/1/14 3:10	890	891	4.070	11/1/14 12:40	821	860	4.050	9:30:00	9.50	295.06				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8	11/1/14 3:10	878	868	3.360	11/1/14 12:40	891	887	3.270	9:30:00	9.50	223.18				
	Bunker Hill	16									0:00:00	0.00	0.00				
	Ward Peak	31	11/1/14 3:19	621	770	3.580	11/1/14 12:40	672	709	3.830	9:21:00	9.35	268.90				
	Morattini	32	11/1/14 3:15	660	868	3.640	11/1/14 11:15	647	776	3.490	8:00:00	8.00	203.69				
	Echo	33	11/1/14 8:51	875	788	3.530	11/1/14 11:35			3.600	2:44:00	2.73	72.42				
													Total	39.08	1063.2	39.08	1063.2
2	Barker Pass	6	11/20/14 20:08	789	838	3.770	11/20/14 22:08	861	876	3.680	2:00:00	2.00	54.53				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16	11/20/14 15:35	822	855	3.600	11/20/14 20:08	265	467	3.610	4:33:00	4.55	120.98				
	Ward Peak	31	11/20/14 16:31	816	868	3.770	11/20/14 22:13	868	863	3.540	5:42:00	5.70	147.78				
	Morattini	32	11/20/14 16:33	856	847	3.410	11/20/14 20:17	816	858	3.400	3:44:00	3.73	91.99				
	Echo	33									0:00:00	0.00	0.00				
													Total	15.98	415.3	55.07	1478.5
3	Barker Pass	6	11/22/14 18:11	793	798	3.670	11/22/14 20:10	846	897	3.480	1:59:00	1.98	50.31				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16	11/22/14 17:44	471	484	3.500	11/22/14 19:23	842	824	3.480	1:39:00	1.65	41.86				
	Ward Peak	31									0:00:00	0.00	0.00				
	Morattini	32	11/22/14 17:47	622	681	3.410	11/22/14 19:23	842	862	3.360	1:36:00	1.60	38.85				
	Echo	33									0:00:00	0.00	0.00				
											0:00	0.00	Total	5.23	131.0	60.30	1609.6
4	Barker Pass	6	11/29/14 7:58	815	849	3.720	11/29/14 14:59	890	870	2.370	7:01:00	7.02	117.87				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16	11/29/14 7:58	680	680	3.450	11/29/14 15:04	879	861	3.460	7:06:00	7.10	178.81				
	Ward Peak	31	11/29/14 11:14	870	840	3.620	11/29/14 14:55	870	839	3.590	3:41:00	3.68	97.23				
	Morattini	32	11/29/14 8:06	765	857	3.400	11/29/14 15:06	835	860	3.490	7:00:00	7.00	178.23				
	Echo	33									0:00:00	0.00	0.00				
													Total	24.80	572.1	85.10	2181.7
5	Barker Pass	6									0:00:00	0.00	0.00				
	Barker Pass	22	11/30/14 5:53	870	850	3.000	11/30/14 8:52	870	850	3.000	2:59:00	2.98	63.41				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16	11/30/14 5:59	756	749	3.520	11/30/14 8:59	756	749	3.520	3:00:00	3.00	77.22				
	Ward Peak	31	11/30/14 6:12	729	657	3.480	11/30/14 8:12	729	657	3.480	2:00:00	2.00	50.74				
	Morattini	32									0:00:00	0.00	0.00				
	Echo	33	11/30/14 6:06	768	629	3.780	11/30/14 9:06	768	629	3.780	3:00:00	3.00	84.76				
													Total	10.98	276.1	96.08	2457.8
6	Barker Pass	6									0:00:00	0.00	0.00				
	Barker Pass	22	12/12/14 6:32	616	618	2.940	12/12/14 9:50	856	970	2.720	3:18:00	3.30	63.17				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16									0:00:00	0.00	0.00				
	Ward Peak	31									0:00:00	0.00	0.00				
	Morattini	32									0:00:00	0.00	0.00				
	Echo	33	12/12/14 7:07	882	852	3.710	12/12/14 15:21	879	717	3.740	8:14:00	8.23	229.35				
													Total	11.53	292.5	107.62	2750.3
7	Barker Pass	6	12/14/14 14:56	887	880	3.650	12/14/14 18:55	800	849	3.460	3:59:00	3.98	100.32				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16	12/14/14 14:51	788	736	3.650	12/14/14 18:58	873	824	3.880	4:07:00	4.12	120.50				
	Ward Peak	31									0:00:00	0.00	0.00				
	Morattini	32	12/14/14 14:59	705	846	3.650	12/14/14 18:57	799	800	3.610	3:58:00	3.97	105.47				
	Echo	33	12/14/14 14:54	849	718	3.740	12/14/14 18:52	813	868	3.610	3:58:00	3.97	105.47				
													Total	16.03	431.8	123.65	3182.1

