Feasibility/Design Study for a Winter Cloud Seeding Program in the Upper Cuyama River Drainage, California

Prepared for

Santa Barbara County Water Agency

by

Don A. Griffith
Stephanie D. Beall
David P. Yorty

North American Weather Consultants, Inc.
8180 S. Highland Dr., Suite B-2
Sandy, Utah 84093

Report No. WM 16-8
Project No. 15-376

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1.0 INTRODUCTION

The Santa Barbara County Water Agency (Agency) contracted with North American Weather Consultants (NAWC) on December 3, 2015 to perform a winter cloud seeding feasibility/design study for the Upper Cuyama River Drainage (UCRD) located in northern Ventura and southern Kern Counties. The stated goal of this program would be to augment the natural precipitation that occurs in the target area to benefit groundwater recharge in the Cuyama Valley. Figure 1.1 provides the location of the proposed target area and the Cuyama Valley.

Figure 1.1 Locations of Proposed Target Area and the Cuyama Valley

NAWC was contacted to perform the following tasks:

- Task I – Provide a Brief Description of Cloud Seeding Theory
- Task II – Review and Summary of Relevant Prior Studies and Research
- Task III – Review and Analysis of the Climatology of the Target Area

- Task IV – Development of a Program Design
- Task V – Develop Estimates of Seasonal Increases in Precipitation and Stream Flow.
- Task VI – Development of Benefit and Cost Estimates
- Task VII – Final Report Preparation

The following sections of this report summarize the work performed in completing the first six tasks.

2.0 THEORY OF CLOUD SEEDING FOR PRECIPITATION AUGMENTATION

Two theories have evolved concerning the potential to augment precipitation through cloud seeding. One theory postulates that a natural cloud's efficiency in producing precipitation can be increased, while the other theory postulates that seeding can enhance cloud development, leading to additional precipitation. The first theory has often been referred to as the *static* seeding hypothesis while the second relies upon *dynamic* effects of cloud growth. In many situations processes could be operative, whereby a cloud's precipitation efficiency is increased and the cloud is made to grow larger due to the seeding.

Clouds contain water vapor, water droplets and frequently ice crystals if cloud temperatures drop below freezing. Discoveries in the late 1940's established that minute particles of silver iodide, when injected into a cloud that contained supercooled water droplets, would cause those droplets to freeze (Vonnegut, 1947). Supercooled water droplets (droplets in a cloud at temperatures below freezing) frequently exist in clouds, as evidenced by icing on aircraft. These supercooled water droplets are the normal targets of most modern day cloud seeding programs designed to increase precipitation.

2.1 Precipitation Processes

There are two basic mechanisms that produce precipitation: coalescence (sometimes referred to as a "warm rain process") and ice formation (sometimes referred to as a "cold rain process). Coalescence is defined as "the growth of raindrops by the collision and coalescence of cloud drops and or small precipitation particles." This process is especially important in tropical locations in the production of rainfall but it can also be a factor in the production of rainfall in more temperate climates like those found in Santa Barbara County. Ice nucleation consists of a process in which ice crystals may be formed by freezing liquid cloud droplets within a cloud region whose temperatures are below freezing. In such cloud regions the ice crystals, once formed, will gain mass by sublimation (formation of a solid phase directly from a vapor phase, known as the Bergeron-Findeisen process) at the expense of the surrounding liquid cloud droplets that lose mass by evaporation. Upon attaining sufficient weight, the ice crystals (by this time they would be snowflakes) would fall to the ground as snow if the surface temperatures were at or below freezing, but would melt and fall as raindrops if the surface temperatures were warmer than freezing. Of interest to this discussion is the fact that cloud droplets frequently exist in portions of clouds that are colder than freezing. In fact, pure water droplets in a very clean laboratory environment can be cooled to -39^0 C before they will freeze through a process known as homogeneous nucleation. An example of the presence of supercooled cloud droplets in clouds is aircraft icing. Supercooled cloud droplets freeze on impact with the leading edges of the aircraft. When such icing is observed or forecast, aircraft are often sprayed with an antifreeze solution prior to takeoff to avoid accumulation of excessive amounts of icing. This ice nucleation process is important in the production of snow and rain in the more temperate climates like those found in Santa Barbara County. The presence of supercooled water droplets in clouds is often the focus of attempts to artificially modify clouds.

2.2 Ice Nucleation

As discussed in the above, clouds often have unfrozen cloud droplets present at sub-freezing temperatures. This is true of many cloud systems affecting Santa Barbara County. These cloud droplets are termed “supercooled”. The natural tendency is for these droplets to freeze, but to do so at temperatures warmer than -39^0 C they need to encounter an impurity. There are natural particles present in our atmosphere that possess the ability to cause these supercooled droplets to freeze; they are known as freezing nuclei. Research has demonstrated that certain natural particles (e.g., soil particles) and certain bacteria in the atmosphere serve as freezing nuclei. The conversion of a supercooled water droplet into an ice crystal is referred to as nucleation (more correctly, heterogeneous nucleation). It is known that the efficiency of these naturally occurring freezing nuclei increases with decreasing temperatures. It has also been established that naturally occurring freezing nuclei active in the temperature range of approximately -5 to -15^0 C are relatively rare. Research has also shown that minute particles of silver iodide begin to act effectively as freezing nuclei at temperatures colder than -5^0 C (Dennis, 1980). Some more recently developed seeding formulations show nucleation at temperatures as warm as -4^0 C. Silver iodide is the agent most commonly used to “seed” clouds, a process often referred to as “cloud seeding.”

There are two types of ice nucleation: condensation-freezing and contact. In condensation freezing, a nucleus first serves as a condensation nucleus in forming a cloud droplet. At temperatures of approximately -5^0 C or colder this same nucleus can serve as a freezing nuclei. In other words, under the right conditions, a nucleus can a) cause condensation, forming a cloud droplet and b) then promote freezing on the same nucleus, forming an ice crystal. Contact nucleation, as the name implies, means that a freezing nucleus must come in physical contact with a supercooled water droplet, thus causing it to freeze (as long as the temperature of the cloud droplet is cold enough for the freezing nuclei to be active). Contact nucleation can be a relatively slow process (from a few to tens of minutes) compared to condensation-freezing nucleation, which can be quite rapid (on the order of one minute) once the nuclei reach an in-cloud temperature of -5^0 C. Rapid nucleation will occur if the nuclei are directly injected into a cloud region whose temperature is -5^0 C or colder.

2.3 Impacts of Silver Iodide Seeding

Since the ice nucleating activity of natural ice nuclei is typically low at in-cloud temperatures in the range of -5 to -15^0 C, many clouds may be inefficient in converting supercooled water droplets into ice crystals. The addition of silver iodide nuclei to these cloud regions can produce additional ice crystals, which, under the right conditions, grow into snowflakes and fall out of the clouds. This results in an increase in the efficiency of the clouds in producing snow (or rain if the freezing level is above the ground surface). This increase in efficiency is usually referred to as a *static* seeding effect.

In the process of converting supercooled water droplets to ice, additional heat is added to the cloud due to the release of latent heat of fusion. This additional heat may invigorate the circulation of air within the clouds, resulting in a *dynamic* effect. This postulated *dynamic* effect was the basis for a National Oceanic and Atmospheric (NOAA) research program conducted in Florida known as the Florida Area Cumulus Experiment (FACE). Two different phases of FACE 1, 1970-76 and FACE 2, 1978-80 (Woodley, **et al**., 1983) indicated increases in area wide rainfall, but results fell short of strict statistical acceptance criteria. Rainfall increases from seeded convection bands in the Santa Barbara II research program (Brown **et al**., 1974) were attributed to both *static* and *dynamic* effects.   NAWC conducted this research program in Santa Barbara County with funding from the Naval Weapons Center at China Lake, California. This area-specific research program is discussed in the next section.

3.0 REVIEW AND SUMMARY OF RELEVANT PRIOR STUDIES AND RESEARCH

3.1 Santa Barbara II Research Program

The Santa Barbara II research program consisted of two primary phases. Phase I consisted of the release of silver iodide from a ground location near 2,500 feet MSL located in the Santa Ynez Mountains northwest of Santa Barbara. These silver iodide releases were made as "convective bands" passed overhead. The releases were conducted on a random seed or no-seed decision basis in order to obtain baseline non-seeded (natural) information for comparison. A large network of recording precipitation gauges was installed for the research program (Figure 3.1). The amount of precipitation that fell from each seeded or non-seeded convective band was determined at each precipitation gauge location. Average convective band precipitation for seeded and non-seeded events was calculated for each rain gauge location. Figure 2.2 shows the results of seeding from the ground as contours of the ratios of average seeded band precipitation versus the non-seeded band precipitation.

Ratios greater than 1.0 are common in Figure 3.2. A ratio of 1.50 would suggest a 50 percent increase in precipitation from seeded convective bands compared to non-seeded bands. The high ratios in southwestern Kern County are not significant in terms of amounts of additional rainfall since the convective bands (both seeded and non-seeded) rapidly lose intensity as they enter the San Joaquin Valley. In other words, a high percentage applied to a low base amount does not yield much additional precipitation. These apparent effects may be due to delayed ice nucleation which would be expected with the type of seeding flares used in this experiment that operated by contact nucleation which is a relatively slow process (see Section 2.2).

The low amounts of natural precipitation in southwest Kern County results from evaporation in "downslope" flow in the winter storms that affect this area. Such predominant "downslope flow" areas are frequently known as rain-shadow areas in the lee of mountain ranges. Figure 3.3 dramatically exhibits this feature from the coastal mountains in Central and Southern California, which are wet, to the San Joaquin and Imperial Valleys, which are dry. The

1.5 ratios along the backbone of the Santa Ynez Mountains are, however, significant in terms of rainfall amounts since this area receives higher natural precipitation during winter storms due to "upslope" flow. This upslope flow is also known as an orographic effect and accounts for many mountainous areas in the west receiving more precipitation than adjoining valleys (especially downwind valleys). It was concluded that convective band precipitation was increased over a large area using this ground seeding approach.

In a similar experiment, Santa Barbara II, phase II, an aircraft was used to release silver iodide (generated by silver iodide - acetone wing tip generators) into the convective bands as they approached the Santa Barbara County coastline west of Vandenberg Air Force Base. The convective bands to be seeded were also randomly selected. Figure 3.4 provides the results of this experiment. Again, a large area of higher precipitation is indicated in seeded convective bands compared to non-seeded convective bands. Notice the westward shift of the effect in this experiment versus the ground-based experiment. This feature is physically plausible since the aircraft seeding was normally conducted off the coastline in the vicinity of Vandenberg AFB (i.e., west of the ground-based release point).

A study of the contribution of "convective band" precipitation to the total winter precipitation in the Santa Barbara County and surrounding areas was conducted (in the analysis of the Santa Barbara II research program). This study indicated that convective bands contributed approximately one-half of the total winter precipitation in this area (Figure 3.5). If it is assumed that all convective bands could be seeded in a given winter season and that a 50 percent increase was produced, the result would be a 25 percent increase in winter season precipitation if we assume the convective bands would have contributed one half of the winter season's rainfall. The two reports mentioned earlier (Thompson **et al.**, 1988 and Solak **et al.**, 1996) provided a more precise quantification of the optimal seeding increases that might be expected at Juncal and Gibraltar Dams (i.e., 18-22%) from seeding convective bands.

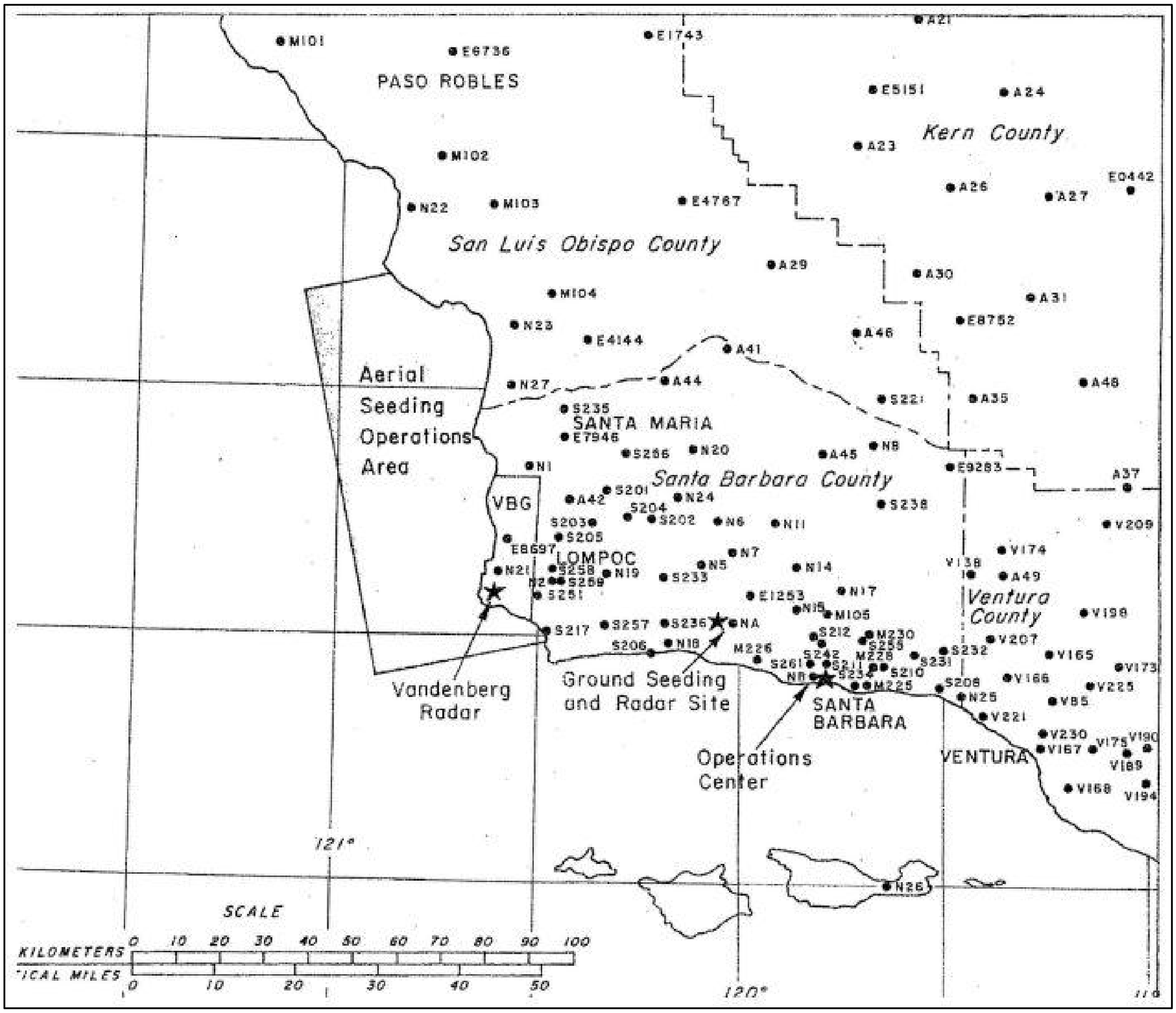

Figure 3.1 Santa Barbara II project map showing rain gauge locations, radar, and seeding sites.

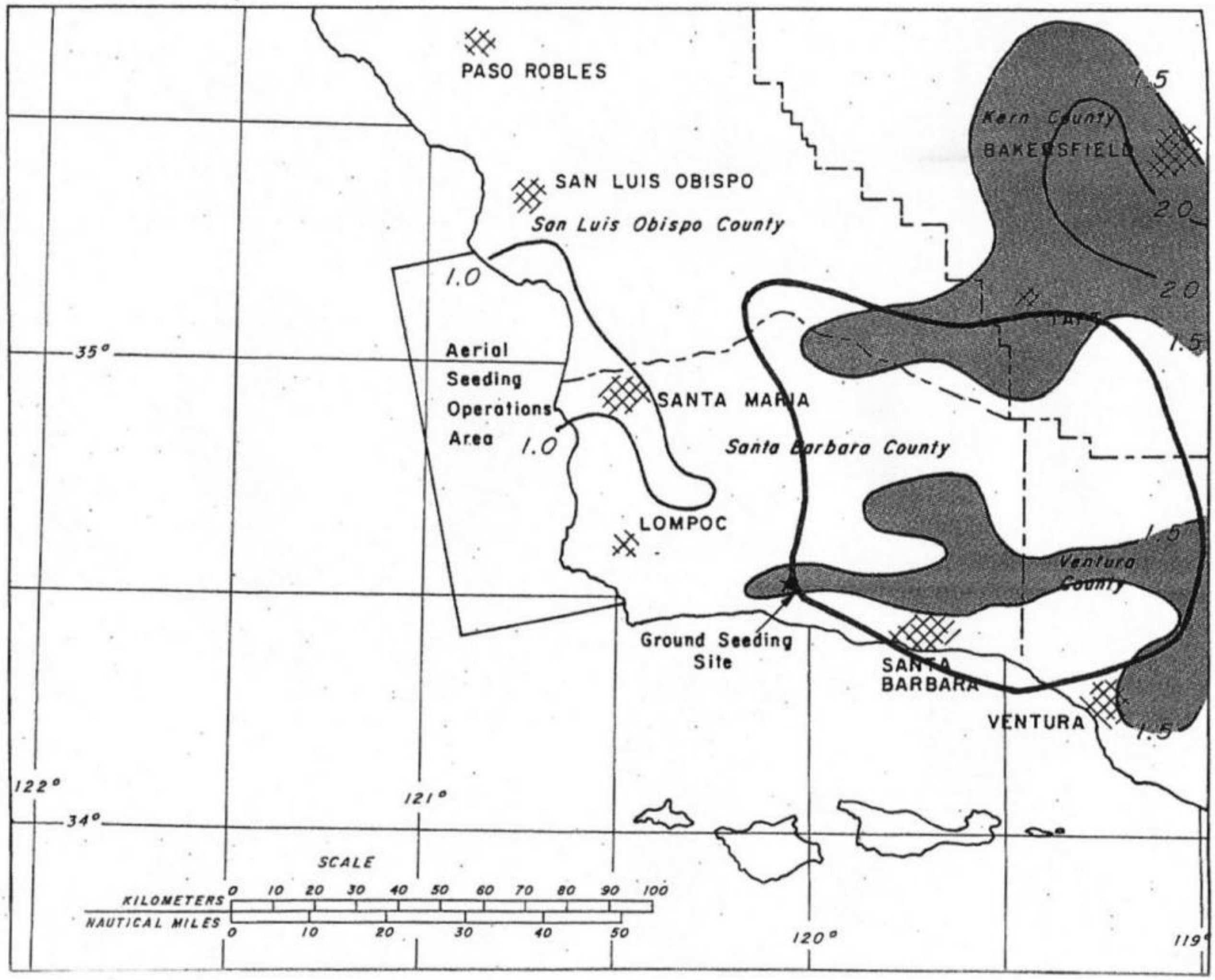

Figure 3.2 **Seeded/not-seeded ratios of band precipitation for Phase I ground operations, 1967-71 seasons; 56 seeded and 51 not-seeded bands.**

