Annual Cloud Seeding Report

Huasna-Alamo Drainage
for the
2020-2021 Winter Season

Prepared For:

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EXECUTIVE SUMMARY

For the 2020-2021 winter season, cloud seeding operations were conducted to enhance precipitation in the Huasna-Alamo drainage located in northern Santa Barbara and southern San Luis Obispo Counties. Three previously established ground-based seeding locations were utilized, located in both San Luis Obispo and Santa Barbara counties. These sites were located at Mt. Lospe, Berros Peak and Harris Grade, the same sites that were utilized during the 2019-2020 winter operations season. The operational period ran from December 1, 2020 to March 30, 2021. No seeding operations were conducted for the Upper Santa Ynez target area during the 2020-2021 winter season due funding restrictions associated with the onset of the COVID-19 pandemic.

The cloud seeding equipment at the ground-based sites provided the ability to fire high-output silver iodide complex seeding flares from these remote locations. Operations for the duration of the project were directed by project meteorologists, who are certified operators by the Weather Modification Association (WMA). Close coordination of all seeding activities was maintained with Mr. Matthew Scrudato of the Agency.

The ENSO (El Niño-Southern Oscillation) phase was classified as a weak La Nina during the 2020-2021 winter season. Precipitation in Santa Barbara County and around the Central Coast was well below normal during the winter season and was also below normal for nearly the entire state of California. Rainfall from the beginning of the water year (September 1, 2019 through May 1, 2020) averaged 48% of normal in Santa Barbara County, with percentages ranging from 29 to 82% of normal at the County gauge sites.

Table 1 shows precipitation amounts from four ALERT stations in Santa Barbara County. The table shows monthly data for those stations, water year to date precipitation and percent of average to date. This table shows how the 2020-2021 winter season varied wildly month to month in terms of precipitation. The wettest month of the 2020-2021 season, January, is highlighted in blue. The four stations all show percent of average precipitation as of April 1, 2021 between 40 and 54% of normal.

Table 1
2020-2021 Monthly Precipitation Data for Locations near the Twitchell Target Area

Location	December	January	February	March	December – March Precipitation	Percent of Normal as of April 1
Twitchell Dam	1.10	4.45	0.12	1.30	6.97	48
Shell Peak	1.26	3.98	0.16	1.69	7.09	40
Sisquoc	1.28	3.91	0.17	0.57	5.93	42
Santa Maria	1.41	3.98	0.22	1.13	6.74	54

Seeding opportunities occurred on eight days during the 2020-2021 operational season. A total of 89 flares were successfully burned at the three ground sites, releasing an estimated 1,424 grams of AgI. Unfortunately, no seeding opportunities occurred during February with very dry conditions in place. Except for February, every month during the season contained at least one seeding opportunity. No seeding suspensions were enacted during the 2020-2021 operational seeding period.

NAWC successfully applied a target/control evaluation technique to the Santa Barbara operational program, which began in 1981. A final report was prepared on this analysis and submitted to the Agency in May 2014 (Griffith, D.A. and D.P. Yorty, 2014). The study indicated an average increase of 9% in winter season precipitation for the Twitchell Watershed target area. Additional details regarding this study can be found in Appendix C of this report.

Based on NAWC's evaluations, ground-based seeding is significantly more efficient than aerial seeding. It is NAWC's recommendation that the Agency continue the ground only operational cloud seeding project with the current NAWC design. This design can and should be modified as needed for specific winter seasons and to account for special circumstances such as burn areas.

A recommendation that NAWC suggests to the Agency is inclusion of the Santa Ynez target area in the 2021-2022 winter operational season. The previously mentioned report indicated a 21% increase for the Santa Ynez target area. The geography and climate of the Santa Ynez watershed respond very well to cloud seeding, resulting in highly efficient precipitation augmentation.