Appendix A. Tahoe Seeding Operations: 15 December 2014 to 28 February 2015

Operation #	Location	Generator	Start Date-Time	TC1	TC2	Flow at On (V)	End Date-Time	TC1	TC2	Flow at Off (V)	Generator Time (hh:mm)	Generator Hours	Agl Release (g)	Event Hours	Event Agl Release (g)	Season Total (hours)	Season Total Agl (g)
8	Barker Pass	6	12/15/14 6:20	880	883	2.710	12/15/14 11:00	911	880	3.570	4:40:00	4.67	122.31				
	Barker Pass	6	12/15/14 15:35	900	907	2.870	12/16/14 3:00	899	889	2.760	11:25:00	11.42	221.84				
	Ward Peak	31	12/15/14 6:13	634	624	3.650	12/15/14 11:00	748	732	3.530	4:47:00	4.78	123.57				
	Ward Peak	31	12/15/14 15:30	769	787	3.510	12/16/14 3:00	737	699	3.440	11:30:00	11.50	287.52				
	Morattini	32									0:00:00	0.00	0.00				
	Echo	33	12/15/14 4:18	846	709	3.530	12/15/14 11:00	911	880	2.840	6:42:00	6.70	134.15				
	Echo	33	12/15/14 15:35	863	720	3.530	12/16/14 1:00	858	816	3.530	9:25:00	9.42	243.26				
													Total	48.48	1132.6	172.13	4314.7
9	Barker Pass	6	12/16/14 21:43	878	859	2.790	12/17/14 7:17	891	874	2.530	9:34:00	9.57	170.56				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16									0:00:00	0.00	0.00				
	Ward Peak	31	12/16/14 21:41	732	757	3.590	12/17/14 7:17	783	601	3.450	9:36:00	9.60	240.90				
	Morattini	32									0:00:00	0.00	0.00				
	Echo	33	12/16/14 21:43	871	786	3.530	12/17/14 7:18	879	744	3.530	9:35:00	9.58	247.56				
													Total	28.75	659.0	200.88	4973.8
10	Barker Pass	6	12/18/14 12:10	843	868	2.600	12/18/14 16:31	870	868	2.730	4:21:00	4.35	83.58				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16	12/18/14 12:08	814	822	3.780	12/18/14 15:08	814	822	3.780	3:00:00	3.00	84.76				
	Ward Peak	31	12/18/14 12:04	693	513	3.600	12/18/14 16:27	889	874	3.600	4:23:00	4.38	116.13				
	Morattini	32	12/18/14 12:06	607	813	3.470	12/18/14 15:06	607	813	3.470	3:00:00	3.00	75.83				
	Echo	33	12/18/14 12:02	780	561	3.360	12/18/14 15:06	780	561	3.360	3:04:00	3.07	74.46				
													Total	17.80	434.8	218.68	5408.53
11	Barker Pass	6	12/19/14 10:19	813	822	3.750	12/19/14 18:39	880	902	2.530	8:20:00	8.33	148.57				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16									0:00:00	0.00	0.00				
	Ward Peak	31	12/19/14 10:13	761	733	3.660	12/19/14 18:43	813	662	3.630	8:30:00	8.50	227.64				
	Morattini	32									0:00:00	0.00	0.00				
	Echo	33	12/19/14 10:15	772	682	3.580	12/19/14 18:42	871	715	3.680	8:27:00	8.45	230.39				
													Total	25.28	606.6	243.97	6015.1
12	Barker Pass	6	1/27/15 10:40	841	900	2.540	1/27/15 14:27	858	878	3.660	3:47:00	3.78	102.42				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8	1/27/15 8:20	840	839	3.400	1/27/15 14:28	791	870	2.290	6:08:00	6.13	100.03				
	Bunker Hill	16									0:00:00	0.00	0.00				
	Ward Peak	31	1/27/15 10:40	794	818	3.720	1/27/15 14:25	829	846	3.820	3:45:00	3.75	107.47				
	Morattini	32	1/27/15 8:20	843	883	3.580	1/27/15 14:26	898	887	3.850	6:06:00	6.10	176.67				
	Echo	33	1/27/15 10:40	768	689	3.100	1/27/15 14:29	799	689	3.100	3:49:00	3.82	84.20				
													Total	23.58	570.8	267.55	6585.9
13	Barker Pass	6	2/8/15 23:56				2/8/15 23:56				0:00:00	0.00					
	Barker Pass	22	2/8/15 23:56	865	835	3.800	2/9/15 5:34	811	821	3.600	5:38:00	5.63	149.25				
	Bunker Hill	8															
	Bunker Hill	16	2/8/15 23:37	741	778	3.680	2/9/15 5:30	786	827	3.670	5:53:00	5.88	159.84				
	Ward Peak	31	2/8/15 23:58	850	790	3.810	2/9/15 5:30	823	841	3.820	5:32:00	5.53	158.57				
	Morattini	32	2/8/15 23:30	730	856	3.500	2/9/15 5:30	710	872	3.500	6:00:00	6.00	153.32				
	Echo	33															
													Total	23.05	621.0	290.60	7206.9
14	Barker Pass	6	2/27/15 22:40	902	895	1.510	2/28/15 15:05	875	884	1.590	16:25:00	16.42	209.49				
	Barker Pass	22	2/27/15 16:56	893	890	3.390	2/27/15 22:36	893	890	3.390	5:40:00	5.67	139.12				
	Bunker Hill	8	2/27/15 16:59	805	778	2.950	2/28/15 15:05	847	840	3.160	22:06:00	22.10	498.52				
	Bunker Hill	16															
	Ward Peak	31	2/27/15 16:58	814	803	3.800	2/28/15 15:05	818	768	3.820	22:07:00	22.12	633.81				
	Morattini	32	2/27/15 16:52	833	849	3.580	2/28/15 15:05	824	848	3.580	22:13:00	22.22	584.38				
	Echo	33	2/27/15 17:02	833	849	3.510	2/28/15 15:05	779	691	3.840	22:03:00	22.05	636.38				
													Total	110.57	2701.7	401.17	9908.6

Appendix A. Tahoe Seeding Operations: 1 March to 25 May 2015

Operation #	Location	Generator	Start Date-Time	TC1	TC2	Flow at On (V)	End Date-Time	TC1	TC2	Flow at Off (V)	Generator Time (hh:mm)	Generator Hours	Agl Release (g)	Event Hours	Event Agl Release (g)	Season Total (hours)	Season Total Agl (g)
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16															
	Ward Peak	31	3/2/15 10:53	775	766	3.800	3/2/15 12:16	788	761	3.820	1:23:00	1.38	39.64				
	Morattini	32									0:00:00	0.00	0.00				
	Echo	33	3/2/15 10:55	632	393	3.410	3/2/15 12:16	771	674	3.810	1:21:00	1.35	38.55				
													Total	2.73	78.2	403.90	9986.8
16	Barker Pass	6									0:00:00	0.00	0.00				
	Barker Pass	22	3/22/15 22:26	884	867	3.760	3/23/15 8:27	692	824	3.770	10:01:00	10.02	282.01				
	Bunker Hill	8	3/22/15 19:00	817	753	1.240	3/23/15 8:29	810	746	1.220	13:29:00	13.48	153.97				
	Bunker Hill	16															
	Ward Peak	31	3/22/15 22:27	685	825	3.820	3/23/15 8:31	800	813	3.800	10:04:00	10.07	286.45				
	Morattini	32	3/22/15 19:05	800	867	3.480	3/23/15 8:31	775	836	3.310	13:26:00	13.43	320.26				
	Echo	33	3/22/15 22:28	767	638	3.820	3/23/15 8:31	777	677	3.770	10:03:00	10.05	282.95				
													Total	57.05	1325.6	460.95	11312.5
17	Barker Pass	6									0:00:00	0.00	0.00				
	Barker Pass	22	4/5/15 8:10	840	860	3.820	4/6/15 0:00	673	778	3.780	15:50:00	15.83	447.36				
	Bunker Hill	8	4/5/15 8:15	710	750	2.760	4/6/15 0:00	756	756	2.960	15:45:00	15.75	329.81				
	Bunker Hill	16															
	Ward Peak	31	4/5/15 8:10	679	738	3.820	4/6/15 0:00	697	805	3.800	15:50:00	15.83	450.55				
	Morattini	32	4/5/15 8:15	800	866	3.520	4/6/15 0:00	790	870	3.480	15:45:00	15.75	399.56				
	Echo	33	4/5/15 16:25	775	590	3.780	4/6/15 0:00	792	685	3.760	7:35:00	7.58	212.75				
													Total	70.75	1840.0	531.70	13152.5
18	Barker Pass	6									0:00:00	0.00	0.00				
	Barker Pass	22	4/7/15 7:07	673	824	3.820	4/7/15 19:51	673	778	3.780	12:44:00	12.73	359.78				
	Barker Pass	22	4/7/15 22:36	670	763	3.800	4/8/15 0:36	670	763	3.800	2:00:00	2.00	56.91				
	Bunker Hill	8										0.00	0.00				
	Bunker Hill	16	4/7/15 7:07	875	866	3.550	4/7/15 19:53	914	914	3.510	12:46:00	12.77	327.42				
	Bunker Hill	16	4/7/15 22:36	871	900	3.470	4/8/15 0:36	871	900	3.460	2:00:00	2.00	50.37				
	Ward Peak	31	4/7/15 7:07	679	738	3.820	4/7/15 19:54	620	660	3.800	12:47:00	12.78	363.76				
	Ward Peak	31	4/7/15 22:36	626	640	3.780	4/8/15 0:36	626	640	3.780	2:00:00	2.00	56.51				
	Morattini	32	4/7/15 7:10	822	852	3.540	4/7/15 19:54	752	786	3.480	12:44:00	12.73	323.03				
	Morattini	32	4/7/15 22:36	794	831	3.490	4/8/15 0:36	794	831	3.490	2:00:00	2.00	50.92				
	Echo	33	4/7/15 7:12	793	694	3.780	4/7/15 19:57	793	684	3.780	12:45:00	12.75	360.25				
	Echo	33	4/7/15 22:36	806	619	3.810	4/8/15 0:36	806	619	3.810	2:00:00	2.00	57.11				
													Total	73.77	1261.9	605.47	14414.4
19	Barker Pass	6	4/14/15 2:23	874	877	3.900	4/14/15 8:56	777	827	3.800	6:33:00	6.55	186.38				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8	4/14/15 2:27	774	716	2.540	4/14/15 8:56	710	721	3.160	6:29:00	6.48	146.25				
	Bunker Hill	16															
	Ward Peak	31	4/14/15 2:27	679	738	3.820	4/14/15 6:00	697	805	3.800	3:33:00	3.55	101.02				
	Morattini	32	4/14/15 2:29	775	850	3.490	4/14/15 9:00	754	820	3.460	6:31:00	6.52	164.12				
	Echo	33	4/14/15 2:29	800	651	3.820	4/14/15 9:02	818	672	3.800	6:33:00	6.55	186.38				
													Total	29.65	784.2	635.12	15198.6
20	Barker Pass	6	4/24/15 21:51	846	838	3.770	4/25/15 12:09	809	771	3.840	14:18:00	14.30	412.71				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8															
	Bunker Hill	16	4/24/15 20:19	766	742	3.660	4/25/15 12:08	878	879	3.510	15:49:00						
	Ward Peak	31	4/24/15 21:56	419	711	5.030	4/24/15 23:58	42	641	5.030	2:02:00	2.03	87.21				
	Morattini	32	4/24/15 20:19	842	858	3.580	4/25/15 12:07	823	846	3.620	15:48:00	15.80	421.63				
	Echo	33	4/24/15 21:59	737	630	3.860	4/25/15 12:05	809	771	3.840	14:06:00	14.10	406.94				
													Total	46.23	1328.5	681.35	16527.1