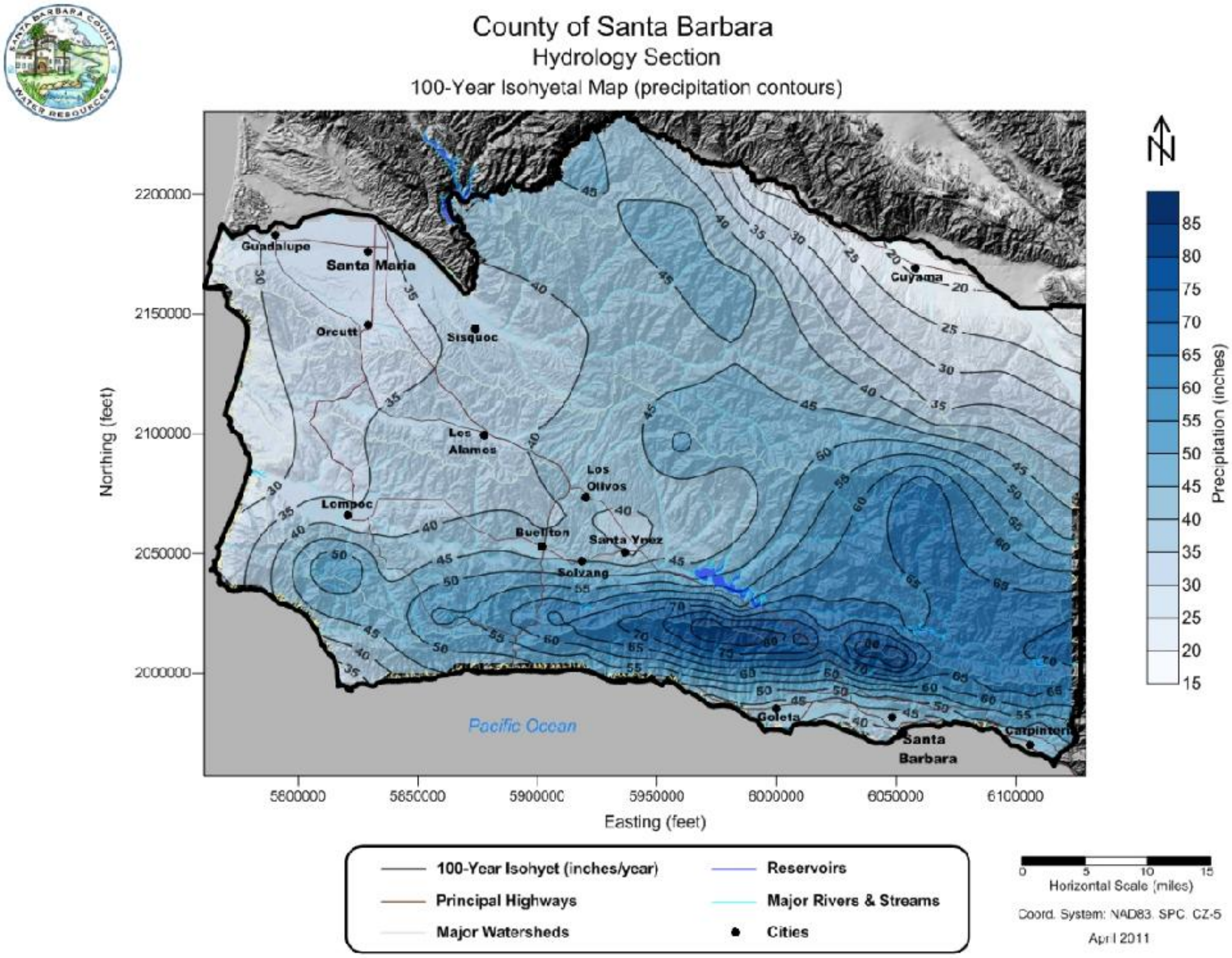

Figure 3.3 100 Year Isohyetal Map, Santa Barbara County

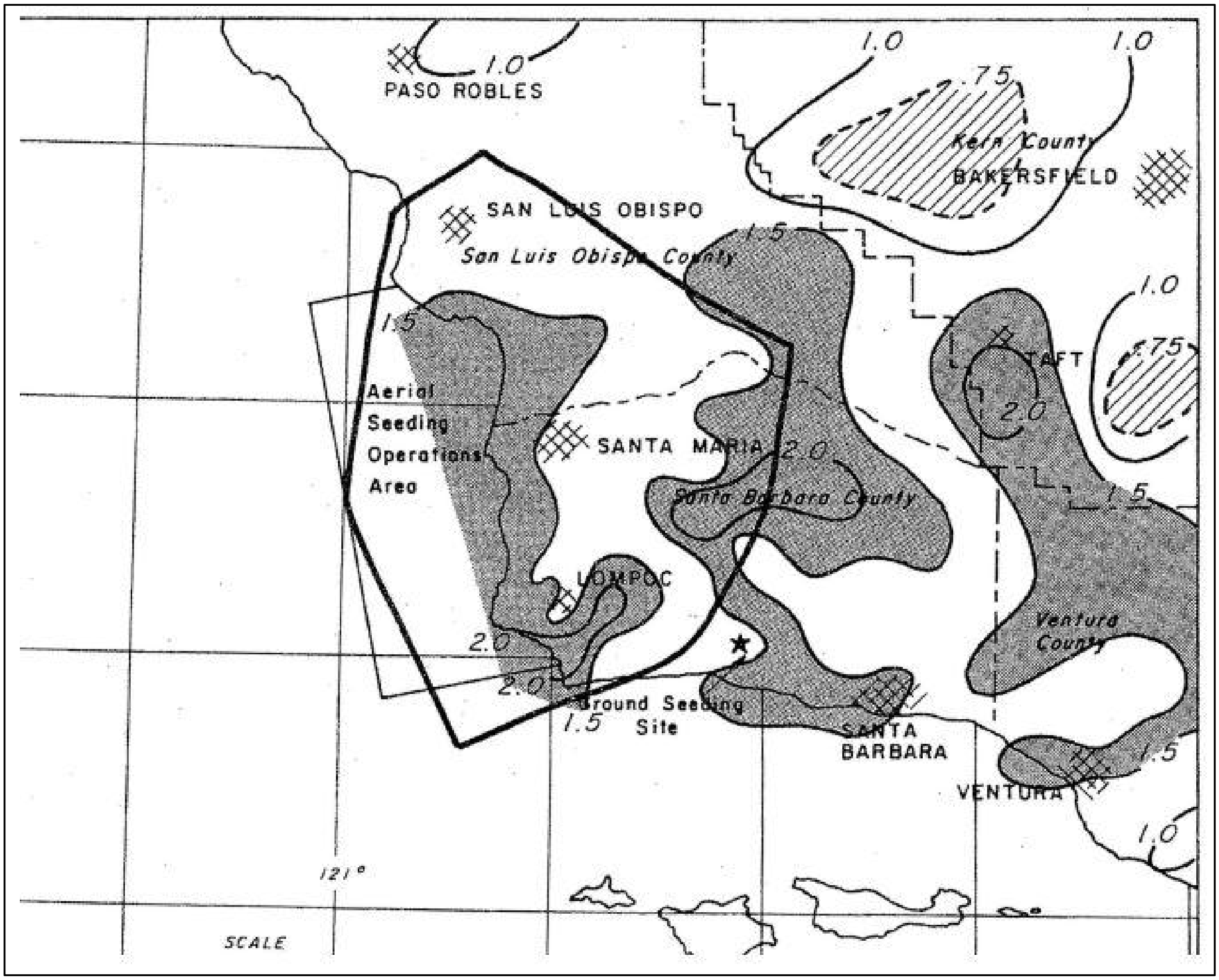

Figure 3.4 **Seeded/not-seeded ratios of band precipitation for Phase II aerial operations, 1970-74 seasons; 18 seeded and 27 not-seeded bands.**

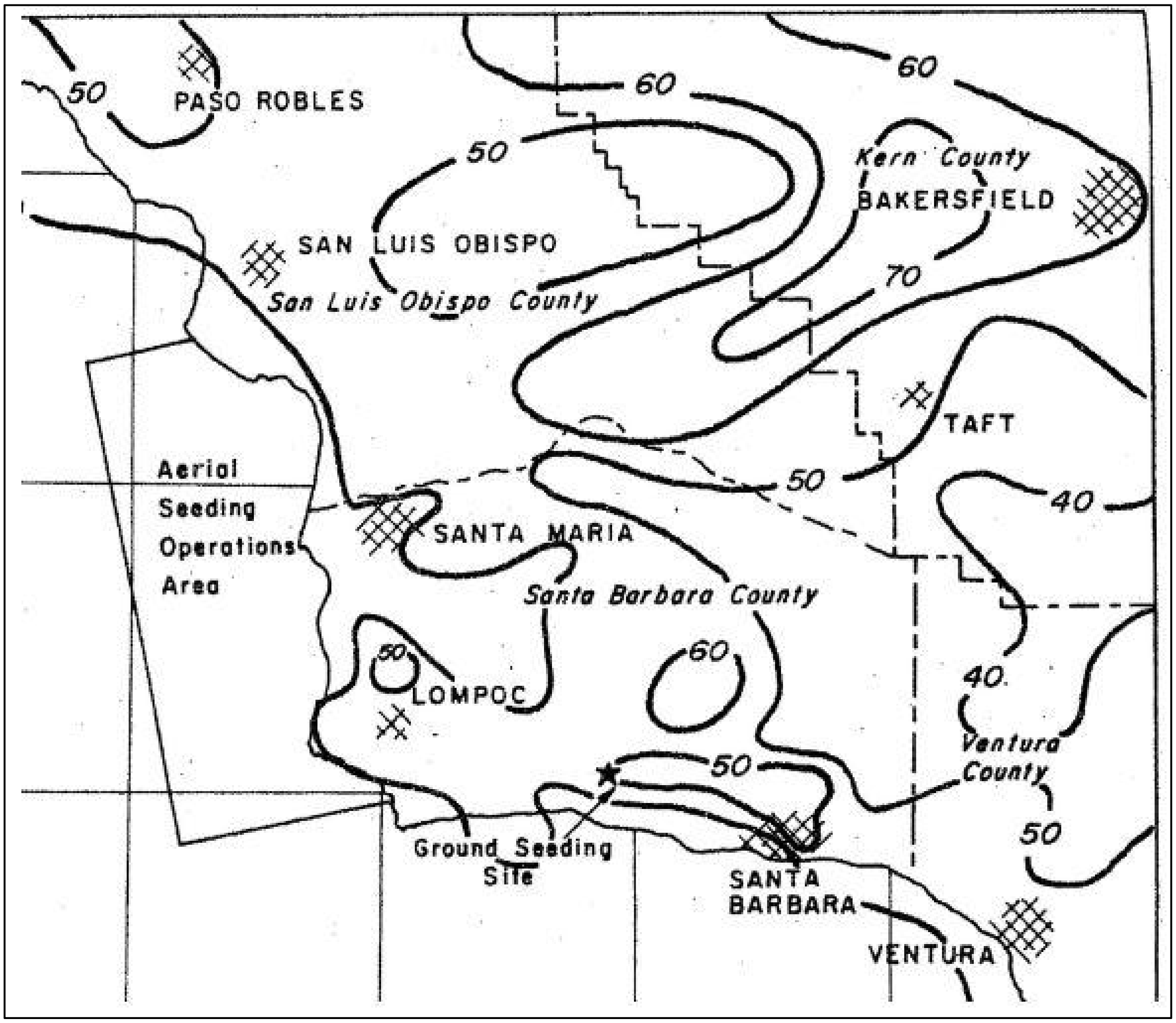

Figure 3.5 Approximate percentage of winter precipitation occurring in convective bands, 1970-74 seasons

For illustration purposes, Figure 3.6 provides a sequence of six radar images of a convective band as it moved into Santa Barbara County on April 11, 2010. The radar images are from the Vandenberg AFB NEXRAD radar site. Table 3-1 shows short duration rainfall values at Santa Maria during this event. Higher intensity rainfall occurred as the heart of the convective band moved over Santa Maria.

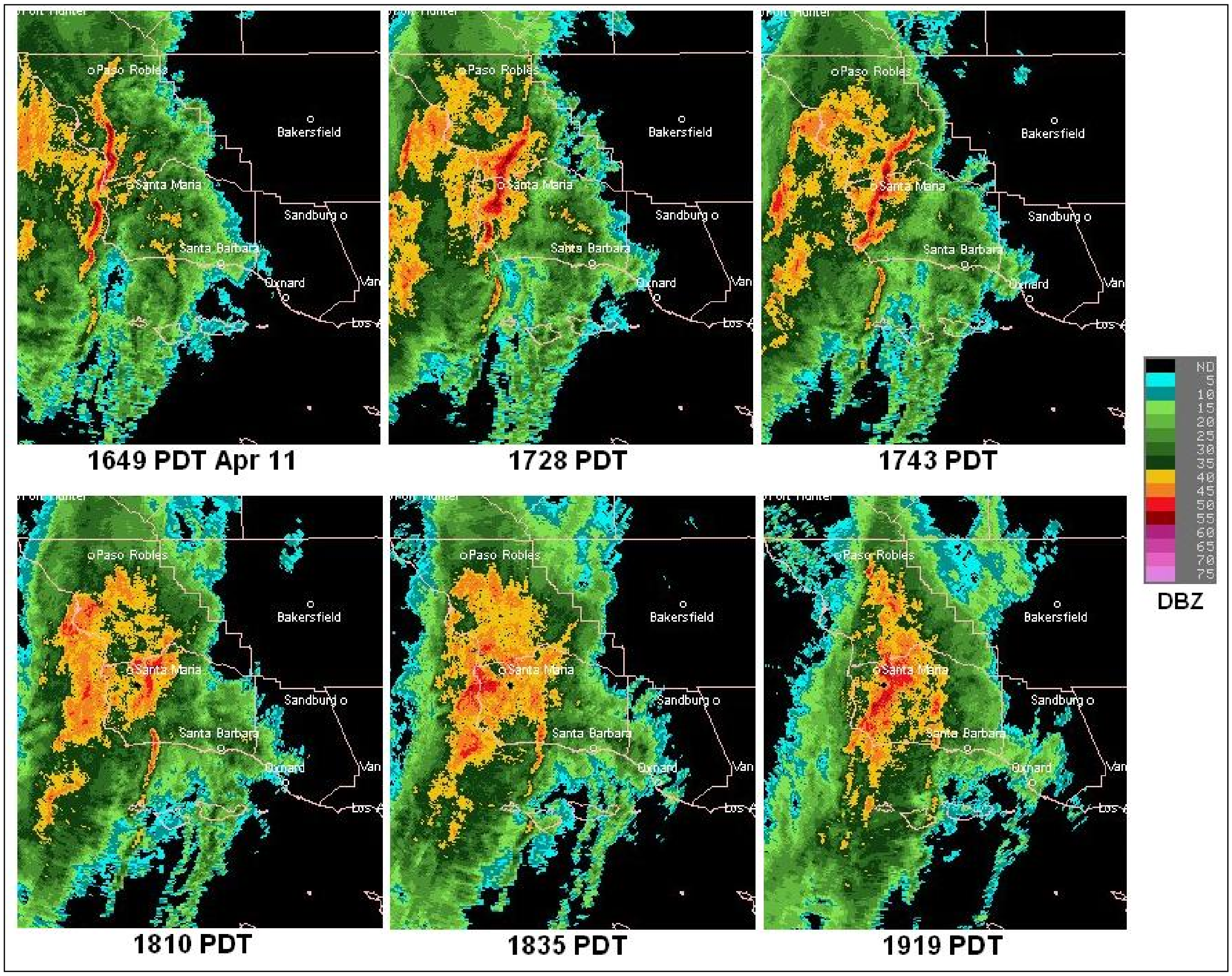

Figure 3.6 Convective band passing over western Santa Barbara County on April 11, 2010 as observed by the Vandenberg AFB NEXRAD Radar

Table 3-1. Short Duration Rainfall Amounts (inches) at the Santa Maria Airport During Storm Event in Figure 3.6

Time Period (PST)	1630 - 1700	1700 - 1730	1730-1800	1800 - 1830	1830 - 1900	1900 - 1930	1930 - 2000
Precipitation (in)	0.03	0.26	0.35	0.12	0.10	0.12	0.02

More recent research conducted in Texas (Rosenfeld and Woodley, 1993; Rosenfeld and Woodley, 1997) and in Thailand (Woodley and Rosenfeld, 1999) has also indicated additional rainfall being produced from silver iodide seeding of convective cloud elements. These increases appear to occur due to increased duration of the seeded entities rather than increases in precipitation intensity. These indications are in agreement with the results observed in the Santa Barbara II research program.

In summary, earlier research conducted in Santa Barbara County indicated that convective bands are a common feature of winter storms that impact Santa Barbara County and that those bands contribute a significant proportion of the area precipitation. In addition, research has indicated that these bands contain supercooled liquid water droplets; the target of most modern day cloud seeding activities (Elliott, 1962). Seeding these bands with silver iodide either from the ground or air increases the amount of precipitation received at the ground. These bands are typically oriented in some north to south fashion (e.g. northeast to southwest, northwest to southeast, etc.) as they move from west to east. It is common to have at least one convective band per winter storm with as many as three or four per storm being fairly common. One band is usually associated with cold fronts as they pass through the county. Frequently these frontal bands are the strongest, longest lasting bands during the passage of a storm. Other bands may occur in either pre-frontal or post-frontal situations. The duration of these bands over a fixed location on the ground can vary from less than one hour to several hours duration.