A recommendation that has been discussed is the decommissioning of the Sudden Peak AHOGS site near Point Conception. This site has played a role in the past, but other sites will serve the target areas in a better capacity. In addition, with the loss of the West Camino site which facilitated seeding for the Santa Ynez target area during southerly wind regimes, NAWC recommends that another AHOGS site be established before the start of the 2021-2022 winter season, if the Santa Ynez target area partners agree to fund the program.

STATE OF THE CLIMATE

Every ten years, the National Oceanic and Atmospheric Association (NOAA) releases a summary of various U.S. weather conditions for the past three decades to determines average values for a variety of conditions, including, temperature and precipitation. This is known as the U.S Climate normal, with a 30-year average, representing the "new normal" for our climate. These 30-year normal values can help to determine a departure from historic norms and identify current weather trends.

The recently released 30-year average ranges from 1990 – 2020. Images in Figure 1 and 2 show how each 30-year average for the past 120 years compares to the composite 20th century average for temperature and precipitation. For the western U.S., the 1990-2020 average show much warmer than average temperatures, in comparison to the 100-year 20th century average. When comparing precipitation for the past 30 years to both the previous 30-year average and the 1901-2000 average, the American Southwest (including portions of Utah, Arizona, California and Nevada) has seen as much as a 10% decrease in average annual precipitation.