Cloud Seeding Operations and Research in the Walker River Basin to Increase Water Delivery to Walker Lake

Grant Agreement between Bureau of Reclamation and the Desert Research Institute

Agreement Number: R10AP20105

Start Date: 1 July 2010 End Date: 30 September 2016

Semi-annual Progress Report for the Period: 1 April 2015 – 30 September 2015
Submitted by: Frank McDonough, Project Manager

Submitted to: Caryn Huntt-DeCarlo, Bureau of Reclamation, Lahontan District

1. Introduction

Since the project is focused on wintertime cloud seeding, the project work tasks are broken into three phases that are roughly coincident with a water year (1 October through 30 September). Phase 1 work, which involves field preparation, had a start date of 15 August 2015 and had a completion date of 26 September 2015 for the 6th year of the project.

2. Completion of Phase 2 Work in WY2015

Phase 2 for Water Year 2015 (WY2015), covering the work related to actual seeding operations, forecasting for operations, and real time monitoring of weather conditions, began on schedule on 1 November 2014. The previous DRI semi-annual report, covering the period 1 October 2014 through 31 March 2015 described seeding operations (ground-based and aircraft) and weather conditions during those seeding operations that occurred through the end of March 2015. As noted in this previous report, the winter of WY2015 was quite warm and dry and there were very few seeding opportunities. Most aircraft and ground seeding occurred later in the winter, in February and April 2015. The aircraft-seeding portion of the project was reduced from previous years and was completed on 12 March 2015 with a meager total of only 4 seeding missions. Most of the Phase 2 work was presented in the report delivered on 30 April 2015. The remainder of this report describes the work accomplished in Phase 3, and the preparatory work in Phase 1 for WY2016.

For reference throughout the report the Walker River Basin project area, equipment locations and aircraft seeding flight tracks are shown on the map in Figure 1. This area is includes the parts of the eastern slopes of the central Sierra Nevada Mountains, the Sweetwater Mountains, and the Pine Grove Hills.

Figure 2 shows snow water equivalent (SWE) traces for two Walker Basin SNOTEL sites for the period 1 October 2014 through 28 May 2015. The Leavitt Lake site at 9.600 ft. elevation along the Sierra Nevada crest (see Fig. 1) recorded its peak SWE (27.8 in.) on 13 April 2015. This maximum was nearly 35 inches less than the long-term (30-yr) average maximum SWE. Lobdell Lake, further east at 9,300 ft. elevation in the Sweetwater Range, had its maximum SWE (only 5.3 in.) in late-February. This maximum was about 32% of its average maximum. These observations show the continuing 4-year drought conditions in the Walker Basin this winter, especially in the lower elevations.

The trend in percent of average SWE for the other equal elevation sites in the Walker Basin (9,300-ft) is shown in Figure 3. It is obvious that the seeding suspension limit for SWE was never an issue for WY2015. The basin's percentage of median SWE remained below 50% for the entire winter season. Figure 3 also indicates that the interior of the basin, as represented by the Lobdell site, had a lower percent of average SWE early in the season than the western basin, but more precipitation (relative to the western basin) occurred in the interior the basin in the mid season. Overall the well below normal SWE accumulations again suggested that water supply in the Walker Basin would be once again be relatively poor during the summer of 2015.

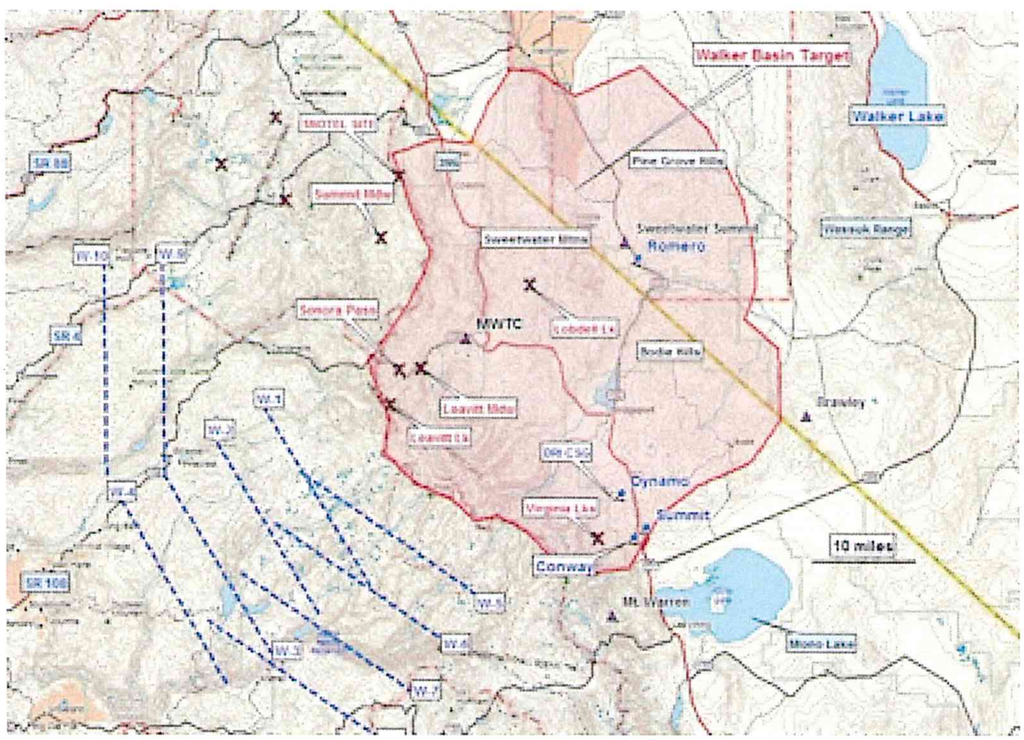

Figure 1. Map of a portion of California and Nevada showing the primary Walker Basin cloud seeding target area (red shaded region), ground-based seeding generator sites (blue pins), NRCS automated snowfall measurements (red Xs), potential aircraft seeding flight tracks (blue dashed lines) and other various landmarks in and around the Walker Basin