In 2013 the Santa Barbara County Water Agency asked NAWC if there was some method that could be employed to estimate the cloud seeding effects of an operational winter program that had been conducted most winters in Santa Barbara County since 1981. There have typically been two target areas in this program: the Upper Santa Ynez drainage above Cachuma Dam located in the eastern part of Santa Barbara County, and the Twitchell Reservoir drainage (sometimes referred to as the Huasna-Alamo target area) located in the northern portion of Santa Barbara County and the southern portion of San Luis Obispo County. This operational program was implemented in water year 1986 following the completion of the Santa Barbara II research program which provided indications of positive seeding effects from seeding convective bands, some of which were statistically significant.

North American Weather Consultants (NAWC) performed an historical target/control analysis of this program for the Santa Barbara County Water Agency in 2013, which had not been attempted previously. A search for potential long-term target and control precipitation measurement sites was conducted which identified three acceptable control sites and four acceptable target sites (two in each of the intended target areas). Figure 3.7 provides these locations. Linear and multiple-linear regression equations were developed for each of the target areas using periods without any cloud seeding in either the control or target areas. Relatively high correlations were obtained between the control and target sites with r^2 values ranging from 0.84 to 0.91 (Griffith, et al, 2015).

When these regression equations were used to predict the amount of precipitation for the December-March period for the two target areas during seeded seasons and then compared to the actual amounts of precipitation, the average results for all the seeded seasons were:

- Upper Santa Ynez Target Area: Estimated increases of 19% to 21% from the linear and multiple-linear equations (24 seeded seasons).
- Huasna-Alamo Target Area: Estimated increases of 9% from both the linear and multiple-linear equations (27 seeded seasons).

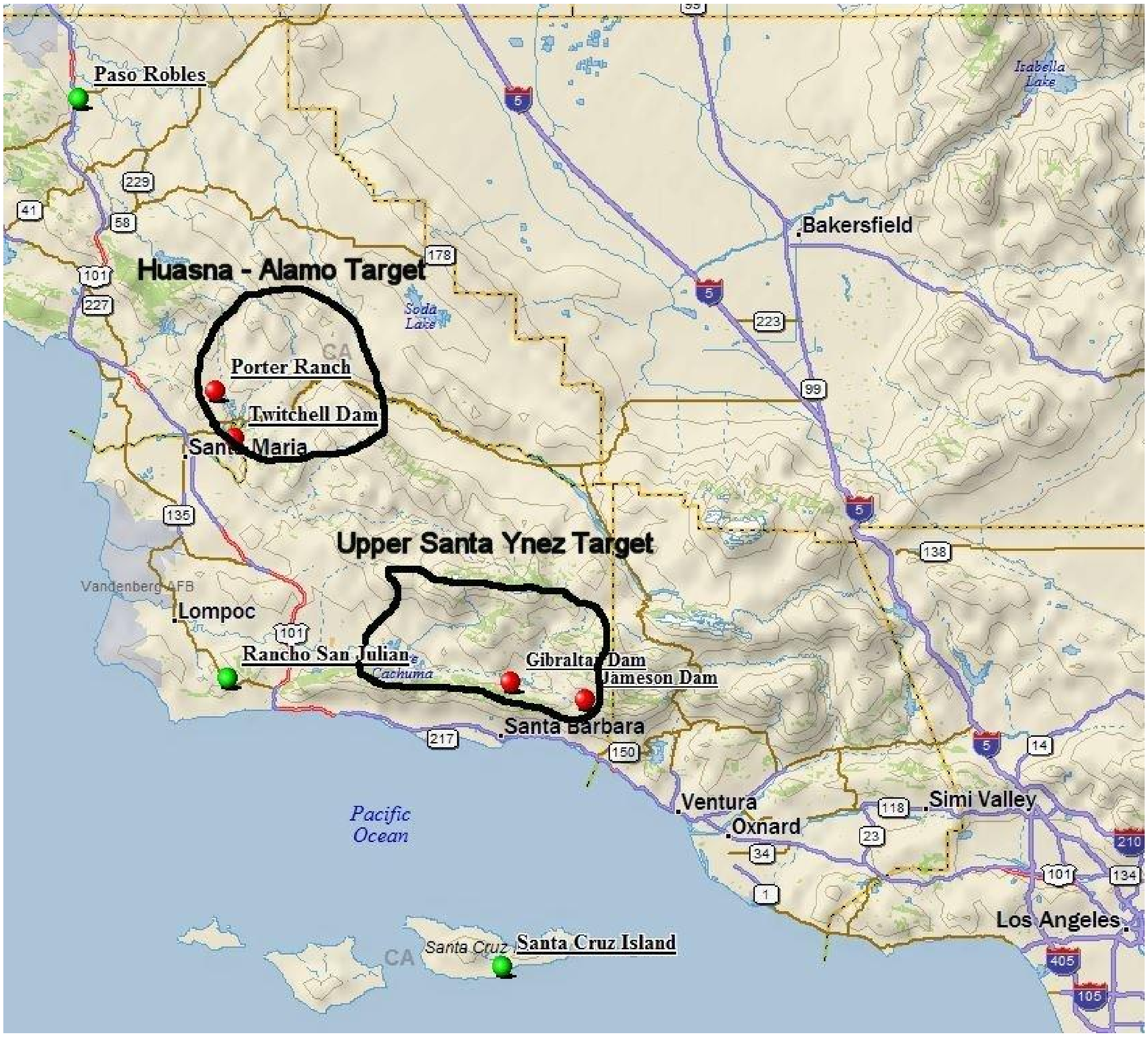

Figure 3.7 Map of the Two Cloud Seeding Target Areas and the Locations of Precipitation Control Sites (green) and Target Sites (red).

3.2 Snowy Mountains Precipitation Enhancement Research Project

Another winter orographic ground based seeding research program of relevance was recently completed in the Snowy Mountains of Australia (Manton, et al, 2011 and Manton and Warren, 2011). The following is the abstract taken from the second paper:

> *"The Snowy Mountains Precipitation Enhancement Research Project (SPERP) was undertaken in winters from May 2005 to June 2009 in the Snowy Mountain region of southeastern Australia. Part I of this paper describes the design and implementation of the project, as well as the characteristics of the key datasets collected during the field phase. The primary analysis in this paper (Part II) shows an unequivocal impact on the targeting of seeding material, with the maximum level of silver in snow samples collected from the primary target area found to be significantly greater in seeded than unseeded experimental units (EUs). A positive but not statistically significant impact on precipitation was found. Further analysis shows that a substantial source of uncertainty in the estimation of the impacts of seeding on precipitation is associated with EUs where the seeding generators operated for relatively few hours. When the analysis is repeated using only EUs with more than 45 generator hours, the increase in precipitation in the primary target area is 14% at the 8% significance level. When applying that analysis to the overall target area, the precipitation increase is 14% at the 3% significance level. A secondary analysis of the ratio of silver to indium in snow supports the hypothesis that seeding material affected the cloud microphysics. Other secondary analyses reveal that seeding had an impact on virtually all of the physical variables examined in a manner consistent with the seeding hypothesis."*

3.3 Wyoming Weather Modification Pilot Program (WWMPP)

Yet another multi-year winter orographic seeding research program recently was completed. This program was conducted in the Sierra Madre and Medicine Bow Ranges located in south central Wyoming (Breed, et al, 2014). The following was taken from a draft executive summary of an analysis of the results obtained from this experiment (NCAR, 2014).

The WWMPP provided an assessment of weather modification as a strategy for long-term water management. Specifically, the project was funded to determine whether seeding in Wyoming is a viable technology to augment existing water supplies, and if so, by how much, and at what cost.

The physical evidence from radiometer measurements showed that ample supercooled liquid water existed at temperatures conducive to generating additional snow by silver iodide seeding over the ranges studied. High-resolution and quality-controlled snow gauges were critical to evaluate the effectiveness of cloud seeding and validate the performance of the model used during the WWMPP.

The accumulation of evidence from statistical, physical, and modeling analysis suggests that cloud seeding is a viable technology to augment existing water supplies, for the Medicine Bow and Sierra Madre Ranges. While the primary statistical analysis did not show a significant impact of seeding, statistical analysis stratified by generator hours showed increases of 3-17% for seeded storms. A climatology study based on high-resolution model data showed that ~30% of the winter time precipitation over the Medicine Bow and Sierra Madre Ranges fell from storms that met the WWMPP seeding criteria. Ground-based silver iodide measurements indicated that ground-based seeding reached the intended target, and in some cases well downwind of the target. High-resolution modeling studies by NCAR that simulated half of the total number of seeding cases showed positive seeding effects between 10-15% for the seeded test *cases. When these indicated results were compiled for possible seasonal estimates of seeding increases the results were 1.5 to 5% increases.*

4.0 REVIEW AND ANALYSIS OF THE CLIMATOLOGY OF THE PROPOSED TARGET AREA

Southern portions of California have a Mediterranean type of climate in general, with warm dry summers and wet winters in most areas. The upper Cuyama watershed lies in the inland portion of Ventura County, with a semi-arid climate over much of the area and higher precipitation in some mountain locations. Precipitation data were available for some stations in this area, including: Alamo Mountain, Apache Canyon , Lockwood Valley Yard, Maxey Ranch, Mt. Pinos, Ozena, and Wagon Camp Road. Monthly climatological averages were available from some of these sites, and only annual or seasonal data from others. Overall, November through April estimates ranged from 8 inches to over 20 inches with Alamo Mountain being the driest and Mt. Pinos the wettest. The majority of the sites have averages between 10-15 inches for roughly the November – April period, which is likely a good estimate for this watershed in the feasibility study as a whole.

Analysis of the monthly precipitation climatology was conducted using four nearby stations (Santa Barbara Canyon, Cuyama Ranch, Cuyama Fire Station, New Cuyama) in eastern Santa Barbara County with complete long-term records that date back to at least the 1950s. The seasonal distribution at these sites should be similar to the upper Cuyama watershed where similar data were lacking. The four-station average in Figure 4.1 shows a distinct peak in February, with interpolation implying a climatological precipitation maximum centered in the early part of February. The November – April period accounted for about 88% of the annual precipitation in this composite plot, with the shorter December – March seasonal period accounting for over 71% of the annual total. Dividing the totals for the two periods shows that the December – March season accounts for about 81% of the November – April totals. For the upper Cuyama watershed, this means December – March precipitation totals ranging from about 6-7" in some of the driest areas to 15-20" in the wetter higher elevation areas. While the magnitude of observed precipitation varies considerable from one location to another, the distribution shown in Figure 4.1 should be relatively consistent across the area.

The proposed target area climatology in terms of seedable events is believed to be quite similar to the upwind Santa Barbara County seeding target areas for which seeding results were originally examined in terms of the meteorological conditions and frequency of convective band passages, the primary exception being that the upper Cuyama watershed is somewhat drier due to its location downwind of some of these other mountain ranges. An analysis of convective band passages over a five-year period in Santa Barbara County was conducted in order to classify the temperature and wind characteristics of these bands. Table 4-1 shows the 700-mb data estimates that were obtained. Figure 4.2is a wind direction frequency plot for these events.

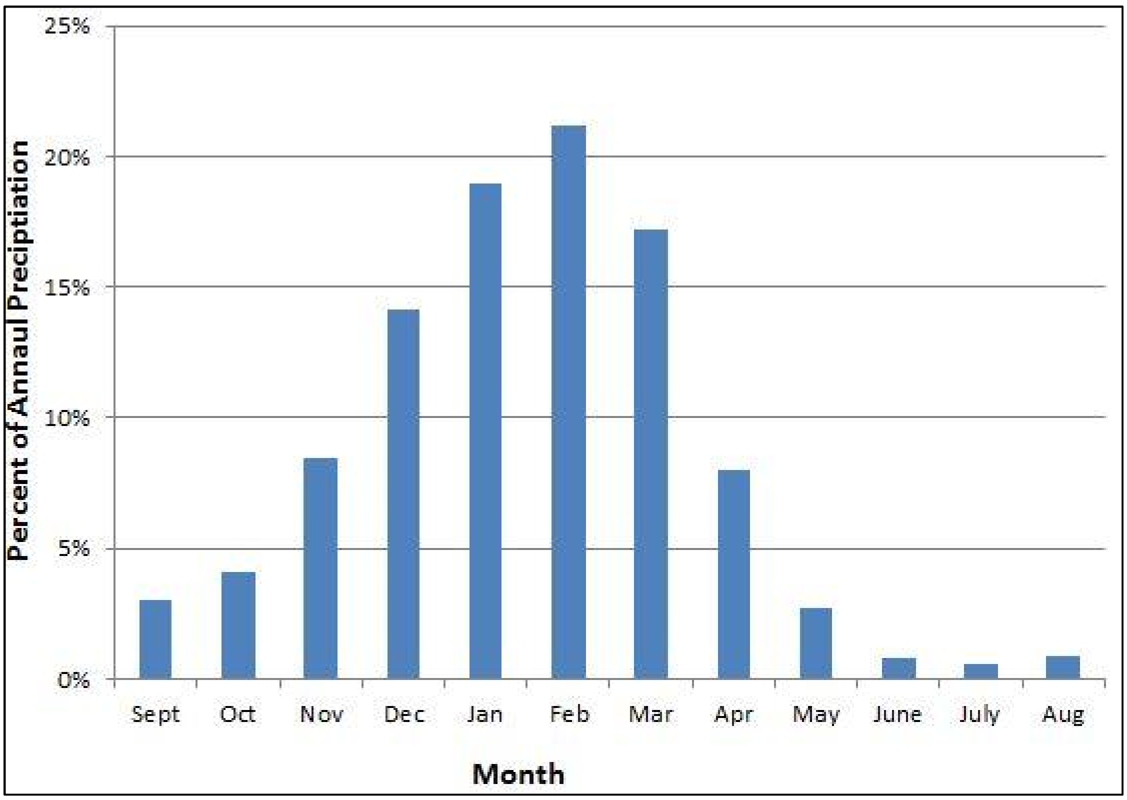

Figure 4.1 Four-station Monthly Precipitation Climatology, Percent of Annual Total

Table 4-1

Convective Band Passage Times and Characteristics, Water Years 2011-2015

Date	Time (PST)	700-mb temp (max)	700-mb temp (min)	700-mb Wind speed kts	700-mb Wind dir range	700-mb wind direction average
12/05/10	1800 - 2200	-2	-2	35	180-200	190
12/21/10	1700 - 2000	-3	-4	35	210-230	220
12/25/10	1800 - 2200	0	-1	45	180-200	190
01/01/11	1300 - 1600	-5	-5	25	260-290	275
01/02/11	0600 - 1000	-5	-7	35	220-240	230
02/16/11	0800 - 1100	-6	-8	45	230-260	245
02/18/11	1400 - 1700	-6	-6	50	220-240	230
02/19/11	1100 - 1400	-10	-12	30	240-270	255
03/02/11	0400 - 0600	0	0	35	240-260	250
03/19/11	2100 - 0000	-5	-7	35	220-240	230
03/20/11	0400 - 0600	-3	-4	35	220-230	225
03/23/11	0900 - 1300	-4	-7	35	230-	250

					270	
01/21/12	0100 - 0500	1	0	55	240-260	250
01/23/12	0500 - 0700	-4	-5	45	260-270	265
03/17/12	0400 - 0700	-2	-5	40	230-250	240
03/25/12	0400 - 0700	-2	-6	45	190-230	210
04/10/12	2200 - 0100	-4	-7	30	190-230	210
04/13/12	0500 - 0900	-8	-9	45	230-260	245
12/12/12	1700-2200	-3	-7	35	230-240	235
12/22/12	0900 - ?	-2	-4	45	230-250	240
12/25/12	2300 - 0100	-1	-4	40	250-270	260
12/29/12	0300 - 0500	-7	-9	20	220-270	245
02/19/13	1500-1700	-8	-10	30	240-270	255
03/07/13	2000 - 0000	-8	-8	30	220-230	225
12/07/13	0500 - 0800	-7	-9	40	260-280	270
02/02/14	1200 -1600	-6	-9	25	250-270	260
02/26/14	1800 - 2100	-1	-2	40	240-	245

					250	
03/01/14	1100 - 1400	-6	-6	35	220-240	230
03/31/14	1900-2300	-6	-7	30	250-270	260
04/01/14	2000 - 2300	-9	-10	30	260-270	265
12/12/14	0500 - 0700	-2	-5	45	210-230	220
12/16/14	2100 - 0100	-5	-7	20	250-270	260
02/07/15	0100 - 0400	1	0	45	240	240
03/01/15	1300-1500	-10	-10	10	200-250	225
03/02/15	1200-1400	-9	-9	10	200-250	225
04/07/15	1100-1400	-4	-6	30	250-270	260

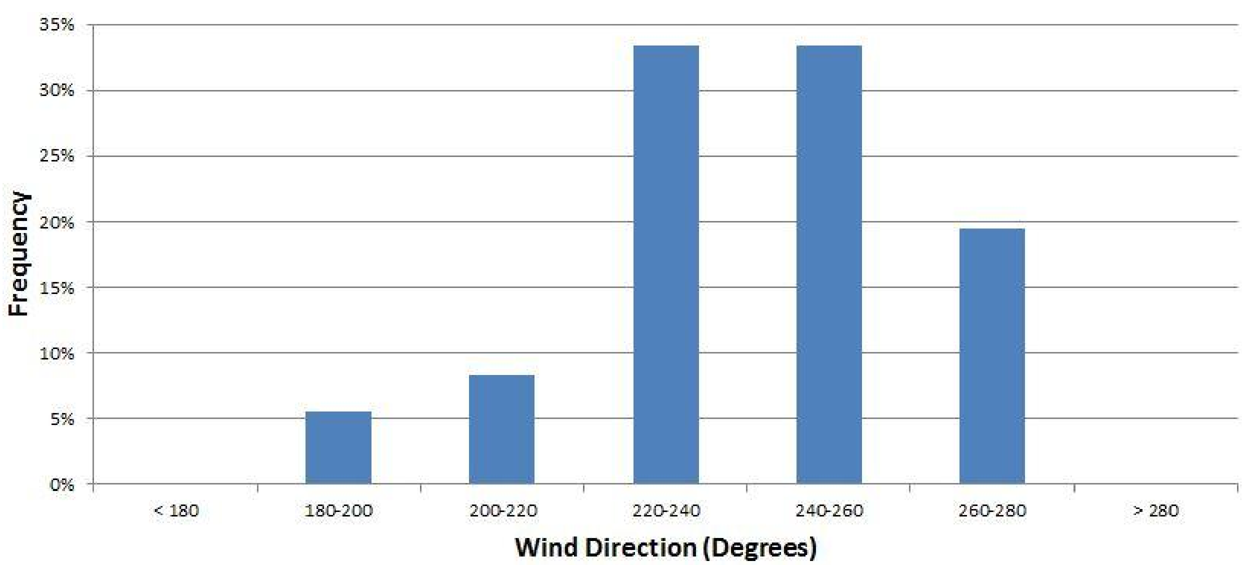

Figure 4.2 700-mb Wind Direction Frequency Plot during Convective Band Passages

Further breakdown of the convective band 700-mb data (estimates) shows that the 700-mb temperature averaged about -4.5^0 C during the early portion of a frontal convective band passage and around -6.0^0 C in the latter portion of the band passages, resulting in an overall average of a little colder than -5^0 C for the events in the table above. This implies a typical -5^0 C level between 9,000 and 10,000 feet MSL. On the cold end of the spectrum, 700-mb temperatures in the -10^0 to -12^0 C range will typically bring the -5^0 C level down to near 6,000 feet MSL during a significant precipitation period. On the warmer end, 700-mb temperatures around 0° C are typically associated with a -5^0 C level around 12,000 to 13,000 feet MSL, and occasionally higher if there is some mid-level thermodynamic stability involved as with some cases of tropical/subtropical moisture plumes. The height of the -5^0 C level is important as discussed in Section 2 since silver iodide nuclei begin to activate near this temperature. This means that silver iodide seeding material released from ground sites must rise to this level in order to begin the artificial augmentation of precipitation process. The generalized seeding criteria in Table 5-4 indicate that NAWC typically considers ground-based seeding operations in this area to be effective if the 700-mb temperature is -5^0 C or colder. Temperatures when using seeding aircraft are not as restrictive since the aircraft can be flown at higher altitudes in warmer storms (e.g., flight levels at the -5^0 C level).