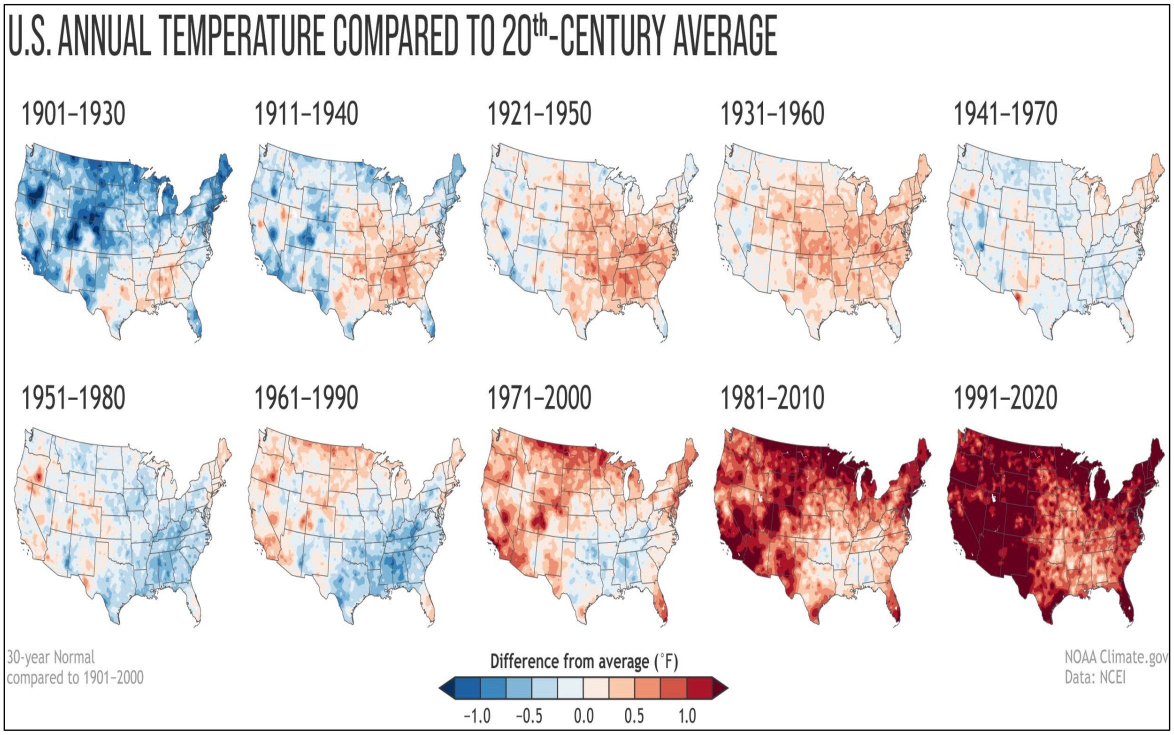

Figure 1 **U.S. Annual Temperature compared to 20th-Century Average**

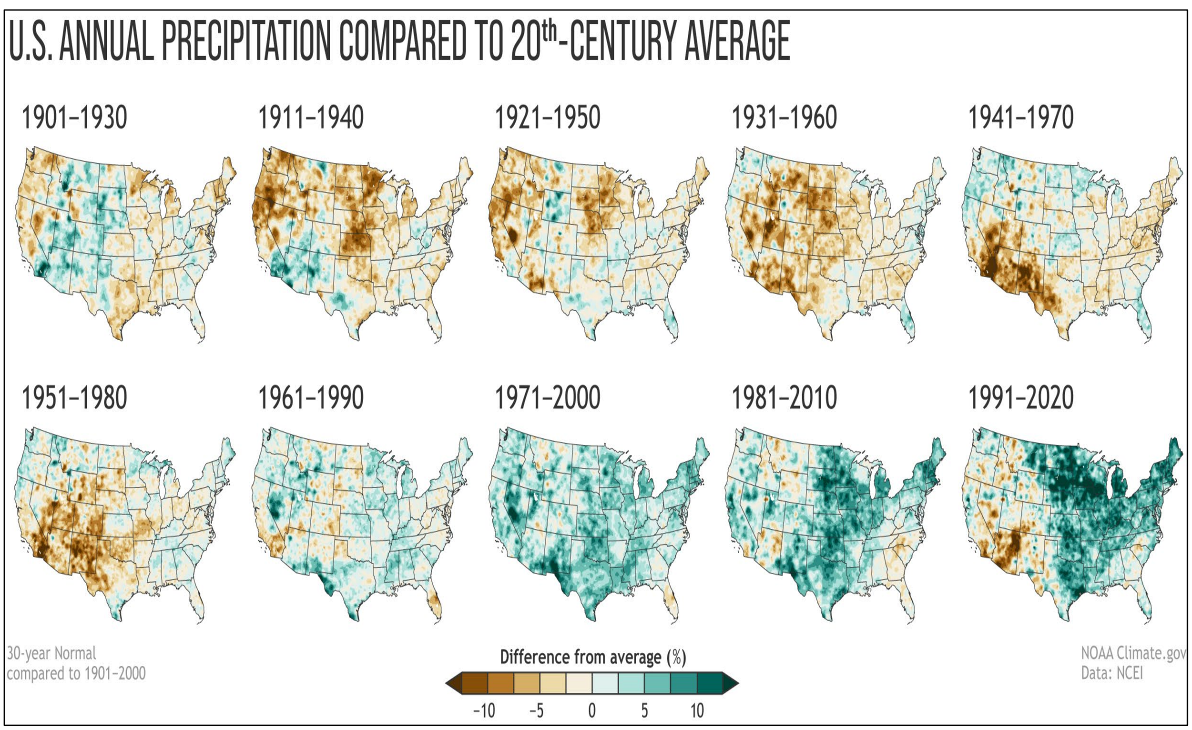

Figure 2 **U.S. Annual Precipitation compared to 20th-Century Average**

1.0 INTRODUCTION

North American Weather Consultants (NAWC) has previously conducted winter cloud seeding programs in Santa Barbara County dating back to 1981. Beginning with the 2001-2002 winter season NAWC has been awarded sequential three-year contracts through a bid process to conduct cloud seeding programs for the Santa Barbara County Water Agency (Agency). The current three-year contract began during the 2017-2018 season and contains an option to extend for an additional two years.

NAWC, with headquarters in Sandy, Utah, conducted a four-month cloud seeding program for the Agency from December 1, 2020 through March 31, 2021. Water purveyors sponsoring the Upper Santa Ynez target area decided not to support a cloud seeding project for the 2020-2021 winter season due to budgetary constraints due to the COVID-19 pandemic. The water purveyors sponsoring the Huasna-Alamo target area decided to support a four month long project. Although NAWC's original proposal called for both airborne and ground-based seeding during the 2020-2021 winter season, the Huasna-Alamo sponsors elected to only support a ground-based program for this winter season due to cost.