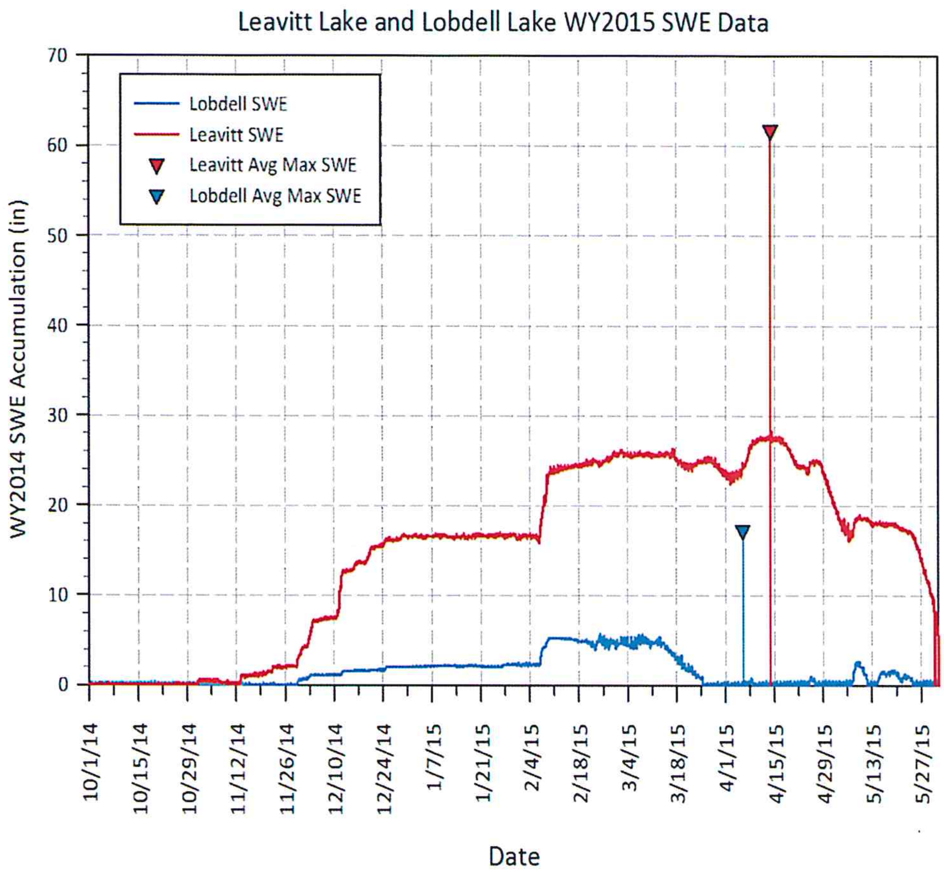

Figure 2. WY2015 Cumulative Snow Water Equivalent (SWE; inches) October 2014 through late May 2015 for Lobdell (9,300 ft.) blue trace; and Leavitt (9,600 ft.) red trace. 30-year average yearly SWE maximum for each site is represented by the blue (Lobdell) and red (Leavitt) triangles.

There were three seeding events in April (Fig. 4) and no ground seeding events in May. That completed the Phase 2 activity for WY2015 (Fig. 5). The lack of seeding activity over much of the winter was mostly due to infrequent storm activity and anomalously warm temperatures, as discussed in the previous semi-annual report.

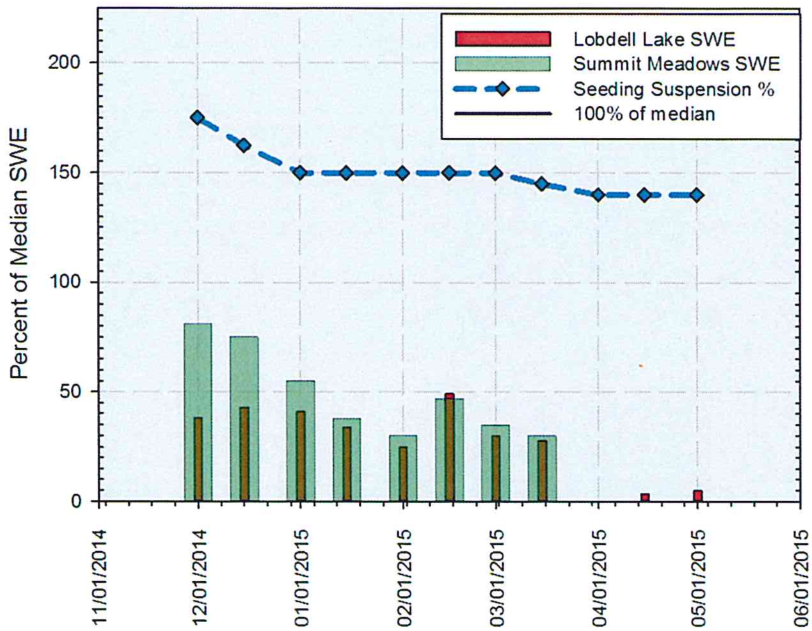

Figure 3. History of percent of SWE for Walker Basin for WY2015 from early November 2014 through late May 2015. Green bars represent the west side of the basin near the Sierra Crest at 9,300-ft and the red bar represents the Sweetwater range to the east, also at 9,300-ft. The blue dashed line indicates the percentage limit for suspending cloud seeding operations.

3. Summary of Phase 3 Work in Year 5

Phase 3 involves the analysis of weather data during seeding events in order to estimate snowfall enhancement from seeding operations. Much of this work was actually reported on in the previous semi-annual report. Additional weather data analysis was accomplished during this reporting period in order to complete the estimation of snowfall enhancement for the 2014-15 winter season.