Another consideration is monthly temperature distributions during storm events. Overall, early season (December and January) storms in the analysis were somewhat warmer (around -4^0 C average 700-mb temperature) than late season (March – April) events which averaged around -6^0 C at 700-mb. This concurs with some past analyses in other areas of California which indicate coldest storm period temperatures and lowest snow levels in general occur during March and April. The 700-mb wind speeds in the analyzed band passages also average higher during the early season (37 knots) compared to the later events (31 knots). This, combined with generally better atmospheric mixing during the spring due to a higher sun angle implies that more favorable seeding conditions are generally more likely during late season storm events. Near the end of the season (i.e., second half of April) synoptic-scale systems tend to transition from open-wave frontal systems with distinct band passages to, more commonly, upper closed-low types of systems which may present more disorganized convective and more variable wind patterns (e.g., easterly component). This becomes a negative factor late in the season when trying to target convective band passages to impact the target areas especially when using ground-based generators which are typically sited taking prevailing wind directions into account.

Weighing the above factors, for a four-month seeding program during a December – March (or mid-December through mid-April) time frame would be the most favorable. A five-month period of December – April would be a potentially good option, as would a more inclusive six-month period of November – April. From past experience, many November events are quite warm and often do not present distinct convective frontal band passages at the latitude of Santa Barbara / Ventura County's , thus November may be the least favorable of this six-month period in general.

Monthly streamflow data from the Cuyama River near Ventucopa could only be obtained for 1946-58 and 2010-14 and has very little overlap with any useful precipitation data, such that it does not appear feasible to obtain any historical relationship between rainfall and streamflow for this area in order to predict potential additional runoff due to seeding.

NAWC attempted to determine the frequency of any potential impacts to the "Grapevine" section of I-5 which runs along the eastern edge of the upper Cuyama Watershed and reaches elevations a little over 4,000 feet. Based on an analysis of five years of frontal band passages, it appeared that only a couple of these events were cold enough for snowfall at that elevation and seeding contributions to any snow accumulation on I-5 should be infrequent. Suspension criteria discussed in Section 5.6 include seeding suspensions if snow is predicted or observed to occur along the Grapevine.

5.0 DEVELOPMENT OF A PROGRAM DESIGN

5.1 Program Feasibility and Technical Program Design

Based upon information contained in the previous sections, it is NAWC's opinion that a winter cloud seeding program to target the UCRD is technically feasible. According to the American Society of Civil Engineers (ASCE 2016) for a proposed cloud seeding program to be considered to be feasible it must be both technically and economically feasible. Due to the lack of long-term streamflow records on the Cuyama River it is difficult to estimate the additional streamflow let alone ground water recharge that might be produced should a cloud seeding program be implemented. Therefore, we cannot assess the likely economic feasibility of this proposed program. We do provide cost estimates in Section 7. We have prepared the following proposed program design based upon our conclusion that a program would be technically feasible.

As stated previously, it has always been NAWC's philosophy that the design of our operational programs should be based upon prior research programs that provided positive indications of increases in precipitation, to the extent that the research results are considered to be representative of the operational programs' conditions (i.e., transferable results). The proposed program for the UCRD has a unique advantage in this regard since a well-funded winter research program Santa Barbara II, Phases I and II was conducted during the winters of 1967-1973. Section 2.4 discusses the results of this research program which were very positive. Furthermore there have been operational seeding programs conducted most winter seasons since 1981 targeting the Twitchell and Upper Santa Ynez drainages in Santa Barbara and southern San Luis Obispo Counties. The design of these programs since the early 2000's has been based upon the design used in the conduct of the Santa Barbara II research program. A recent peer reviewed evaluation of this operational program provided estimated results from seeding ranging from 9 to 21% (Griffith, et al, 2015).

Even though the Santa Barbara II research program was conducted approximately 40 years ago, it is our professional opinion that it offers the most relevant information for the design of precipitation enhancement programs for this area at the present time. There has not been any winter weather modification research conducted in representative coastal areas of the United States since Santa Barbara II. **This is a prime example of technology transfer from research to operations. We believe the best project design for a winter cloud seeding program in the UCRD is one that duplicates, as much as possible, the design of the Santa Barbara II research program. In fact, the combination of Phase I and II seeding modes (ground and airborne) should optimize the seeding potential for the area. Our design is based upon this approach.** More details regarding the proposed design are provided in a categorical fashion in the following sections.

The recommended operational five-month period would be December 1st through April 30th each winter season. The vast majority of the annual precipitation in this area occurs during this five month period. A base program is recommended that would involve the siting, installation and operation of two or three ground-based remotely operated flare tree units. Figure 5.1 provides a photo of a site being used on the current Santa Barbara winter seeding program. Section 5.9 provides some potential sites based upon some HYSPLT modeling runs. Follow-on site surveys would be needed to determine the utility of these sites which are beyond the scope of this study. Land ownership will also need to be considered. The Santa Barbara County Water Agency arranges annual leases for the six sites used on the Twitchell and Upper San Ynez drainage programs.

A cloud seeding aircraft could be added to augment (perhaps for a three or four month period) the recommended base program using ground-based flare units. Seeding aircraft are expensive to lease and operate. There may be the potential to share the utilization of seeding aircraft like ones that the Water Agency has often included in their programs for the Twitchell and Upper San Ynez drainage target areas. This may be feasible since the targeted clouds are convective bands that tend to travel across Santa Barbara County in generally a west to east fashion. In other words a seeding aircraft may be able to travel with bands as they move through one or both of the Water Agencies target areas, then continue seeding bands as they enter the UCRD Cuyama target area. Figure 5.2 provides a photo of a Cheyenne II cloud seeding aircraft used in Santa Barbara County during the 2015-2016 winter season. This seeding aircraft uses the same silver iodide flares as used in the ground-based sites.

Figure 5.1 West Camino Cielo AHOGS Site

Figure 5.2 Cheyenne II Cloud Seeding Aircraft with End Burning Flare Racks

5.2 Personnel

Depending upon the seeding mode (i.e., ground based flares, aircraft seeding) or modes used there may be the following staff positions: 1) a program supervisor, 2) a program meteorologist, 3) a pilot, and 4) a local part time technician. The supervisor and meteorologist could operate from the contractor’s headquarters. The pilot would be stationed at a suitable airport in proximity to the target area. NAWC recommends that a Weather Modification Association (WMA) Certified Manager be the program manager and that a WMA Certified Operator serve as the program meteorologist.

The program meteorologist will perform the various project duties needed to conduct a safe and effective operation. A partial list of these duties is provided in Table 5-1.

Table 5-1

Partial List of Duties to be Performed by Program Meteorologist

1)	Constantly monitor weather conditions and determine, based on meteorological data and radar observation, the approach of seedable storm systems.
2)	Estimate the probable results and impacts of seeding using predictive computer models, real time rain and river flow data ("Alert System" provided by Flood Control), and other information. Such estimates shall be updated regularly as conditions change.
3)	Coordinate with Flood Control and Water SBCWA personnel to determine potential flows in key water courses and determine the appropriate action regarding seeding activities.
4)	Direct the actual seeding operations using appropriate storm selection and target area criteria and continuously monitor air and ground seeding operations using radar and remote interrogation systems.
5)	Maintain constant and continuous control over all air and ground seeding devices and keep an accurate written or digital log of the time that each and every generator is activated and deactivated (flare fire times) and in the case of aerial seeding, aircraft position.
6)	Inform Flood Control and SBCWA Personnel, through prescribed communication channels and in a timely manner, of all significant events relative to the program, including beginning and ending seed times.
7)	Provide necessary radar and precipitation data to Flood Control and Water SBCWA staff as requested during periods of heavy rainfall or flooding.
8)	Determine when conditions are such that program operations should be suspended for any weather related reason and adhere to suspension criteria designed by Flood Control and the SBCWA prior to project initiation.
9)	Maintain, and submit copies of written operations reports to the SBCWA in a timely manner. At a minimum, such reports shall be submitted subsequent to each seeding event and should involve a discussion of the above referenced items (see Communications for final report requirements).

If a seeding aircraft is part of the program, a licensed and instrument-rated pilot qualified to fly weather modification or similar weather and terrain demanding conditions should be available on a 30 minute notice during the aerial part of the project period. This pilot would need to meet the requirements imposed by aircraft insurance carriers which can be rather stringent.

The combination of an experienced pilot with an experienced meteorologist provides a very workable combination. It is possible for aircraft operations to be directed from the Contactors headquarters using a phone patch system that allows communications between the pilot and meteorologist during seeding flights. A specialized system known as Spider Tracks can be mounted in the seeding aircraft which provides frequently updated aircraft tracking information that can be displayed in the contractor's headquarters on a computer via the internet.

A local part time technician would provide technical on an as needed basis. For example, this technician could be responsible for the installation, recharging, maintenance and de-commissioning of the ground based flare sites. This technician could also provide support to the pilot if a seeding aircraft is utilized.

5.3 Weather Radar

Prior to 1992 weather radar information from the National Weather Service (NWS) was limited in the western United States. This situation changed dramatically when the NWS, through a modernization effort in the 1992-1997 period, installed a network of very sophisticated 10 cm weather radars throughout the U.S. These sites are known as NEXRAD (Next Generation Radar) installations. Each installation cost on the order of $1,000,000. Figure 5.3 provides the array of these sites across the U.S. There are 160 NEXRAD sites now in service. NEXRAD radars provide information on precipitation intensities and wind speed and direction within the precipitation echoes. The radars step scan through 14 different elevation angles in a 5 minute period and a computer program integrates the stepped scans into a volume scan. Several very sophisticated algorithms then produce a large number of specialized displays and products from each volume scan. The maximum range for the detection of precipitation echoes is 143 miles from each site. The NWS provides all the necessary support for these systems; operation, calibration, spare parts and maintenance since the NEXRAD network is very important to NWS forecasting and public safety responsibilities, to many hydro-meteorological applications and to aviation safety. As a consequence these radars enjoy high priority support and resultant reliability. The Vandenberg AFB and the Los Angeles NEXRAD radars would provide good coverage of the proposed target area.

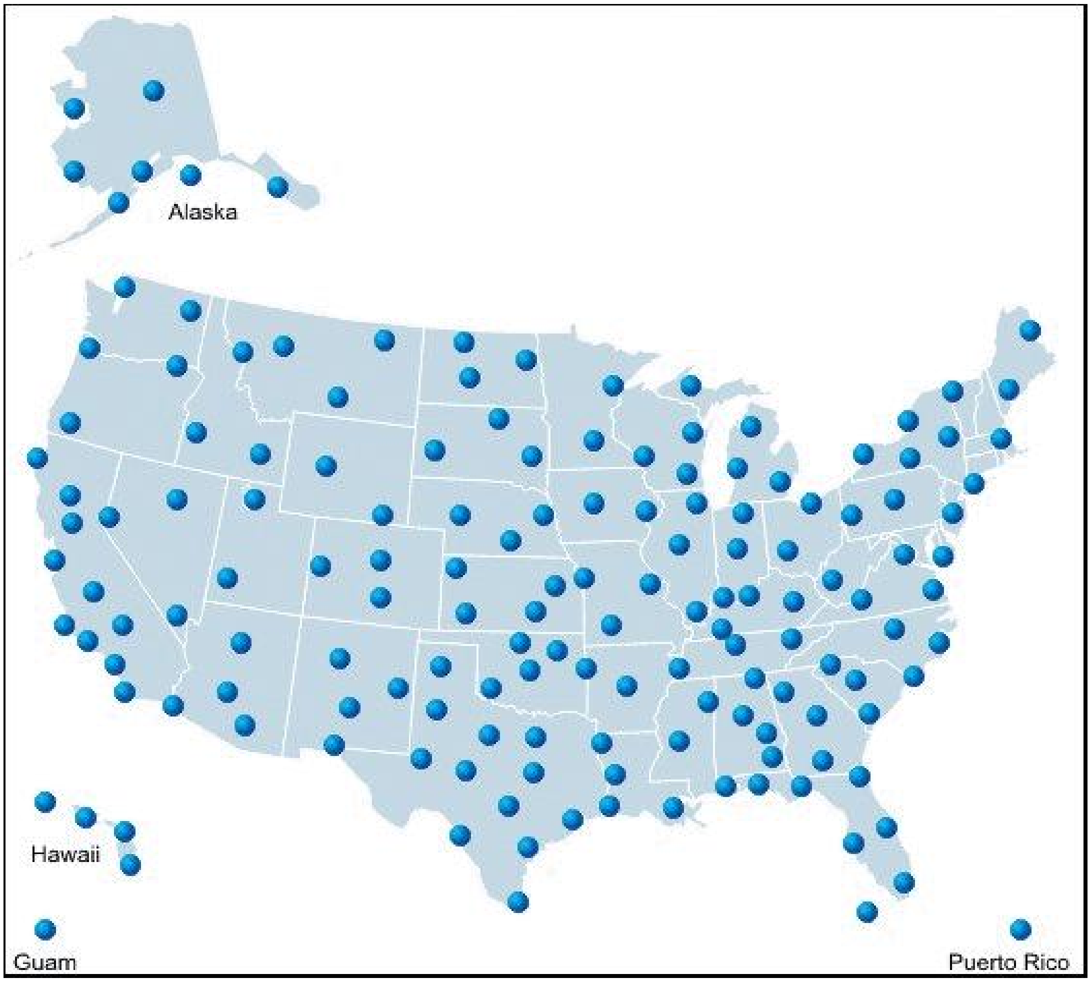

Figure 5.3 US NEXRAD radar locations

NEXRAD data are available in near real time at approximately 5-6 minute intervals through a variety of internet web sites. NAWC has utilized the WeatherTap (commercial, subscription) web site extensively over the past eleven years to provide radar data to conduct wintertime cloud seeding programs in Santa Barbara County. This web site provides a variety of useful products including: echo intensities (precipitation), echo tops, vertical distribution of wind speed and direction (the very useful VAD upper level wind displays), composite echo displays that integrate radar returns from all of the 14 different elevation scans. There are two primary NEXRAD sites that provide coverage of Santa Barbara County: Vandenberg AFB and Los Angeles (actually located near Ojai).

The Doppler wind capability provides rapid update (every six minutes) NEXRAD vertical azimuth display (VAD) wind profiles which are invaluable in visualizing and identifying changes in the environmental wind fields that may affect seeding material and precipitation fallout trajectories. Figure 5.4 provides an example of VAD wind profiles for approximately a one hour period during a storm that impacted Santa Barbara County on February 26, 2014. This figure provides wind barbs at 1,000 foot intervals from 0340-0423 PDT. The wind direction is given by the direction the barbs are pointing. Lower-level winds during this period were blowing from the south in lower levels then veering to southwesterly above 6,000 feet. This is typical of a pre-frontal wind field during the passage of winter storms passing through Santa Barbara County. The strength of the wind is indicated by the number of flags on each barb. Typically each barb represents a wind speed of 10 nautical miles per hour, a short barb 5 nautical miles per hour. A triangular colored barb represents a value of 50 nautical miles per hour. It is seen that the wind speeds were 15-30 knots above the 6,000 foot level during this period.