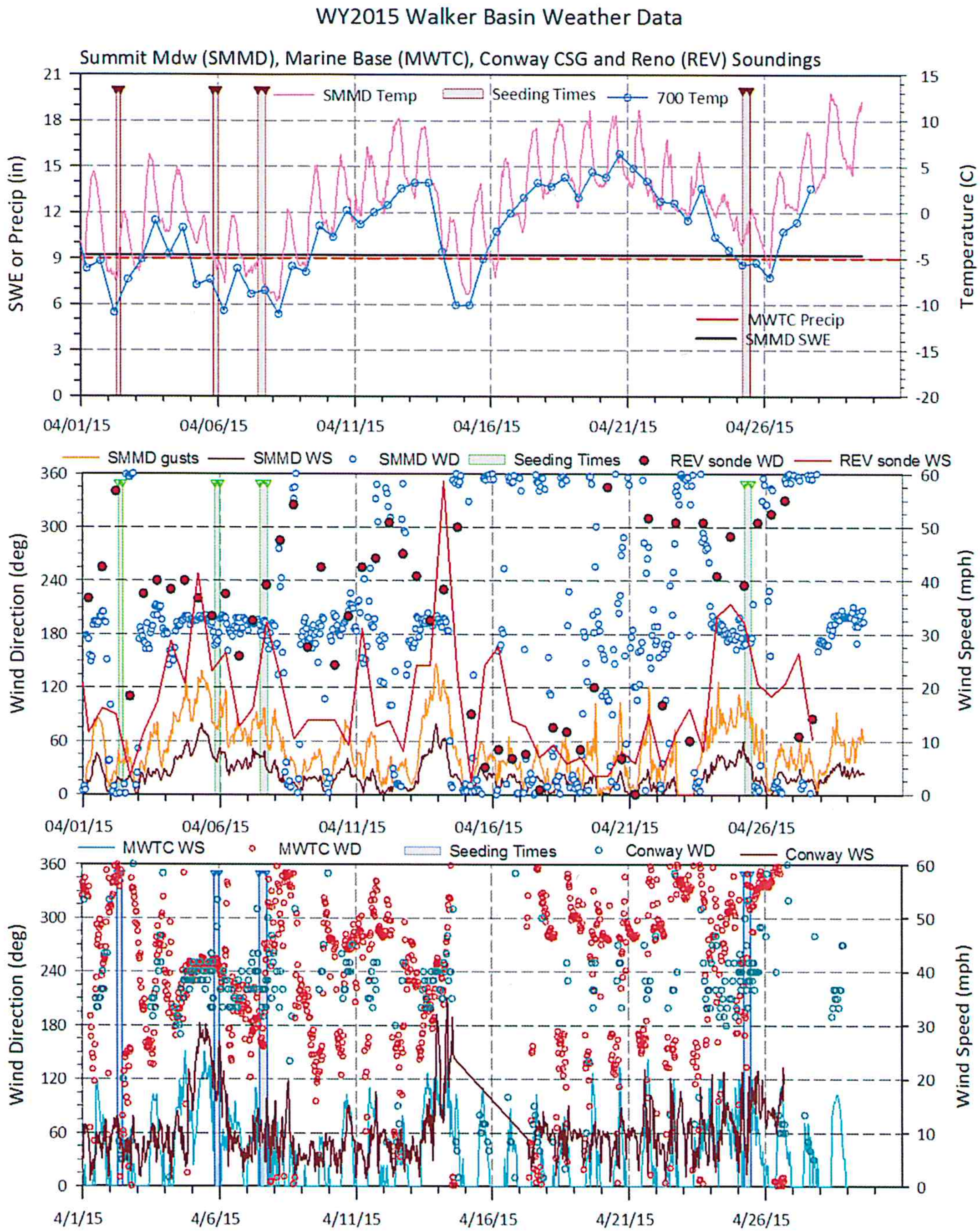

Figure 4. Meteorological data for the four seeding events April 2015 from sites in the Walker Basin and from the 700 mb pressure level of the Reno upper air sounding. Data are as identified in the legends.

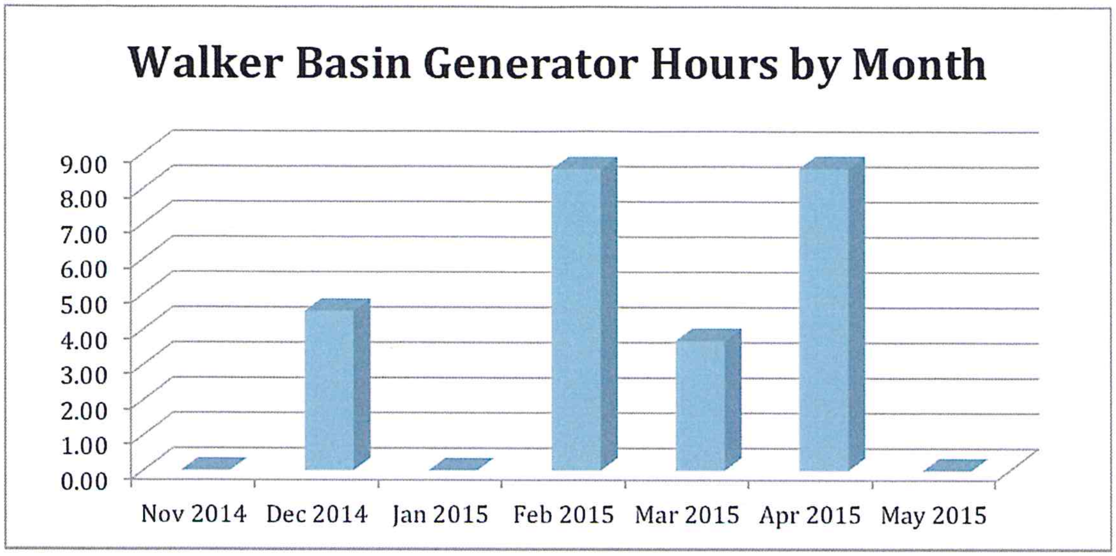

Figure 5. Total ground generator seeding hours by month in the Walker Basin.

All Phase 2 ground and aircraft seeding events are documented in Appendix A. Figure 6 summarizes the meteorological variables used as Walker Basin seeding criteria for all ground-based WY2015 seeding events. The temperature criterion for ground seeding requires that either mountain top temperature or the 700 mb temperature is ≤-5°C, the activation temperature for silver iodide (AgI). Figure 6 indicates that this criterion was satisfied for all ground seeding events except perhaps event 9 (the Reno 700mb temperatures were colder than -5°C). Depending on the specific seeding location, the wind direction criterion varies from northeast to east at the Romero site and southeast clockwise through northwest at the other sites. Figure 6 shows this criterion was met for nearly all (except perhaps event 6) of the seeding events. The observation of precipitation at the SNOTELs is desirable (but not mandatory) for seeding to occur, and Figure 6 indicates that precipitation or SWE was recorded at the two selected SNOTEL sites on 7 of 9 ground-based seeding events. Other meteorological evidence, such as cloud base heights, radar echo coverage or satellite cloud coverage, was used to initiate seeding during the other cases.

WY2015 Snow Water Augmentation Estimates

Estimates of snowfall enhancement over specific areas of the Walker Basin are needed as input to the hydrologic model that will be used to estimate the impact of cloud seeding on stream flow in the Walker River and into Walker Lake. Three surface observation sites were used to quantify precipitation that occurred during seeding periods over three mountainous regions; the Walker River headwater region in the Sierra Nevada, the Sweetwater Mountains, and the Pine Grove Hills. The Summit Meadows SNOTEL site was used to represent precipitation over the Sierra Nevada, and the Lobdell Lake SNOTEL was used to represent the Sweetwater Mountains. The Pine Grove Hills had no representative precipitation site, so the Lobdell SNOTEL data was adjusted downward, using percentages derived from work in previous years, to estimate snow water content in this region. The data in Table 1 provide one method of estimating the impact of seeding on the Walker Basin. Assuming the SWE observed during seeding events includes the enhancement from seeding, then with a 10% effect the enhanced portion of SWE would be 0.13 in, 0.17 in, and 0.04 in, respectively, for the three target areas. Relative to the maximum SWE observed in each region, the percentage increase in SWE from seeding would be 1.5% (Sierra Nevada), 3.2% (Sweetwater Mountains) and 3.3% (Pine Grove Hills). The estimated SWE increases are smaller overall than WY2014, WY2013, WY2012, and still much less than in WY2011. For the hydrologic modeling part of Phase 3 the absolute amounts of SWE estimated here will be used to predict the impact of seeding on streamflow.

Table 1. Estimated SWE totals during seeding periods for three regions in the Walker Basin

Target Area	SWE during seeding (in)	Max SWE over target (in)	% of Max SWE
Sierra Nevada	1.3	8.5	15.3
Sweetwater	1.7	5.4	31.4
Pine Grove	0.4	1.1	36.3

Another method used to assess the impact of ground seeding involves using the actual seeding hours and an assumed nominal increase in precipitation rate based on prior research results. This method was used to estimate snow water enhancement for operational seeding in the Walker Basin during years when the project was funded by the State of Nevada, and was also used in previous semi-annual reports to estimate snow water enhancement in the Walker Basin. The analysis of weather events and seeding criteria in the current and previous semi-annual reports indicated that the standard seeding criteria were satisfied 89% of the time during ground seeding events in WY2015. There was one event with temperatures warmer than standard seeding criteria but embedded convection may have occurred within that winter storm. This was characterized by warmer 700 mb temperatures but lower 700 - 600 mb stability than is usually the case for seeded storms. Examination of composite radar reflectivities (not shown) during these events suggested a degree of precipitation enhancement as exhibited by local increases in radar reflectivity over the mountain regions. However, due to the significant distance the Walker Basin lies from the Reno radar, a more thorough analysis is needed to determine if this enhancement occurred in a suitable portion of the cloud to indicate a positive seeding effect. One event had marginal winds.

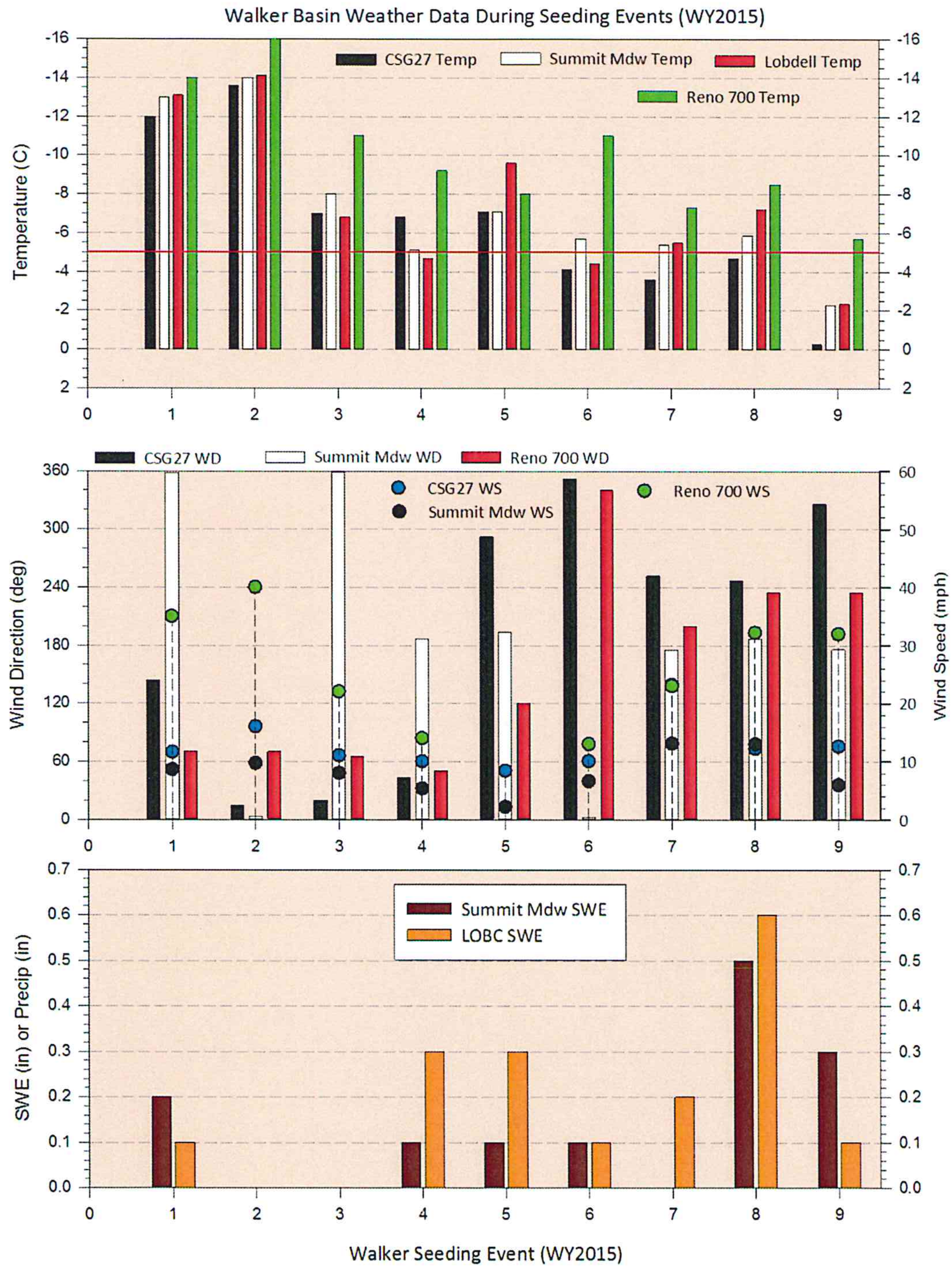

Figure 6. Meteorological variables used as seeding criteria for the Walker Basin Project. Top panel: Average temperature at three surface sites and 700 mb from the Reno sounding. Middle panel: Wind direction and speed at the Summit Meadow SNOTEL and at 700 mb from the Reno sounding. Bottom panel: Precipitation or SWE observed at Summit Meadows and Lobdell Lake SNOTEL.

The estimate of snow water increase from seeding is factored according to the percent of time that criteria are met. As suggested above, the seedability factor (SF) is considered to be 0.89. An estimate of the effect of seeding is taken as a precipitation rate increase of 0.25 mm per hour (~0.01 inch per hour). Past research studies (Huggins, 2009; Reynolds, 1988; and Super, 1996) have shown this to be a reasonable rate increase for wintertime ground-based seeding. Also, 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 area affected by one seeding generator is approximately 35 square miles. This area of effect will vary as cloud conditions and wind speeds vary, and also can change as the dimension of the mountain barrier along the wind direction changes, but for simplicity (and because all the parameters affecting area cannot be precisely evaluated) the area is taken as a constant.

An estimate of the amount of snow water produced by seeding (W_s) is provided by multiplying the total time of generator operation (T_s = 64.15 hours from Table A2) 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 also needed:

0.25 mm = 0.00328 ft.

1 sq. mile = 640 acres.

So, for the 2014-15 winter season the estimated snow water increase from ground-based seeding is:

W_s = 64.15 h x 0.25 mm/h x 0.00328 ft. /mm x 35 sq. mi x 640 acres/sq. mi x (0.89)

W_s = 1048.69 acre-feet.

The effects of aircraft seeding are computed in a different way. Reynolds (1988) reported precipitation increases from aircraft seeding in the range of 0.2 to 0.6 mm/hr, and the area covered by seeding to be about 860 km^2 per hour. Based on a rate increase of 0.4 mm/hr and the area covered, the increase in the volume of precipitation produced by seeding can be estimated as about 279 acre-ft. per hour. This estimate was based on an aircraft seeding release rate of 245 grams of AgI per hour. For Walker Basin seeding in WY2015 the seeding rate averaged about 170 grams per hour, so for the current estimates the volume rate increase is adjusted by the ratio of the two release rates. For aircraft seeding the seedability factor (SF) is based on the supercooled liquid water conditions encountered along the seeding track (SF = 1 for moderate to severe icing; SF = 0.75 for continuous moderate icing; SF = 0.5 continuous light icing; 0.1 light intermittent icing). Analysis of the aircraft supercooled liquid water content measurements from the seeding aircraft and icing pilot reports suggested significant icing on all flights and an SF of 1.0 was assigned. Table A1 summarizes the water augmentation estimates for both ground and aircraft seeding in WY2015. For both seeding methods the estimated water rate increase is adjusted by the seedability factor. The combined water augmentation estimate for WY2015 is 2059.01 acre-ft. This is significantly lower than WY2014 and WY2013 mainly because of considerably fewer storms, warmer storms, and fewer aircraft seeding hours.

Cloud seeding in the Walker Basin has been conducted since the mid-1990s. A comparison of WY2015 seeding hours and augmented water estimates with data from 18 seasons is shown in Figure 7. Seeding hours in WY2015 were well below the 17-year average mainly because fewer CSGs were used, some communication problems occurred, and there were a limited number of possible seeding events.