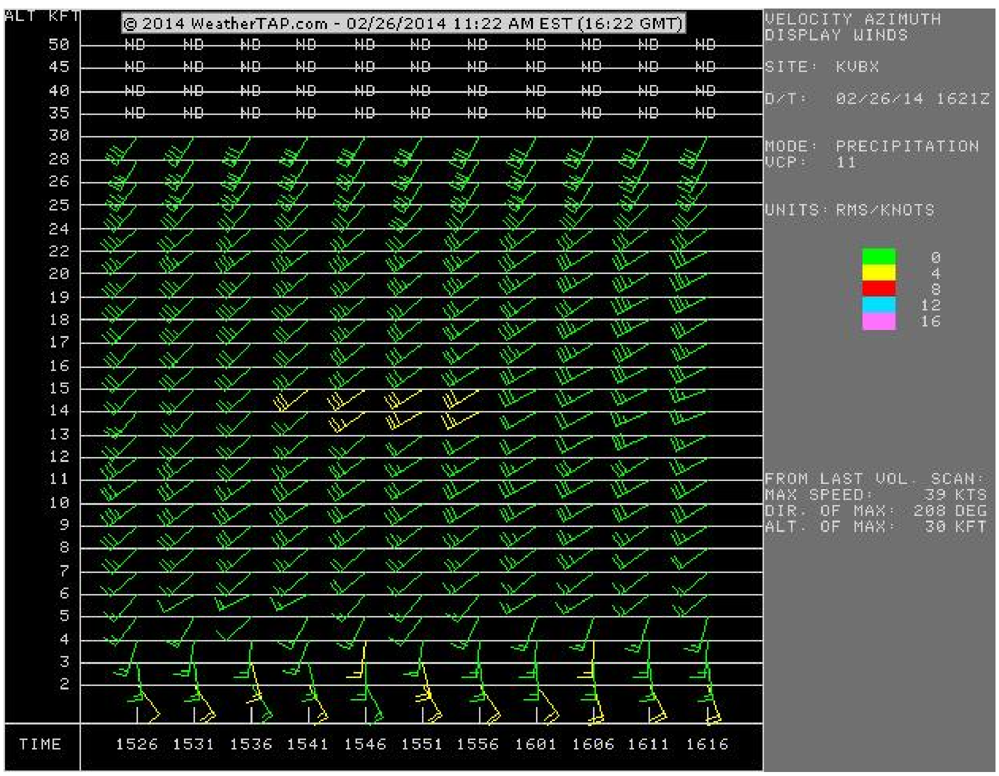

Figure 5.4 Vandenberg AFB Doppler winds, 0726-0816 PST, February 26, 2014

Figure 5.5 provides a Vandenberg Air Force Base NEXRAD radar image showing a convective band approaching Santa Barbara County at 1000 PST February 28, 2014. The different colors in this figure represent different radar reflectivity (dBz) levels, which correspond to different rainfall rates. Utilization of NEXRAD data to conduct cloud seeding programs in the Santa Barbara area requires a separate provision of cloud seeding aircraft location and flight track information.

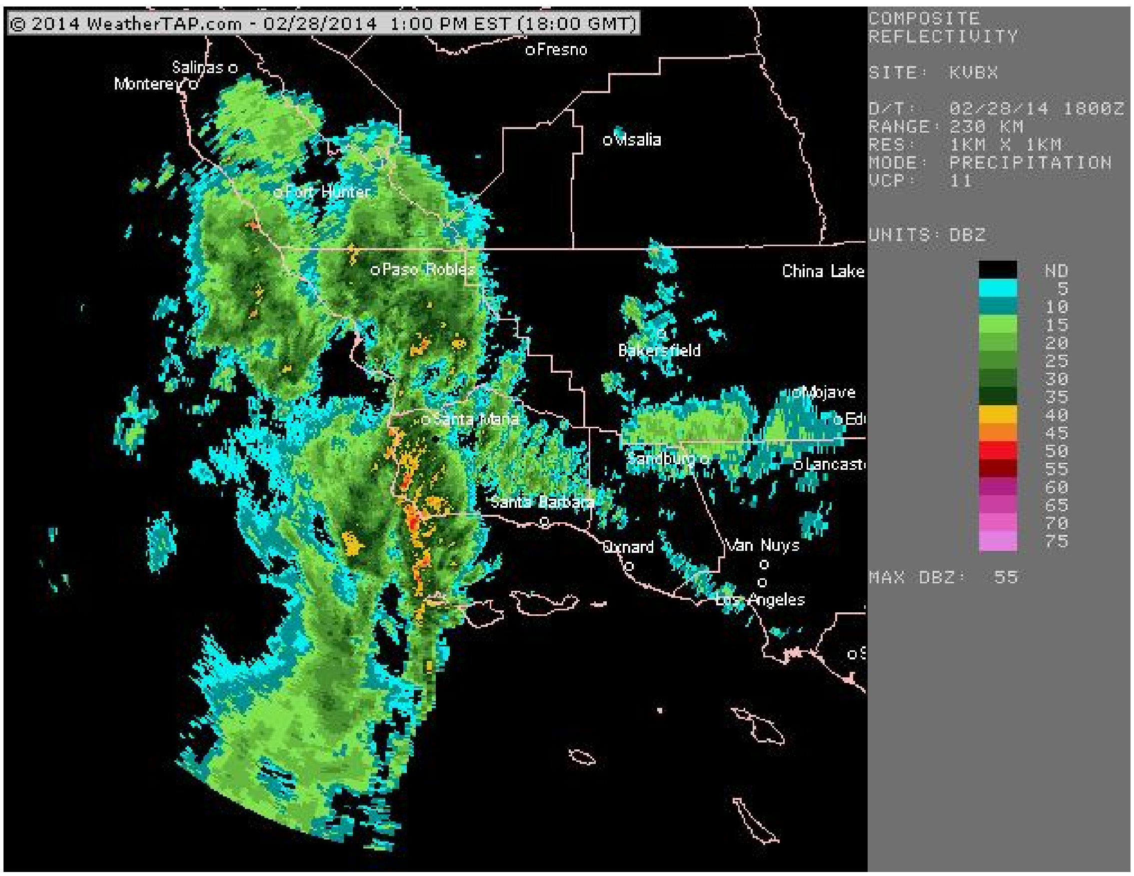

Figure 5.5 Vandenberg AFB radar image at 1000 PST on February 28, 2014

5.4 <u>Ground Seeding Sites</u>

NAWC developed a completely new design for a remotely controlled ground based flare sites for the 2001-2002 Santa Barbara winter program (AHOGS - Automated High Output

Ground Seeding System). This new design was used for the 2001-2016 programs with some upgrades with time. The AHOGS system allows automated, focused, high-output seeding releases from strategic ridgeline locations under program control from the project operations center with the proper computer software and password. These systems give the project meteorologist the ability to conduct intensive seeding of convective rain bands as they track into and across the project area under different wind flow regimes on a 24/7 basis. Each AHOGS consists of the following primary onsite components:

- Two flare masts, which hold a total of 32, 150-gram (fast-acting AgI) flares.
- Spark arrestors that enclose each flare.
- An environmentally sealed control box containing a cellular phone communications system, digital firing sequence relays/controller, data logger and system battery.
- A solar panel/charge regulation system to maintain site power.
- Cellular phone antenna.
- Lightning protection.

Each site is controlled via a modem-equipped PC at the operations center, running custom software to manage the flare seeding operations. The meteorologist has the option of firing flares individually in real time, or to order batch firing of any number of flares at selectable intervals at each site, e.g., three flares at 15-min intervals, beginning at any selected time. The software allows monitoring and reporting of AHOGS site status information, such as flare inventory and battery voltage. These units do not require back up power since they each have their own DC battery that is recharged using a solar panel. These units have performed very reliably over the years of operations.

The same or similar system is proposed to be used on the UCRD program. The siting, installation and operation of two or three sites is proposed. Approximate tentative locations are discussed in Section 5.9 based upon some HYSPLIT modeling studies.

Figure 5.6 shows a close-up of flares mounted in one of the masts. The original AHOGS design was modified for the 2005-2006 program through the introduction of a NAWC custom designed spark arrestor. These spark arrestors, which fit over each of the flares, were developed to assure no large sparks or burning embers were released from the flare burns that could pose a fire concern. Normally, this would not be a concern since flares are only burned when rain is occurring eliminating any fire danger. These arrestors were developed in case of an accidental misfire or burning flares at the beginning of a storm following an extended dry spell. Figure 5.7 provides a photo of a flare burning inside a spark arrestor.

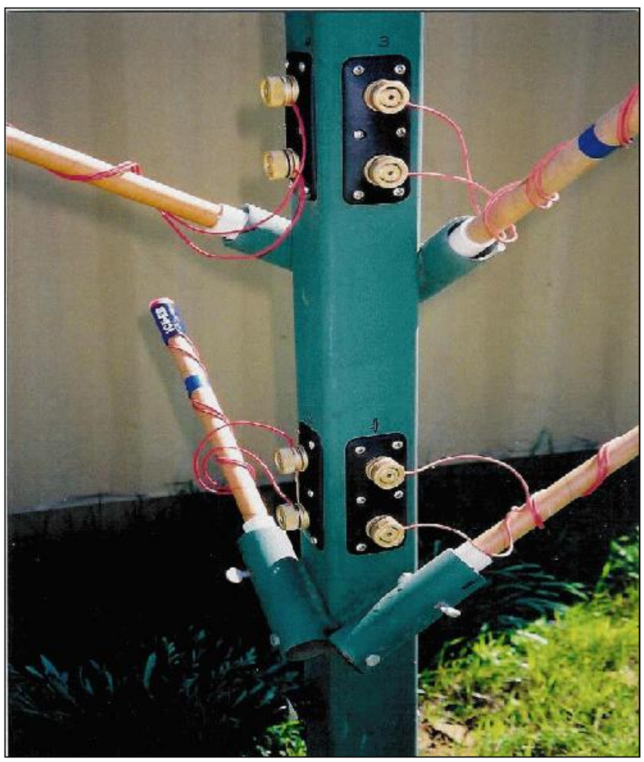

Figure 5.6 Close-up Photo of Flares

Figure 5.7   Flare Burning Inside Spark Arrestor

The basic concept of both the aircraft and ground seeding in the Santa Barbara II research program was to place as much seeding material as possible into the warmer updraft regions of the convective bands with cloud tops colder than freezing (i.e., -4^0 to -10^0 or -12^0 C). High output liquid fueled silver iodide generators were flown on the aircraft and 400 gram output ground silver iodide flares were fired every 15 minutes during the passage of convective bands over the single seeding site. The 400 gram flares (known as LW 83's) were considered very high output at the time, but have been replaced by even more effective (in terms of nuclei production) units utilized by NAWC starting with the 2001-2002 program.

The pyrotechnic flares used at the AHOGS sites will emit ~15 grams of fast-acting silver iodide complex seeding material during a burn time of approximately four minutes. Ice Crystal Engineering (ICE) of Fargo, North Dakota manufactures these flares. Some information concerning the flare manufacturer ICE is as follows: ICE was incorporated in 1999. ICE primarily manufactures three types of flares; an ejectable 20 gram silver iodide flare, a burn in place 150 gram silver iodide flare and a burn in place 1000 gram hygroscopic flare. ICE supplies flares to 20 different countries on 5 continents. Over 90% of ICE sales are to customers outside the United States.

The output of the ICE flares has been tested at the Colorado State University (CSU) Cloud Simulation Laboratory. Table 5-2 provides the results of this testing. For reference purposes, 1 trillion is equal to 10^{12}. These flares exhibited activity up to temperatures of -4^0 C, which is considered very desirable since activity at these warm temperatures can result in the creation of more artificially generated ice crystals at lower altitudes in the clouds. A couple of advantages can result:

- Ground releases of seeding material can activate more quickly since the -4^0 C level will be reached sooner than say -6 to -8^0 C which may have been the case with earlier generation flares.
- Conversion of water droplets to ice crystals at the -4^0 C level can release additional latent heat of fusion at lower altitudes within the seeded clouds, which should enhance the dynamic response of the clouds to seeding (refer to section 2.0 for a discussion).

A second important outcome of the testing of these flares at the Cloud Simulation Laboratory was that, when the seeding material was introduced into the cloud chamber, 63% of the ice crystal nucleation was produced within the <u>first minute</u> of introduction of the material into the chamber. It was therefore concluded that these flares were operating by the condensation-freezing mechanism. This is also considered to be an advantage over the earlier generation flares that no doubt operated by the contact nucleation process, which is much slower. This should mean that nearly all of the seeding material that reaches temperatures of -4^0 C within target clouds should quickly be utilized in producing ice crystals. Use of the earlier LW-83 flares, due to the slowness of the process, could mean that some of the seeding material was not activated in time to produce a seeding effect in the intended target areas. In fact, this characteristic may partially explain the extended downwind effects shown in Southwest Kern County during the conduct of Santa Barbara II, Phase I (see Figure 2.2).

Table 5-2 CSU Cloud Chamber Test Results for Ice Crystal Engineering Burn in Place Flare

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

The newer ICE flare can be compared to the earlier LW 83 flare based upon tests conducted at the CSU Cloud Simulation Laboratory. Table 5-3 compares the ICE and LW 83 output. Figure 5.8 provides a comparison of the nucleating characteristics of the ICE and the LW 83 flares.

Table 5-3 Nuclei Production per Gram of Seeding Material for LW-83 and ICE Flares

Temperature (^{0}C)	LW-83 (400g)	ICE (150g)
-4	2 x 10^{9}	1.5 x 10^{11}
-6	4 x 10^{10}	6 x 10^{12}
-10	3 x 10^{13}	3 x 10^{13}

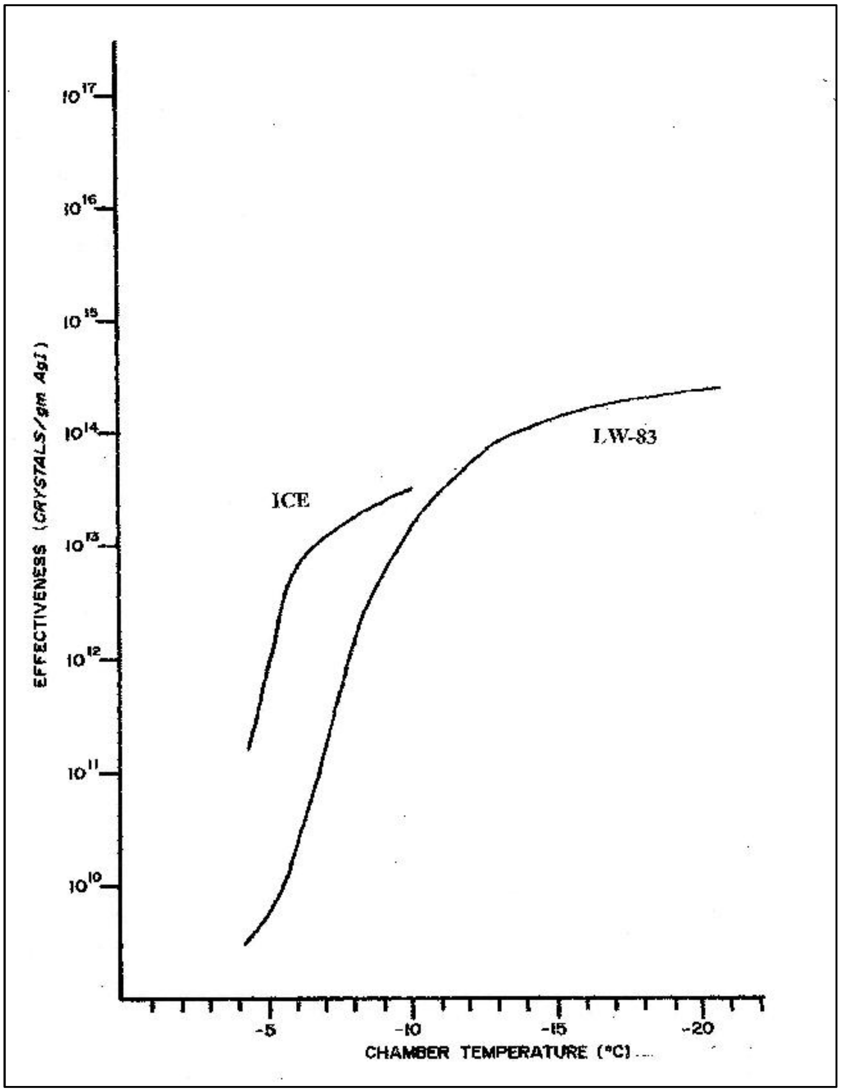

Figure 5.8 Comparison of Effectiveness of the LW-83 Verses the ICE Burn-in-place Flare, CSU Cloud Chamber Results

Figure 5.8 demonstrates that the ICE flare can produce more ice crystals (per gram of seeding material) in the critical temperature regions from -4 to -10^0 C (as much as two orders of magnitude higher at –4^0 C) than the older LW 83 flare, although the latter flare contained more seeding material. This temperature region is of prime importance to seeding-induced increases in precipitation in Santa Barbara County. Freezing supercooled water droplets in the upper (colder) portions of the bands may not necessarily contribute substantially to the production of increased rainfall at the ground. NAWC proposes that the ICE 150 gram burn in place flares be used at the ground flare sites established for the UCRD Cuyama program.

5.5 Cloud Seeding Aircraft

As mentioned earlier, a cloud seeding aircraft could be used to augment the basic ground based flare seeding program. Typical aircraft used on programs of this type include Cessna 340's, Cheyenne II's and King Air 90's. Any seeding aircraft used should be certified for flight in known icing conditions due to the type of clouds that would be seeded.

This aircraft would be equipped with two burn in place flare racks (mounted on the trailing edge of each wing). The same 150 gram ICE flares used at the ground sites would be used in the burn in place flare racks.

5.6 Seeding Operations

NAWC's conceptual model of the dynamics of the convective bands is that they are similar to summer squall lines in the Great Plains. NAWC believes that the primary low to mid-level inflow to these bands is along the leading edge of the bands. The inflow regions are thought to be the likely accumulation zones of supercooled liquid cloud droplets water, which are the targets of the seeding. Consequently this is the desired region for the introduction of the seeding material. This would mean that flares burned at the ground sites should be timed to occur as the leading edge of the bands, as determined by the 6-minute PPI Vandenberg AFB or Los Angeles NEXRAD radars, approach the ground sites. The seeding aircraft would be flown along the leading edge of the bands somewhere between the freezing and -5^0 C level. Low-level winds need to be considered in terms of targeting of seeding effects as well as the avoidance of seeding over suspension areas. The HYSPLIT model, discussed in Section 5.8.2 would be used in real time to help predict the plume dispersion from flares burned. In addition to the specific criteria in the above which focus on the presence of convective bands, NAWC also recommends consideration of some generalized seeding criteria provided in Table 5-4. These are general guidelines and the Project Meteorologist may override these criteria based upon his or her professional judgement about the meteorological conditions associated with a specific storm.

Table 5-4 Generalized Seeding Criteria

1) CLOUD BASES ARE BELOW THE MOUNTAIN BARRIER CREST.

2) LOW-LEVEL WIND DIRECTIONS AND SPEEDS THAT WOULD FAVOR THE MOVEMENT OF THE SILVER IODIDE PARTICLES FROM THEIR RELEASE POINTS INTO THE INTENDED TARGET AREA. WINDS AT THE 850MB LEVEL (~ 4,000 FEET MSL) ≤ 50 KTS.