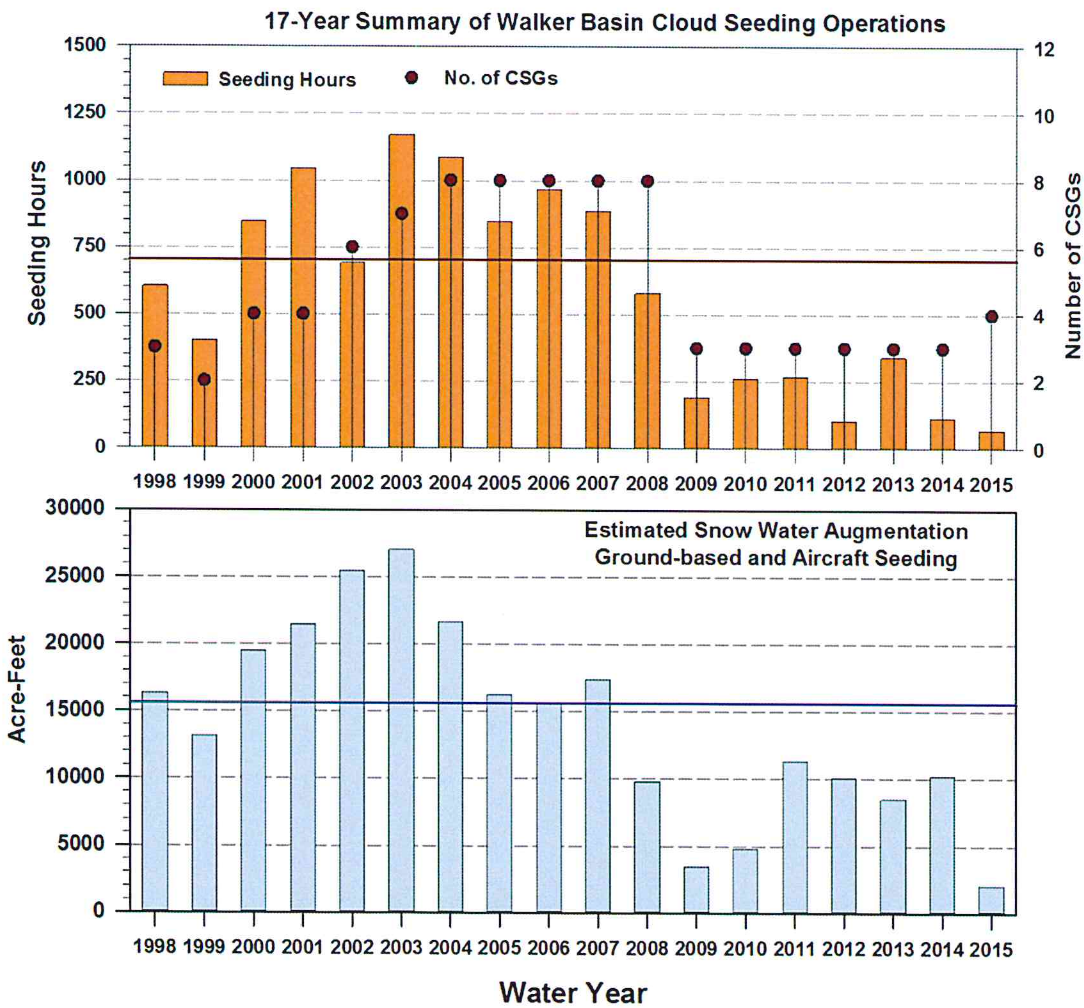

Figure 7. An 18-year summary of cloud seeding operations in the Walker Basin. Top: seeding hours (aircraft and ground) and the number of CSGs used by water year. Bottom: SWE augmentation estimates by water year. Dark horizontal lines in both plots represent the 17-year averages.

4. Water Supply in the Walker Basin and Hydrologic Modeling Studies

In the past four water years the Walker Basin has experienced a very wet winter in WY2011, a very dry winter in WY2012, the WY2013 winter which was wet early and late and quite dry in the heart of the season, a winter in WY2014 that was dry early and late in the season but relatively wet for a six-week period in the heart of the season, and a very warm and dry winter in WY2015. The NRCS Nevada State Basin Outlook Report for 1 June 2015 indicated that the Walker Basin snowpack on 1 June 2015 was near 0% of the median value, consistent with the Lobdell Lake and Leavitt Lake SWE traces shown earlier. The basin response to the 2015 snowpack was again a far below average runoff year and a continual drop of reservoir water storage. Though the Basin was impacted by the relatively wet early December and an early February period, the lack of storms/seeding events and quite mild conditions contributed to an earlier melt of the snow pack, earlier runoff and greater evapotranspiration, leading to a continuation in the fall in Walker Lake. Indeed, as shown in Figure 8, a steady decline in lake levels has continued over the summer of 2015.

The contrasting water years provide a unique opportunity for using the Walker Basin hydrologic model to evaluate the impact of cloud seeding on Walker River flow and flow into Walker Lake. Dr. Douglas Boyle, within the Geography Department at UNR, is heading up this work, which will allow for some preliminary investigations of cloud seeding activities. Further work with the new WRF-Hydro modeling system is also anticipated to be completed this winter by DRI staff. The upcoming studies will assess the impacts of cloud seeding at (and above) the Wabuska stream monitoring station. Included in this work will be an analysis on the differences in stream flow between the two model runs at various points on the Walker River and will be used to estimate the cloud seeding impact on streamflow.

5. Additional Year 5 Phase 3 Work and Start of Year 5 Phase 1 Work

Relative to seeding generator network activities in Phase 3, the four Walker CSGs were given their final maintenance checks following the end of Phase 2. The Dynamo CSG was removed and returned to Reno for the summer as mandated by our BLM permit for that site.

With the start of Phase 1 for the sixth and final year of the project, the Dynamo CSG was returned to its usual location, seeding supplies were topped off and propane tanks were refilled at the existing CSG sites. Preseason maintenance at all sites was initiated and the refilling of seeding solution tanks was completed by late September 2015.

6. Assessment of Accomplishments through 30 September 2014 Based on Objectives and Project Timeline

The objective of the Walker Basin Cloud Seeding Project, as stated in the DRI proposal, was to <u>initiate cloud seeding operations in the Walker Basin for WY2011 and continue these</u>

operations for four additional seasons, and to estimate the impact of seeding operations on Walker River flow using a hydrologic model. The objective was to be accomplished in three steps, and the work was to be divided into three phases. This reporting period covers the end of Phase 2 (1 April 2015 through 30 September 2015) for the extension of the project into Year 5, and involved mainly the final four ground seeding operations. The bulk of this report was focused on Phase 3 data analysis and water augmentation estimates; and the first month of Year 6 Phase 1 (1-31 September 2015) field preparations and modifications to forecasting products. The following bullets highlight the accomplishments for this 6-month period.

- Phase 2 seeding operations were completed after four ground seeding events, with the last operation ending on 25 April 2015. Aircraft seeding ended on 12 March 2015.
- Nine ground seeding operations were conducted, compared to the more typical 20-30 per year and one more than the preceding year (WY2014).
- A total of 4 aircraft flights (6 flight seeding hours) were conducted. (Table 3).
- Based on a 10% seeding increase, the seeding impact of the ground generators over three specific mountain targets was estimated to be a lower percentage than for WY2014 and significantly reduced from the 16 prior years of seeding in the Walker Basin.
- Using previously documented rate increases from seeding, snow water augmentation for WY2015 was estimated to be 1048.69 acre-feet from ground seeding and 1010 acre-ft. from aircraft seeding. The total represents a season equally divided by aircraft and ground seeding.
- Generators are ready for WY2016 operations.