3) NO LOW LEVEL ATMOSPHERIC INVERSIONS OR STABLE LAYERS THAT WOULD RESTRICT THE VERTICAL MOVEMENT OF THE SILVER IODIDE PARTICLES FROM THE SURFACE TO AT LEAST THE -5°C (23°F) LEVEL OR COLDER.

4) TEMPERATURE AT MOUNTAIN BARRIER CREST HEIGHT IS -5°C (23°F) OR COLDER.

5) TEMPERATURE AT THE 700-MB LEVEL (APPROXIMATELY 10,000 FEET) IS WARMER THAN -15°C (5°F).

6) CLOUD TOP TEMPERATURES $< -25^{0}$ C (-13^{0} F).

A detailed operations plan should be developed by the contractor specifically for this program. This plan would be available as a reference for all program personnel. An important part of this Operations Plan will be program suspension criteria; criteria that specifies under what conditions seeding operations should be suspended or not initiated. Table 5-5 provides some recommended criteria. Most of these criteria were taken from criteria currently being used on the Twitchell and Upper Santa Ynez watershed programs. Some additional criteria may need to be considered based upon predicted or observed streamflow on the Cuyama River. Another possible concern could be rainfall intensities. Criteria could be developed for some cutoff criteria (e.g. > 1.00" per hour).

Table 5-5 Recommended Upper Cuyama River Suspension Criteria

1. Whenever the National Weather Service (NWS) issues a severe storm, precipitation, flood warning or flash flood warning that affects any part of the project area, the project meteorologist shall suspend operations which may affect that part. Operations will be suspended at least for the period that the warning is in effect.

2. The Project Meteorologist or District/Agency personnel shall retain independent authority to suspend cloud seeding operations for any part, or all of the project area in the event that unforeseen conditions develop during storm events which in their best judgment have the potential to cause flooding or other adverse conditions anywhere within the project area.

3. No targeting of seeding operations which affect the urbanized areas of the South Coasts of Santa Barbara or Ventura County south of the Santa Ynez Mountains Ridgeline will be conducted.

4. No seeding if the Oxnard National Weather Service office forecasts snow on the Grapevine potion of I-5 north of Los Angeles or if snow is reported on this section of the highway.

5.7 Weather Data

There is a wealth of weather information available via the internet. There are a number of products that are useful in the conduct of cloud seeding operations. NAWC's web site (www.nawcinc.com) contains an extensive list of useful weather links.

The following list some of the weather products that may be useful in the conduct of the UCRD program:

1) The Santa Barbara and Ventura County ALERT weather networks.

2) The National Weather Service surface, upper air and precipitation observations and predictions (e.g., the GFS, NAM and WRF models). Other forecast models are discussed in the next section.

3) The California River Forecast Center Quantitative Precipitation Forecasts (QPFs).

4) Satellite images; infrared (IR), water vapor (WV), or visible. IR images provide Information both day and night and also provide information on cloud top temperatures. Visible images are only available during daylight hours but the resolution on the images is better than the resolution on the IR products.

5) National Weather Service NEXRAD radar images, showing reflectivity values associated with precipitation near the times when seeding occurred. These displays are called Plan Position Indicator (PPI) images which are horizontal depictions of the radar reflectivity values within range of the radar. These images give an indication of the type, intensity, and extent of precipitation during seeding periods. Wind direction and velocity are also observed by the NEXRAD radars through the Doppler feature, which is part of the NEXRAD design. Plots of winds in the vertical in 1000-foot increments are available with a 6-minute time resolution from NEXRAD radars. These displays are called Velocity Azimuth Displays (VAD). Customized programs utilizing NWS NEXRAD data will also be used; for example WeatherTap.

6) Skew-T upper-air soundings from Vandenberg AFB. The skew-T sounding is a plot of temperature, dew point, and winds vs. height, observed by a radiosonde (balloon borne weather instrument). This sounding information is useful for analyzing various parameters of the atmosphere including temperature and moisture profiles, and convective potential. Soundings are available twice daily at 0400 and 1600 PST. The 700 mb (approximately 10,000 feet) temperatures are frequently reported in the following storm summaries. NAWC typically prefers to see these temperatures at -5^{0} C or colder during seeded periods since silver iodide becomes effective as a seeding agent between –4° and -5^{0} C. The closer the height of the -5^{0} C level is to the ground seeding, the quicker a seeding effect will begin to be produced as the convective elements embedded in the

convective bands begin to move over Santa Barbara County. These convective elements vertically transport the seeding material from the ground seeding sites to colder temperatures aloft.

7) National Weather Service weather watches, weather warnings, and flash flood warnings.

5.8 Computer Modeling

Specialized computer models can be used in the conduct of this program. These models are of two basic types: 1) those that forecast a variety of weather parameters useful in the conduct of the cloud seeding program (e.g. NAM or WRF) and 2) those that predict the transport and diffusion of seeding materials (e.g., HYSPLIT).

The National Oceanic and Atmospheric Administration NOAA) runs standard atmospheric models: NAM (formerly ETA) and GFS in forecasting seedable events and associated parameters of interest (e.g. temperatures, winds, precipitation). These models can be used, especially for longer range forecasts. A more sophisticated model can be used for shorter range forecasts. This is the Weather Research and Forecasting (WRF) model developed by the National Center for Atmospheric Research (NCAR) and NOAA. Recently this model has shown considerable skill in predicting precipitation, pressure fields, wind fields and a variety of other parameters of interest in conducting the cloud seeding operations. There are several web sites that provide WRF model output (e.g., NOAA, NCAR, and University of Utah).

The HYSPLIT model developed by NOAA provides forecasts of the transport and diffusion of either ground or aerial releases of some material, which in our case would be silver iodide seeding particles. The WRF and HYSPILT models will be discussed separately in the following.

5.8.1 WRF Model

The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. It features multiple dynamical cores, a 3-dimensional variational (3DVAR) data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometers.

The effort to develop WRF has been a collaborative partnership, principally among the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (the National Centers for Environmental Prediction (NCEP) and the Forecast Systems Laboratory (FSL), the Air Force Weather SBCWA (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA). WRF allows researchers the ability to conduct simulations reflecting either real data or idealized configurations. WRF provides operational forecasting a model that is flexible and efficient computationally, while offering the advances in physics, numerics, and data assimilation contributed by the research community.

The WRF model has a 3km grid spacing compared to the more standard grid model spacing of 12km (e.g. NAM model), plus it is re-initialized every hour using the latest radar observations. Smaller grid spacing in models generally produce more accurate predictions especially in complex terrain (e.g. mountainous areas). The NAM and GFS models are currently re-initialized every 6 hours. Hourly forecast outputs from the HRRR model are available for a variety of parameters out to 15 hours. Table 5-6 provides a summary of some of forecast parameters of interest in conducting cloud seeding program.

Table 5-6 HRRR Forecast Parameters of Interest

Parameter	Application
1km above ground level reflectivity	Forecast of convective band locations based on radar returns 1km above ground
Composite reflectivity	Forecast of convective band locations using reflectivity values from different scan elevations. This is useful when bands approach the radar

	site since low elevation scans may go underneath the bands.
Max 1km above ground level reflectivity	Forecasts that pinpoints the location of the heart of the convective bands
1 hour accumulated precipitation	Forecasts of radar derived estimates of precipitation reaching the ground in a one-hour period (QPF).
Total accumulated precipitation	Forecasts of radar derived estimates of precipitation reaching the ground for a specified time period, for example 1-6 hours in the future (QPF).
850 mb winds	Forecasts of the 850 mb (~4,000 feet) wind direction is useful in determining if and when wind directions may go out of bounds in regards to suspension criteria.(e.g., avoiding burn areas)
700mb temperature	NAWC uses this level, which is ~10,000 feet, to indicate whether silver iodide will activate. Temperatures< -5^0 C are desirable at this level
700mb vertical velocity	Forecasts the strength of the upward or downward movement at ~the 10,000 foot level. Stronger updrafts favor transport of seeding material to colder, more effective cloud regions.
Echo top height	Forecasts of cloud echo tops. Can be useful in determining whether the cloud tops are forecast to be cold enough for silver iodide to be effective (~-5^0 C) and perhaps too cold <-25^0C to produce positive seeding effects.

Since the design of the program which is focused upon seeding convective bands, and the seeding techniques as described in Section 5.6, it can be seen that forecasts of convective band locations are not a requirement but are useful when using the ground-based seeding sites. Seeding decisions for ground-based sites can be made using real-time NEXRAD radar information indicating when a convective band is approaching a particular seeding site. These forecasts become more useful in airborne operations in order to provide lead time in filing flight plans to coincide with convective band passages. The precipitation type forecasts are useful when considering suspension criteria.

5.8.2 HYSPLIT Model

The HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model is the newest version of a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations. As a result of a joint effort between NOAA and Australia's Bureau of Meteorology, the model has recently been upgraded. New features include improved advection algorithms, updated stability and dispersion equations, a new graphical user interface, and the option to include modules for chemical transformations. Without the additional dispersion modules, HYSPLIT computes the advection of a single pollutant particle, or simply its trajectory.

The dispersion of particles released into the atmosphere is calculated by assuming either puff or particle dispersion. In the puff model, puffs expand until they exceed the size of the meteorological grid cell (either horizontally or vertically) and then split into several new puffs, each with its share of the pollutant mass. In the HYSPLIT particle model, a fixed number of initial particles are advected about the model domain by the mean wind field and a turbulent component. The model's default configuration assumes a puff distribution in the horizontal and particle dispersion in the vertical direction. In this way, the greater accuracy of the vertical dispersion parameterization of the particle model is combined with the advantage of having an ever-expanding number of particles represent the pollutant distribution.

The model can be run interactively on the Web through the READY system on the NOAA site, or the code executable and meteorological data can be downloaded to a Windows PC. The Web version has been configured with some limitations to avoid computational saturation of the web server. The registered PC version is complete with no computational restrictions, except that the user must download the necessary meteorological data files. The unregistered version is identical to the registered version except that it will not work with forecast meteorology data files.

NAWC has utilized the HYSPLIT model to predict the transport and diffusion of silver iodide seeding material during selected storm periods in Santa Barbara County during the past six winter seasons of operations.

The real-time predictions of plume transport that were used previously utilized input fields from the NAM model at a 12km grid spacing. Data are now available for real-time simulations that have a grid resolution of 4 km (similar to some of the WRF models). The 3km data are not archived due to the size of the files, thus providing only simulations in real-time. Simulations for prior storm events may be run using NAM 12 km archived data. The accuracy of the plume predictions is sensitive to the grid size, especially in areas that have underlying complex terrain (e.g. mountainous areas). The smaller the grid spacing becomes the better the predictions in these situations.

The depictions from HYSPLIT are of the transport of the seeding plumes. The seeding material needs to interact with the convective bands forming ice crystals which grow into snowflakes which then fall to the ground changing into rain drops as they pass through the freezing level. These processes occur as the band moves downwind in time. Consequently, these depictions are of the initial transport and diffusion phase of the plumes while the resultant fallout of augmented precipitation would occur downwind of these plume depictions (typically to the east or northeast of these plume depictions). Although the plumes predicted by HYSPLIT may pass over urbanized areas (e.g., Santa Maria), there would be no or minimal impact in these areas since the upper portions of the plume are just reaching activation levels near the tail end of these predicted plume locations. Of note is the fact that the National Center for Atmospheric Research (NCAR) has been developing and validating a plume transport, seeded microphysical interactions and fallout of seeding generated particles. This model may be available to the public sometime in the future.

5.9 HYSPLIT Modeling for the Proposed Upper Cuyama River Seeding Program

The HYSPLIT model was run to access the potential use of five ground-based AHOGS sites and potential airborne seeding tracks for the proposed UCRD program. We did not expect that five sites would be warranted but felt by running the model for five sites we could select the best 2 or 3 sites based on predicted impacts in the target area. The five potential ground sites were selected from Google Earth with the intent being to locate sites along ridgelines or elevated locations upwind of the proposed target area. Figure 4.3 from section 4.0 indicates that the 700 mb wind directions with convective bands range from 180^0 to 270^0 with prevailing directions from 220^0 – 260^0. Wind directions in meteorology are reported from the direction the winds are blowing from. For example a 270^0 wind direction would mean the winds are blowing directly from the west towards the east. The 700 mb level (approximately 10,000 feet MSL) is a good representation of the movement of convective bands as well as the mean transport of ground-based seeding plumes. Given these considerations, ground-based AHOGS sites should be located upwind of the proposed target in the 180^0 to 270^0 quadrant.

HYSPLIT modeling was performed on eight convective bands that moved through the county during water years 2011-2015. The time of band passage through the proposed target area was estimated from the time of convective band passage through Santa Barbara County and the 700-mb wind speeds. Several representative cases were chosen from this five year period, with varying temperature and wind speed values. Table 5-7 below shows these periods with other information relevant to band passage through the intended target area

Table 5-7 Storm Periods Used for HYSPLIT Model Runs

Date	Passage Time (Z)	700-mb temperature (°C)	Wind Speed (knots)	700-mb wind direction	Synoptic feature
12-05-10	0200-0600	-2	35	S/SW	
01-02-11	0400-0800	-7	35	W/SW	Closed Low
02-19-11	1900-2200	-10	30	W/SW	
04-10-12	0600-0900	-6	30	S/SW	
2-19-13	2300-0100	-6	30	W/SW	
2-2-14	2000-0000	-7	25	W/SW	Closed Low
4-7-15	1900-2200	-4	30	W	

The map in Figure 5.9 illustrates the theoretical target area, outlined in white and five possible ground sites. Each of the ground sites is numbered and corresponds to the latitude, longitude, and elevation listed in Table 5-8. In addition, a purple marker has been placed on the map to denote the location of the Gibraltar AHOGS site used for the Santa Ynez Target area for the Santa Barbara cloud seeding project. This was included, as this site might be good for seeding from the ground when strong southwesterly winds are occurring.

Table 5-8 Coordinates and Elevations for Potential Ground Sites

Site	Latitude	Longitude	Elevation (feet)
1	34.498	-119.108	6300
2	34.479	-119.381	4400
3	34.600	-119.554	4900
4	34.697	-119.654	6800
5	34.782	-119.655	5400

HYSPLIT was used to simulate both ground seeding and airborne seeding. For ground seeding, the locations in Table 5-7 were chosen based on sites that would accommodate a number of wind directions favors the transport of the seeding material into the target area. As is the case with many of the storm systems that move across southern California during the winter months, the prevailing winds direction when convective band passages occur was that of a southerly or westerly component.

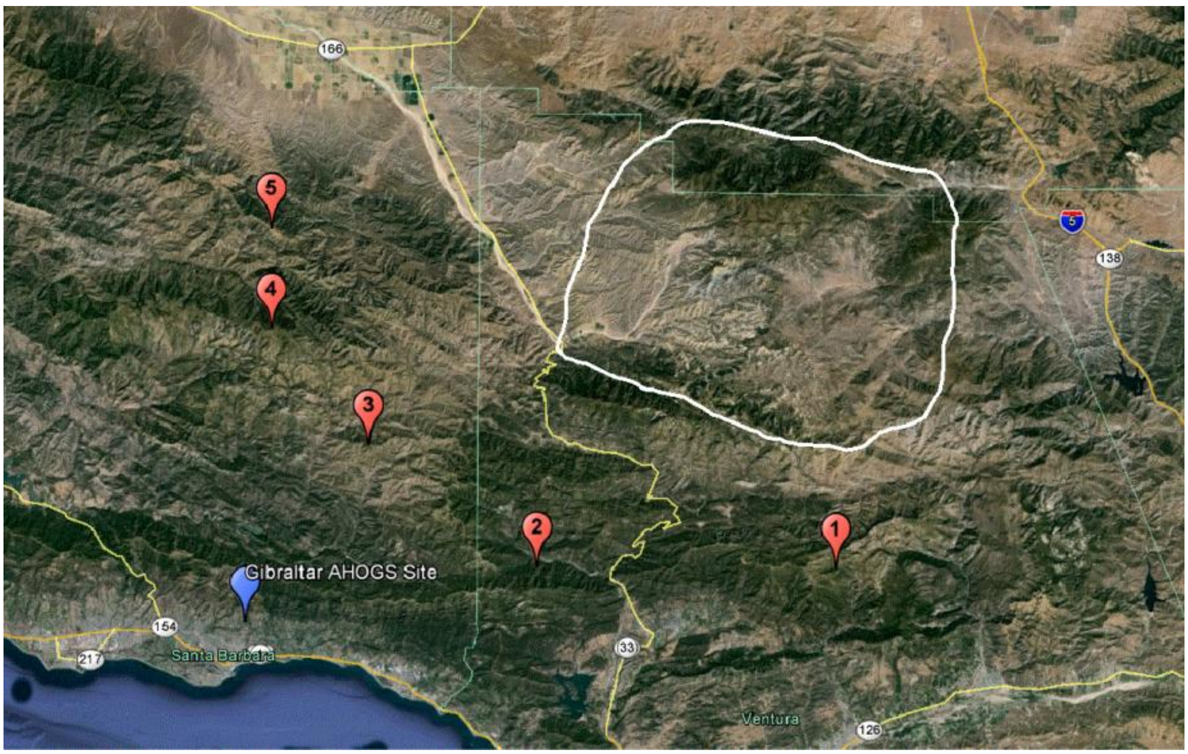

Figure 5.9 Target Area Base Map and Ground Site Locations

Figures 5.10 – 5.14 show HYSPLIT plumes generated by the five potential ground-based sites when the convective bands (Table 5-4) were moving into the proposed target area. These predictions are for one hour of transport. Plumes would extend further for two hour predictions.