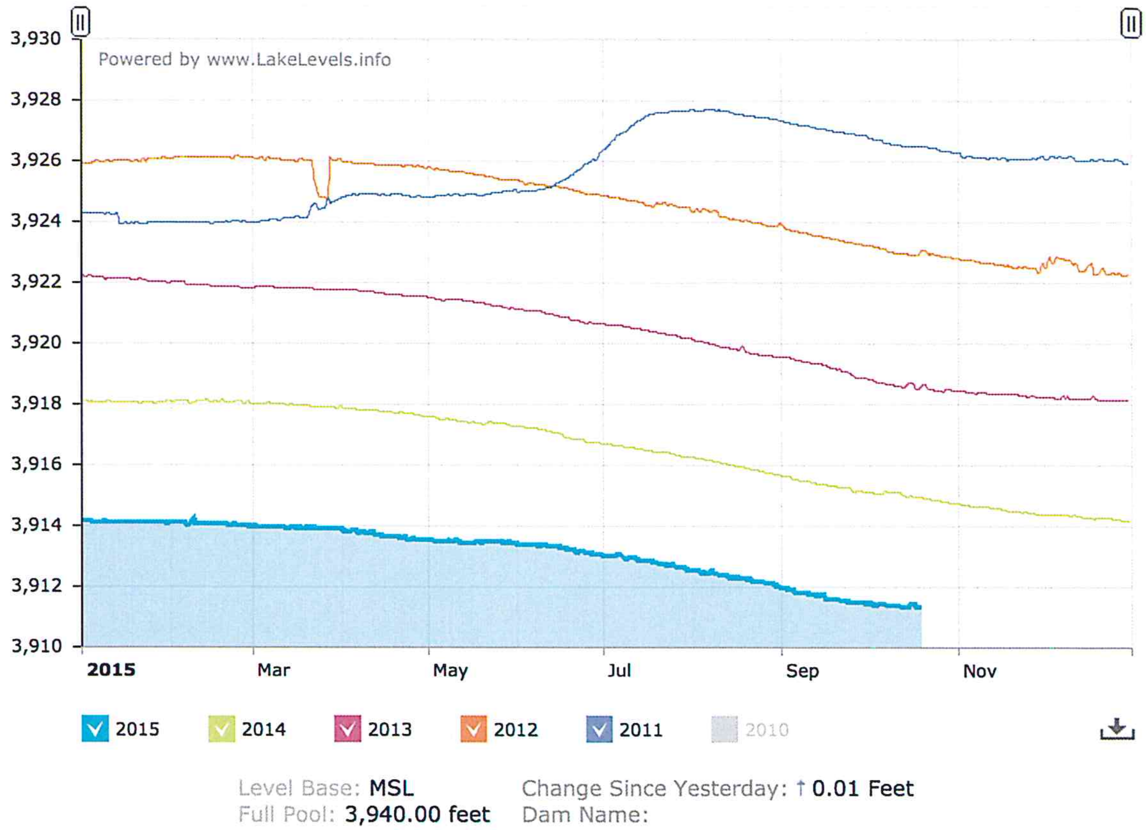

Figure 8. Plot of Walker Lake elevation levels (in feet above mean sea level) for 1 January 2011 through 30 October 2015. Area beneath the 2015 hydrograph curve is shaded solid blue. Note that a 'full' lake level is approximately 3940 feet. Figure from http://www.LakeLevels.info

Flight #	Date	Track	Seed Hrs	Temp C	Winds	Flares
1	2/6/15	W-4	1:15	-7	210/45	41
2	2/7/15	W-4	1:30	-6	240/60	11
3	2/8/15	W-3	1:15	-9	210/50	19
4	3/11/15	W-9	2:00	-10	270/30	43

Table 3. Walker Basin aircraft seeding events for WY2015.

Appendix A. Summaries for WY2015 seeding events

	Seeding Hours	Seedability Factor	Snow Water Rate Increase (hour)	Snow Water Increase
Ground	64.15	0.89	16.35	1048.69
Aircraft	5.25	1.0	192	1010.32
Total	69.30			2059.01

Table A 1. Comparison of Walker Basin aircraft and ground based seeding events WY 2015.

Table A 2. Walker Basin ground based seeding events WY 2015.

Operation #	Location	Generator	Start Date-Time	TC1	TC2	Flow at On (V)	End Date-Time	TC1	TC2	Flow at Off (V)	Generator Time (hh:mm)	Generator Hours	Agl Release (g)	Event Hours
1	Romero	10	12/30/14 2:38	863	841	3.400	12/30/14 10:25			3.330	7:47:00	7.78	186.93	
	Summit	17									0:00:00	0.00	0.00	
	Dynamo	20									0:00:00	0.00	0.00	
	Conway	27									0:00:00	0.00	0.00	
														7.78
2	Romero	10	12/30/14 14:00	863	854	3.450	12/30/14 15:15			3.400	1:15:00	1.25	30.80	
	Summit	17									0:00:00	0.00	0.00	
	Dynamo	20									0:00:00	0.00	0.00	
	Conway	27									0:00:00	0.00	0.00	
														1.25
3	Romero	10	2/22/15 8:49	760	765	3.790	2/22/15 17:00			3.790	8:11:00	8.18	232.04	
	Summit	17									0:00:00	0.00	0.00	
	Dynamo	20									0:00:00	0.00	0.00	
	Conway	27									0:00:00	0.00	0.00	
														8.18
4	Romero	10	2/28/15 16:54	686	747	3.810	3/1/15 1:50			3.780	8:56:00	8.93	252.41	
	Summit	17									0:00:00	0.00	0.00	
	Dynamo	20									0:00:00	0.00	0.00	
	Conway	27									0:00:00	0.00	0.00	
														8.93
5	Romero	10	3/1/15 22:19	564	613	3.760	3/2/15 2:00	-	-	3.760	3:41:00	3.68	103.33	
	Summit	17									0:00:00	0.00	0.00	
	Dynamo	20									0:00:00	0.00	0.00	
	Conway	27									0:00:00	0.00	0.00	
														3.68
6	Romero	10	4/2/15 6:50	769	769	3.780	4/2/15 10:50	-	-	3.780	4:00:00	4.00	113.02	
	Summit	17									0:00:00	0.00	0.00	
	Dynamo	20									0:00:00	0.00	0.00	
	Conway	27									0:00:00	0.00	0.00	
														4.00
7	Romero	10	4/5/15 19:43	757	725	3.920	4/6/15 0:00			3.920	4:17:00	4.28	127.1	
	Summit	17									0:00:00	0.00	0.0	
	Dynamo	20									0:00:00	0.00	0.0	
	Conway	27									0:00:00	0.00	0.0	
														4.28
8	Romero	10									0:00:00	0.00	0.0	
	Summit	17	4/7/15 11:06	864	896	3.810	4/7/15 17:45			3.780	6:39:00	6.65	187.9	
	Dynamo	20	4/7/15 11:06	740	684	3.750	4/7/15 17:44			3.820	6:38:00	6.63	190.1	
	Conway	27	4/7/15 11:06	716	606	3.780	4/7/15 17:40			3.830	6:34:00	6.57	188.9	
														19.85
9	Romero	10	4/25/15 5:12	742	818	3.840	4/25/15 11:23			3.680	6:11:00	6.18	168.6	
	Summit	17									0:00:00	0.00	0.0	
	Dynamo	20									0:00:00	0.00	0.0	
	Conway	27									0:00:00	0.00	0.0	
														6.18
											Total			64.15