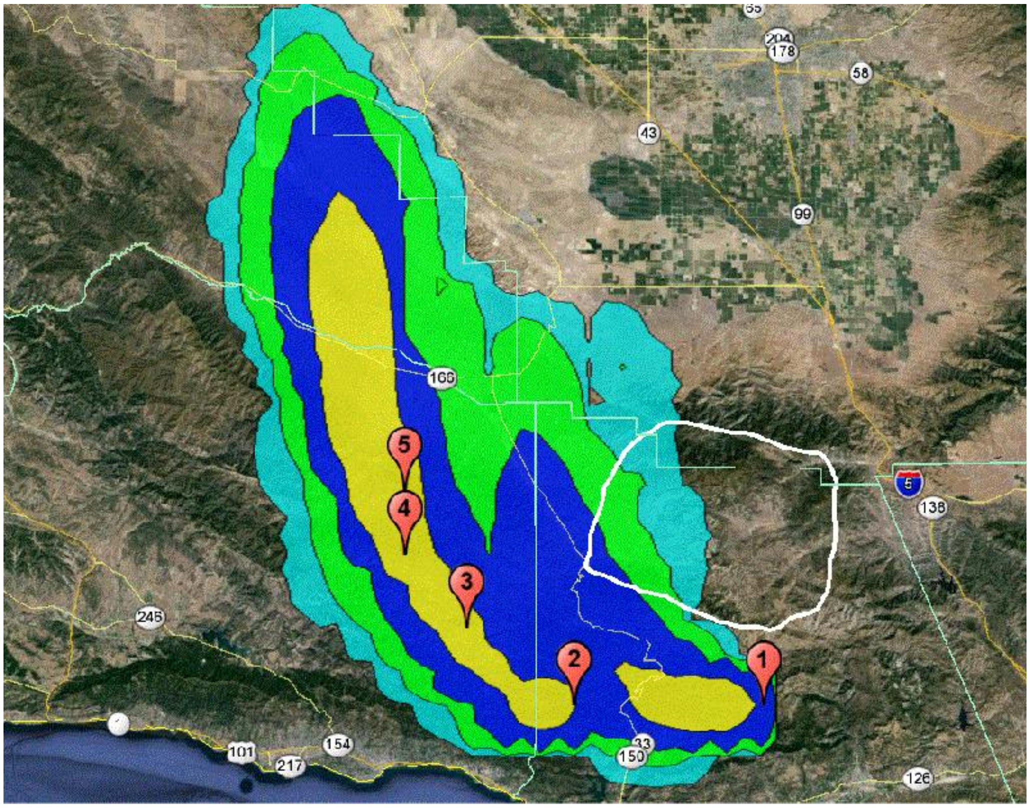

Figure 5.10 HYSPLIT Run, January 2, 2011, Ground Based Sites

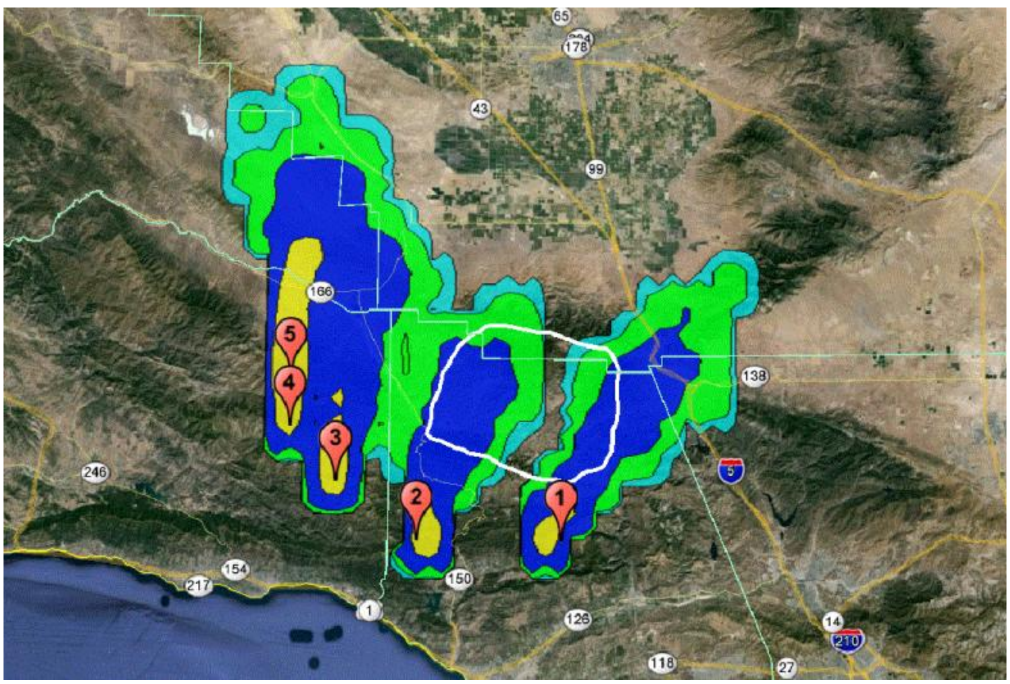

Figure 5.11 HYSPLIT Run, February 19, 2011, Ground Based Sites

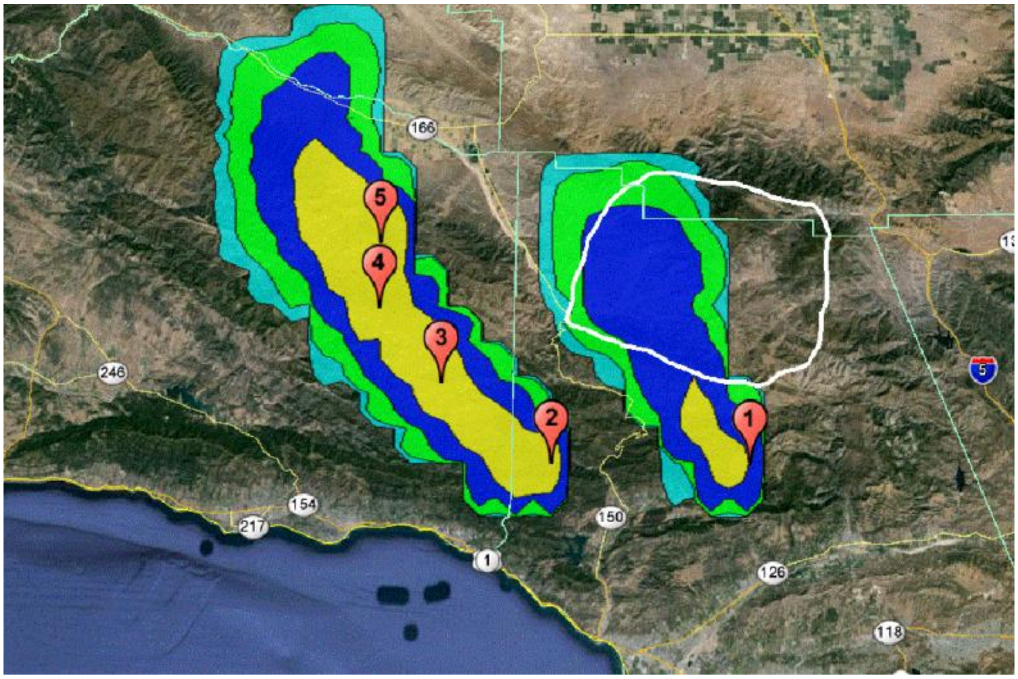

Figure 5.12 HYSPLIT Run, April 10, 2012, Ground Based Sites

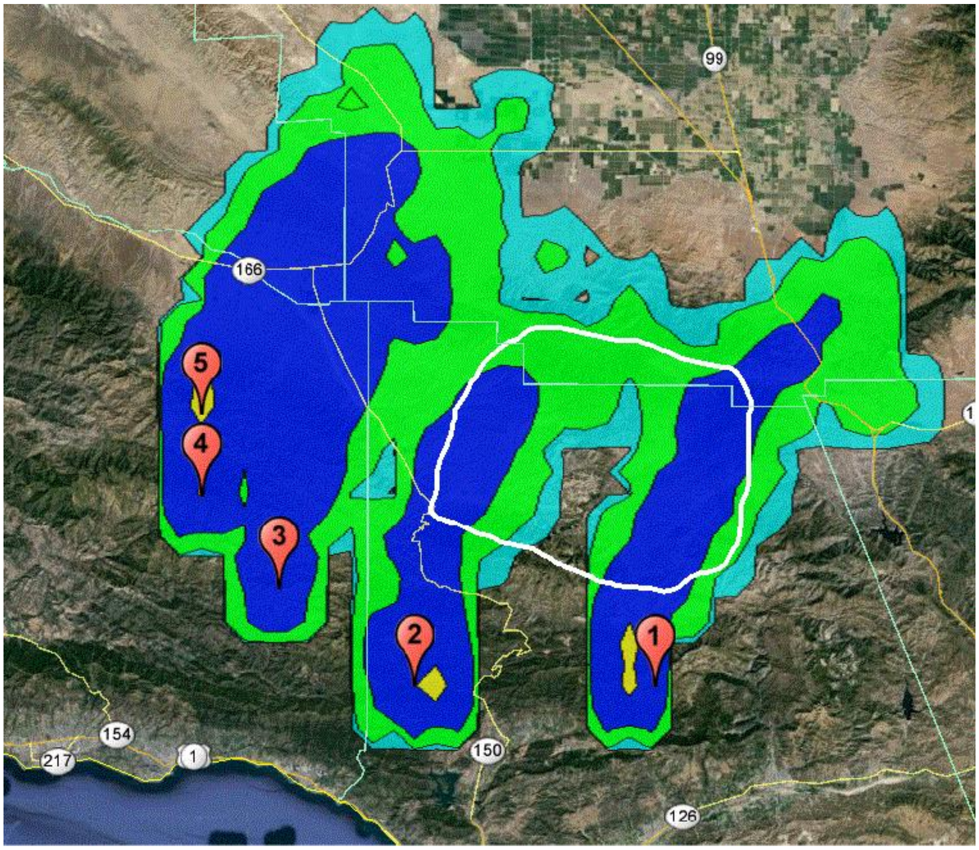

Figure 5.13   HYSPLIT Run, February 2, 2014, Ground Based Sites

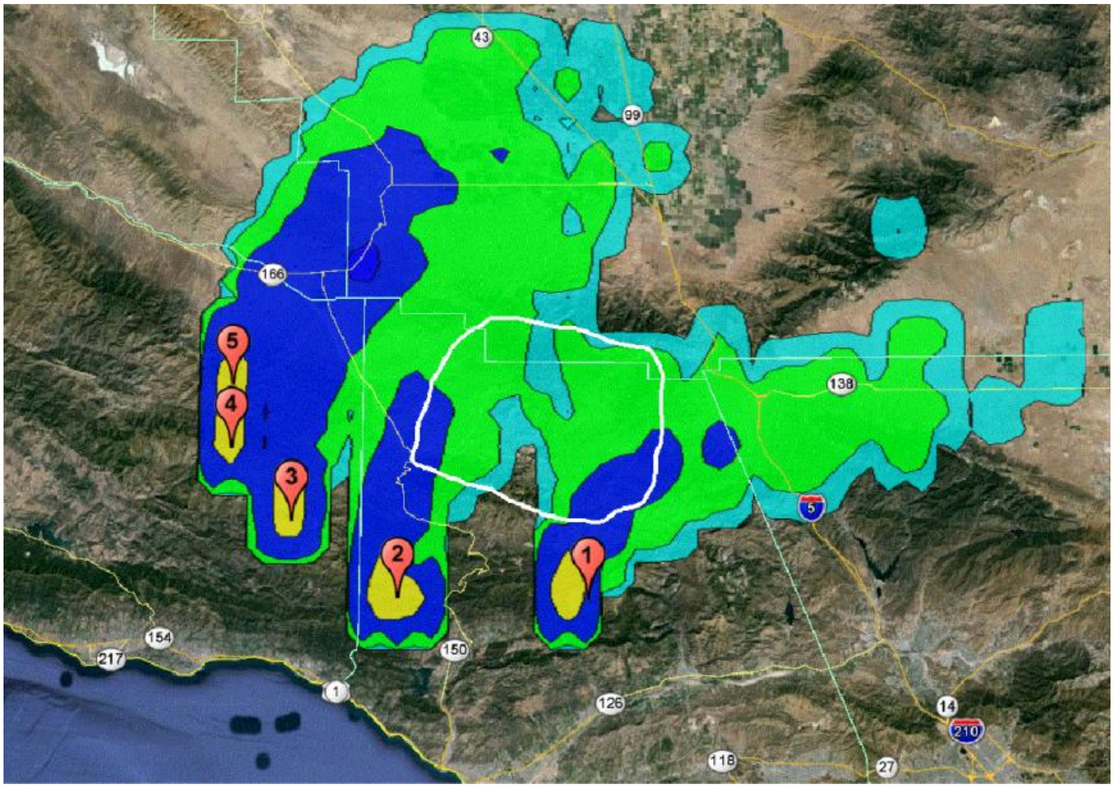

Figure 5.14 HYSPLIT Run, April 7, 2015, Ground Based Sites

Figures 5.15 through 5.18 provide simulate plumes from releases of seeding flares from aircraft. The red lines represent the hypothetical seeding tracks. The flare burn locations were picked to favor the transport of the seeding material from the aircraft track into the target area depending on 700-mb wind direction.

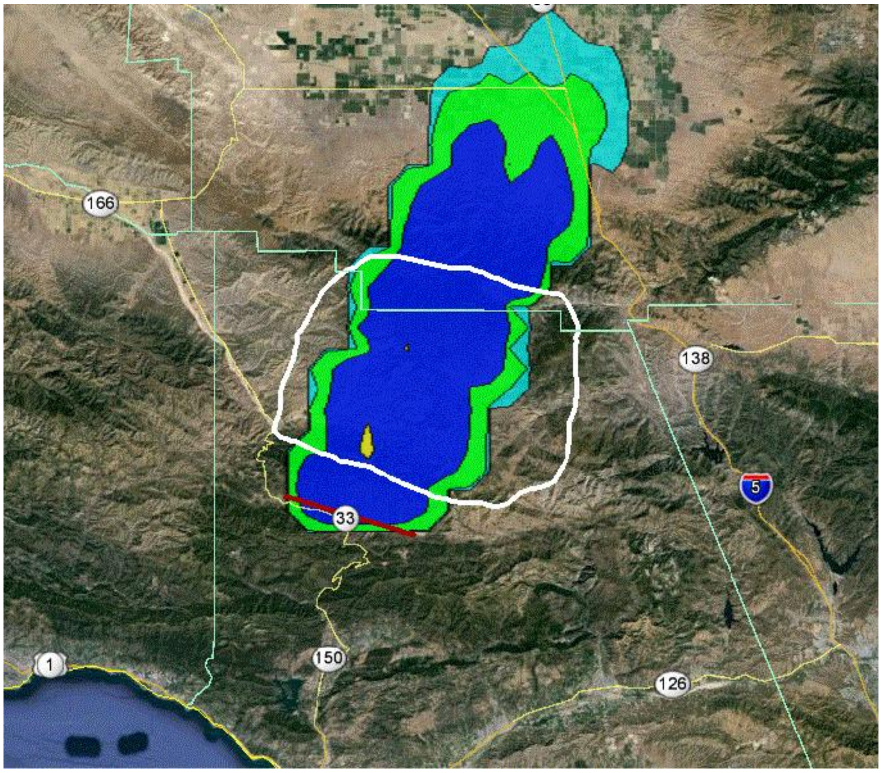

Figure 5.15 HYSPLIT Run, December 5, 2010, Aircraft Seeding

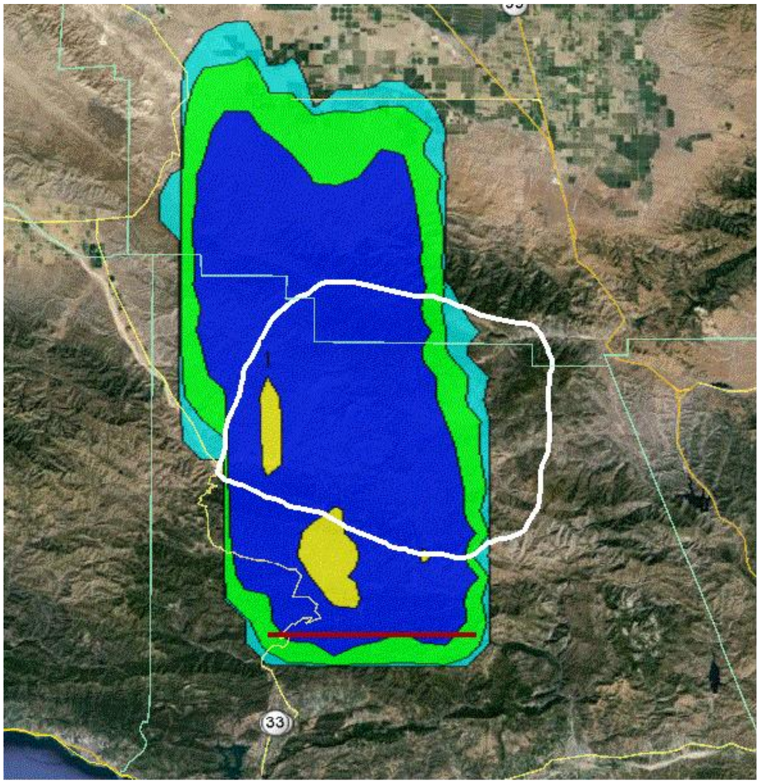

Figure 5.16 HYSPLIT Run, April 10, 2012, Aircraft Seeding

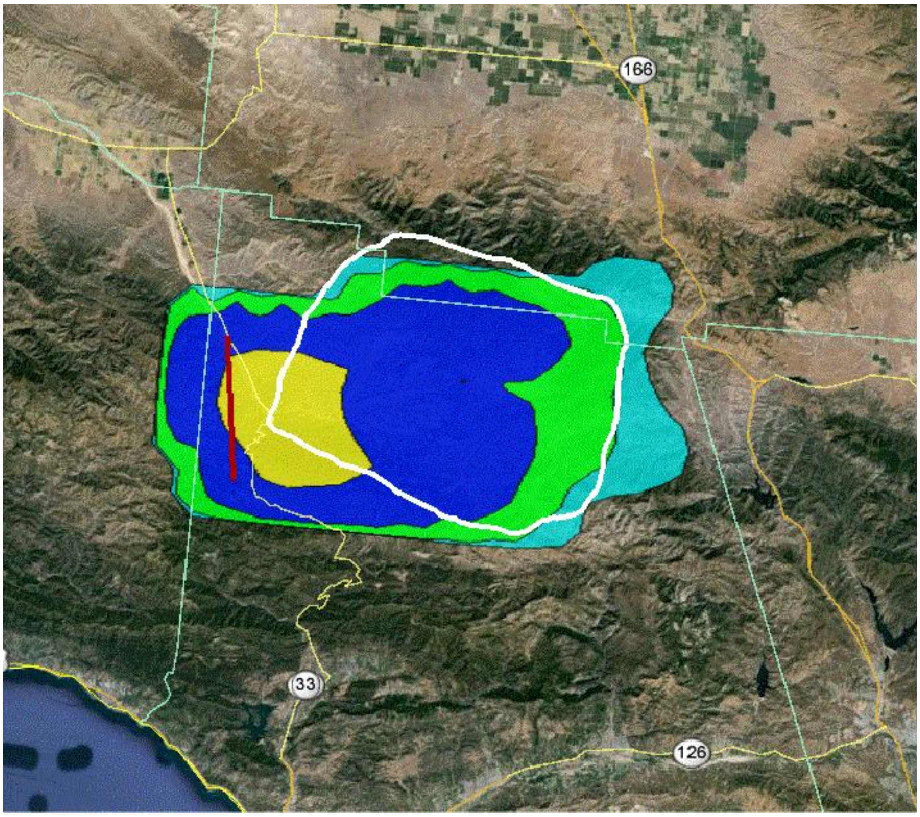

Figure 5.17 HYSPLIT Run, February 19, 2013, Aircraft Seeding

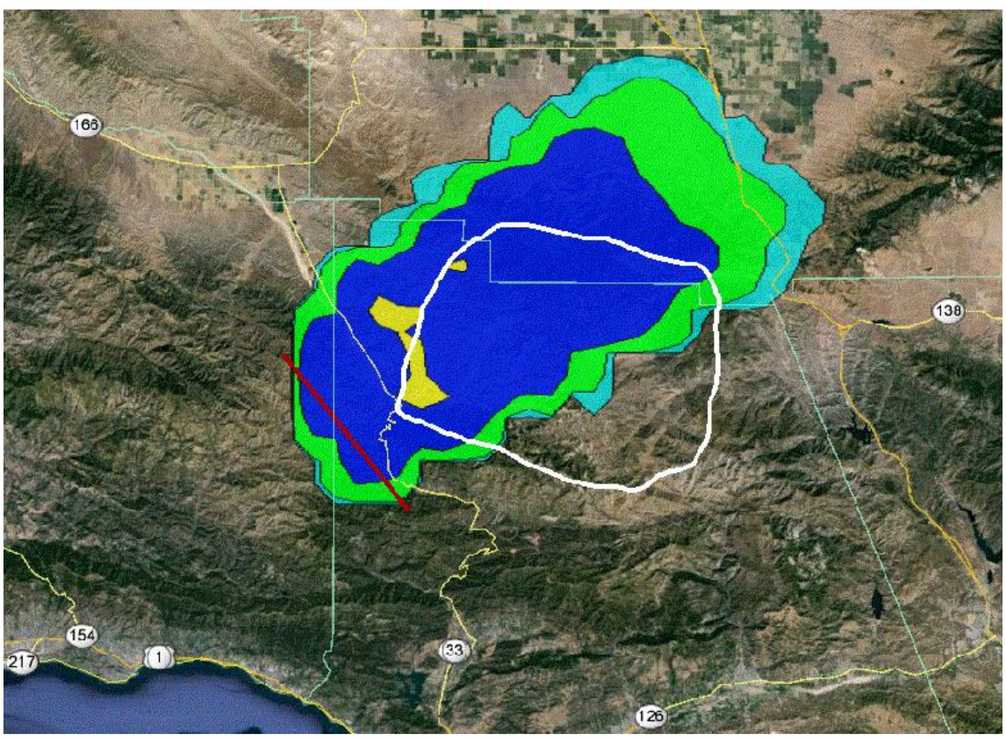

Figure 5.18 HYSPLIT Run, February 2, 2014, Aircraft Seeding

5.10 Program Funding

It is NAWC's understanding that if the UCRD cloud seeding program was considered feasible that this target area would be added to the ongoing Santa Barbara Water Agencies program that currently targets the Twitchell Reservoir and Upper Santa Ynez River watersheds (Figure 5.19). This certainly would be advantageous to the water interests in the Cuyama Valley in an economic sense; it is much less expensive to be part of a larger program than attempting to conduct an independent program. Assuming this is the case and based upon the HYSPLIT modeling work discussed above, NAWC recommends the addition of two or three remotely operated ground-based flare systems (AHOGS) to be used in targeting the UCRD target area. These systems were described in Section 5.4. Referring to Figures 4.3 (700mb wind direction frequencies) and Figure 5.9 (potential ground sites), we recommend three new sites be located at or near points 2, 3, and 4. Another consideration regarding this ground-based network is that the site labeled Gibraltar Road is an existing site being used to target the Upper Santa Ynez target area. Under a south-west to west-southwest flow regime, this site could also be used to target the UCRD target area. If only two new sites were considered affordable and considering the use of the existing Gibraltar Road site, NAWC recommends sites in or near locations 2 and 3. As indicated previously, any new ground sites chosen would require that on-site surveys be conducted and exploration of land ownership be investigated. The Water Agency would need to establish long-term site leases for the selected sites as has been done for the six existing AHOGS sites in Santa Barbara County. The new sites would be self-sufficient, that is no commercial power requirements since they would operate from a battery charged by a solar panel. Good cell phone communications from these sites would be necessary to allow remote communications with these units.

The Agency has frequently employed airborne seeding operations in addition to ground seeding on the Twitchell and Upper Santa Ynez seeding programs. As indicated in Figures 5.15 to 5.18, airborne seeding should be effective for the proposed target area. Since the convective bands, the seeding targets, often progress from west-east through Santa Barbara County, it should be feasible to extend seeding flights as these bands move eastward to produce seeding effects in the UCRD target area.

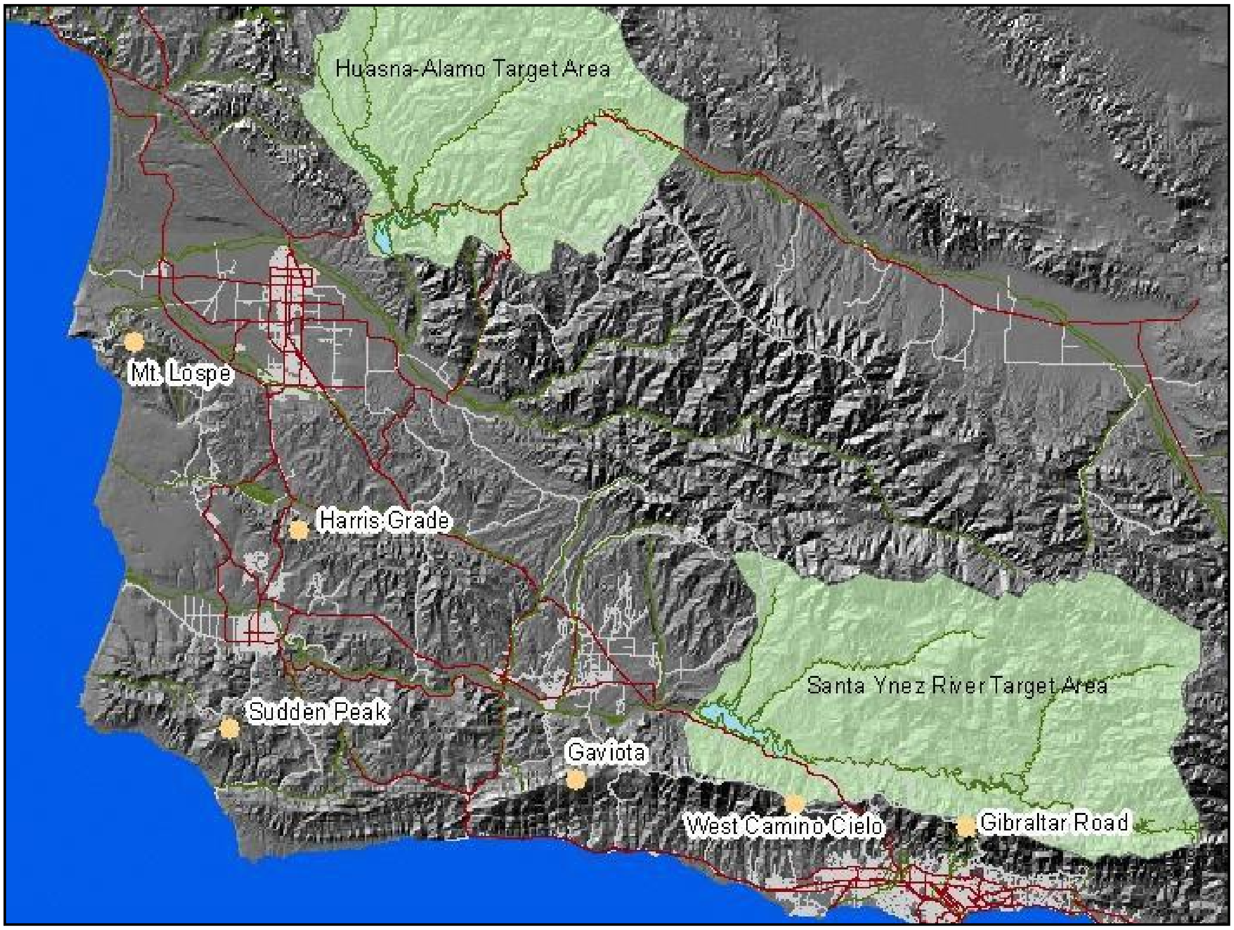

Figure 5.19 Santa Barbara Cloud Seeding Project Areas, Topographic Features and AHOGS Locations

5.11 Estimated Precipitation Increases

NAWC estimates that the average seasonal increases in precipitation from this program would fall in the range of +5% to +15%. This range is based upon an analysis of the long-term operational program being conducted in Santa Barbara that estimated December-March average increases of +9% to +21% (Griffith, et al, 2015). The +5% to +15% is also the range of expected average increases as stated in the Weather Modification Association's statement of capabilities (WMA 2011).

If a 5-15% seasonal precipitation increase was obtained in the UCRD for the November – April season (with about 10-15” seasonal average for most areas), this would potentially yield between 0.5”- 2.25” of additional rainfall during a season. Given that cloud seeding programs are already being conducted upwind in Santa Barbara County and are likely having some downwind (positive) impact on the Upper Cuyama watershed currently, the additional increase due to the addition of more cloud seeding sites to target the UCRD may in reality be less than the above values.

6.0 ESTIMATED PROGRAM COSTS

There could be some upfront costs in establishing a winter cloud seeding program for the UCRD target area. One unknown is whether the Santa Barbara Mitigated Negative Declaration (MND) finalized on October 15, 2013 would need to be updated to include this target area. If so, the Santa Barbara Water Agency may be able to amend this document internally and have it approved by the appropriate agency. It is unknown whether the Agency would incur any costs in doing so.

The other initial expense, should the ground-based seeding mode be implemented, would be conducting site surveys and obtaining leases for two or three AHOGS ground seeding sites. A rough estimate of the cost of completing this task is $15,000. Perhaps the Water Agency could complete this task internally with no additional costs except for the annual lease fees. The estimated cost to fabricate an install two or three AHOGS units are as follows:

<u>Two AHOGS Units</u>

Fabrication and Testing- 2 units @ $30,000	$60,000
Installation	<u>$12,000</u>
Estimated Total	$72,000

<u>Three AHOGS Units</u>

Fabrication and Testing- 3 units @ $30,000	$90,000
Installation	<u>$16,000</u>
Estimated Total	$106,000

After the initial fabrication and installation there would be some maintenance charges in subsequent seasons estimated at $10,000 per unit.

There should be no initial costs associated with the extension of aircraft seeding to impact the Upper Cuyama target area assuming the Water Agency is operating an aerial seeding program for the Twitchell Reservoir and Upper Santa Ynez watersheds. In this situation this scenario may be appealing at least to begin a program due to the reduced upfront costs.

The annual set-up, take-down and reporting costs associated with the Cuyama program are estimated at $10,000 for a program with two or three AHOGS units and $5000 for an aerial program.

The personnel assigned to conduct the two Agency programs in Santa Barbara County could expand their duties to include the Upper Cuyama target area. In this scenario, it is estimated that the monthly fixed personnel costs would be $5,000/month.

The other costs would be for flight hours and seeding materials. Current flight hour costs are $550/hour. In the case of the use of either ground or aerial seeding flares, the current costs are $90.00 each. Rough estimates of usage for a four month program are 15 flight hours and 50 airborne flares. For two AHOGS sites an estimated 50 flares would be used.

If the initial costs are ignored, then the estimated annual operating costs for a four month program with two AHOGS units would be $45,500. Estimated costs for three AHOGS units for a four month program would be $67,500. Table 6-1provides a breakdown on these estimated costs. These estimates assume that a program will be conducted concurrently in Santa Barbara County (Twitchell and Upper Santa Ynez watersheds).

The estimated cost of a four month aerial program would be: $37,750 assuming direct aircraft costs (e.g., aircraft ferry, aircraft insurance, monthly lease costs, and pilot costs) is covered by the Water Agency's Twitchell and Upper Santa Ynez River program.

It is unclear if some or all of the above costs would be borne by the Agency and the consortium of water purveyors that support the Twitchell and Upper Santa Ynez programs.

Table 6-1 Estimated Costs for a Four Month Program for Two or Three AHOGS Units after the Initial AHOGS Site Surveys, Fabrication and Installation Costs

Task	Two AHOGS Units	Three AHOGS Units
Set-up, Maintenance, Take-Down, Reporting Fixed Costs	**$20,000**	**$30,000**
Monthly Fixed Cost	**$20,000**	**$20,000**
Est. Reimbursable Costs, Flares	**$4,500**	**$6750**
Est. Totals	**$45,500**	**$56,750**

7.0 SUMMARY

North American Weather Consultants (NAWC) was contracted by the Santa Barbara County Water Agency (Agency) to conduct a feasibility/design study for a winter cloud seeding program to target the Upper Cuyama River Basin located in southwest California. NAWC reviewed available information, compiled and analyzed data, and developed a proposed program design. Recommendations from the American Society of Civil Engineers (ASCE 2016) include the following:

1. *"When possible, the feasibility study for a program should draw significantly from previous research and well-conducted operational programs that are similar in nature to the proposed program (e.g. similar topography, similar precipitation occurrences, etc.)."*
2. *"The primary purpose of the feasibility study is to answer two questions. First, does it appear that a cloud seeding program could be implemented in the intended target area that would be successful in achieving the stated objectives of the program? Second, are the estimated increases in precipitation expected to produce a positive benefit-cost ratio?"*

NAWC's response to the first recommendation is strongly positive for the proposed Upper Cuyama River program. The Santa Barbara II Research program was conducted in two phases (a ground-based and airborne based seeding modes) from 1967-1974. This program demonstrated that significant increases in precipitation could be achieved when convective bands (common features embedded in coastal California winter storms) were seeded with silver iodide. The Water Agency has supported operational seeding programs beginning in 1986 and continuing for most winter seasons to the present. Both ground-based and airborne seeding modes have typically been utilized. A recent evaluation of this operational program indicated average December-March precipitation increases ranging from 9% to 21%. (Griffith, et al, 2015)

Response to the second recommendation is much more difficult since there are no long-term streamflow records available for the Cuyama River. As a consequence, NAWC is unable to develop an estimated benefit/cost ratio.

NAWC typically estimates seasonal increases in precipitation from a proposed program then correlates precipitation to streamflow. Average increases in precipitation are inserted into the regression equation correlating precipitation with streamflow to estimate an average increase in streamflow. If the value of the additional streamflow can be estimated, a benefit/cost ratio can be established based upon the estimated costs of conducting the program. The ASCE recommends a 5/1 ratio for a program to be considered economically feasible.

Consequently, NAWC concludes the proposed program is technically feasible but we are unable to determine whether the proposed program would be economically feasible.

The program design calls for the seeding of convective bands using either ground-based remotely operated flare units or airborne seeding with flares or a combination of the two. Two or three ground-based flare units are proposed. A WMA Certified Manager would supervise the program and a WMA Certified Operator or Operators would be in charge of operating the program. A project specific Operations Plan would be used to guide the conduct of the program.

NAWC estimates that the average seasonal increases in precipitation from this program would fall in the range of +5% to +15%. This range is based upon an analysis of the long-term operational program being conducted in Santa Barbara County that estimated December-March average increases of +9% to +21% (Griffith, et al, 2015). The +5% to +15% is also the range of expected average increases as stated in the Weather Modification Association's Capabilities Statement (WMA 2011).

It is NAWC's understanding that if the Upper Cuyama River cloud seeding program was considered feasible that this target area would be added to the ongoing Santa Barbara Water Agencies program that currently targets the Twitchell Reservoir and Upper Santa Ynez River watersheds. This certainly would be advantageous to the water interests in the Cuyama Valley in an economic sense; it is much less expensive to be part of a larger program than attempting to conduct an independent program.

There would be some upfront costs in establishing a winter cloud seeding program for the Upper Cuyama target area. One unknown is whether the Santa Barbara Mitigated Negative Declaration (MND) finalized on October 15, 2013 would need to be updated to include this target area. If so, the Agency may be able to amend this document internally and have it approved by the appropriate agency. It is unknown whether the Agency would incur any costs in doing so.

The other initial expense, should the ground-based seeding mode be implemented, would be conducting site surveys and obtaining leases for two or three AHOGS ground seeding sites. A rough estimate of the cost of completing this task is $15,000. Perhaps the Agency could complete this task internally with no additional costs except for the annual lease fees. There would be additional upfront costs to fabricate and install two or three ground-based AHOGS seeding units (~$72,000 and $106,000, respectively). Annual operating costs for a four month ground-based or aerial programs are $34,500 and $37,500 respectively assuming a concurrent program is conducted in the longer term target areas in Santa Barbara County and that the direct expenses related to the aircraft program (e.g., aircraft ferry, aircraft lease aircraft insurance and pilot) are borne by the Agency. Assuming the Agency is operating an airborne seeding program and that the direct costs are being covered for this capability as described above, adding seeding flights that cover the Upper Cuyama River target area would incur less upfront costs than the two or three ground-based, remotely controlled flare sites (AHOGS). If a long-term seeding program is envisioned for the Upper Cuyama River target area, the installation of two or three AHOGS sites is recommended.

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North American
Weather Consultants, Inc.

8180 S. Highland Dr., Suite B-2
Sandy, Utah 84093

801-942-9005