Ground-based seeding was conducted from December 1, 2020 to March 31, 2021 for the Huasna-Alamo Watershed. Three previously established ground-based seeding sites, Mt. Lospe, Harris Grade, and Berros Peak were active during the operational season. The cloud seeding equipment located at these sites provided the ability to fire high output seeding flares from remote locations in real time on a 24/7 basis. All seeding decisions were made by Weather Modification Association (WMA) certified project meteorologists. All seeding decisions included consultation with Agency project personnel prior to and during the seeding periods.

The 2020-2021 winter season brought mostly dry months to Santa Barbara County, with overall below normal precipitation for the December through March operational period. All months through the operations period, with the exception of Jaunary, which was the wettest, were much below normal. February was by far the driest month of the 2020-2021 winter season, with monthly percent of normal precipitation around 5%. Table 1-1 provides rainfall totals for stations with established normals in the county for the season through April 1, 2021.

Table 1-1
Seasonal Rainfall and Percentage of Normal through April 1, 2021

Santa Barbara County - Flood Control District

130 East Victoria Street, Santa Barbara CA 93101 - 805.568.3440 - www.countyofsb.org/pwd

Rainfall and Reservoir Summary

Updated 8am: 4/1/2021 **Water Year: 2021** **Storm Number: NA**

Notes: Daily rainfall amounts are recorded as of 8am for the previous 24 hours. Rainfall units are expressed in inches. All data on this page are from automated sensors, are preliminary, and subject to verification.
*Each Water Year (WY) runs from Sept 1 through Aug 31 and is designated by the calendar year in which it ends
County Real-Time Rainfall and Reservoir Website link: ➤ http://www.countyofsb.org/hydrology

Rainfall	ID	24 hrs	Storm 0day(s)	Month	Year*	% to Date	% of Year*	AI
Buellton (Fire Stn)	233	0.00	0.00	0.00	8.54	57%	51%	
Cachuma Dam (USBR)	332	0.00	0.00	0.00	10.51	60%	53%	
Carpinteria (Fire Stn)	208	0.01	0.00	0.01	4.52	29%	26%	
Cuyama (Fire Stn)	436	0.00	0.00	0.00	3.62	54%	47%	
Figueroa Mtn. (USFS Stn)	421	0.00	0.00	0.00	8.37	44%	39%	
Gibraltar Dam (City Facility)	230	0.00	0.00	0.00	10.63	44%	40%	
Goleta (Fire Stn-Los Carneros)	440	0.00	0.00	0.00	9.14	55%	50%	
Lompoc (City Hall)	439	0.00	0.00	0.00	10.68	81%	73%	
Los Alamos (Fire Stn)	204	0.00	0.00	0.00	8.41	61%	55%	
San Marcos Pass (USFS Stn)	212	0.00	0.00	0.00	14.17	45%	42%	
Santa Barbara (County Bldg)	234	0.00	0.00	0.00	7.31	44%	40%	
Santa Maria (City Pub.Works)	380	0.00	0.00	0.00	7.16	60%	54%	
Santa Ynez (Fire Stn /Airport)	218	0.00	0.00	0.00	8.31	58%	53%	
Sisquoc (Fire Stn)	256	0.00	0.00	0.00	6.31	47%	42%	

County-wide percentage of "Normal-to-Date" rainfall : 53%

County-wide percentage of "Normal Water-Year" rainfall : 47%

County-wide percentage of "Normal Water-Year" rainfall calculated assuming no more rain through Aug. 31, 2021 (End of WY2021).

AI (Antecedent Index / Soil Wetness)
6.0 and below = Wet (min. = 2.5)
6.1 - 9.0 = Moderate
9.1 and above = Dry (max. = 12.5)

Reservoirs

Reservoir Elevations referenced to NGVD-29.
**Cachuma is full and subject to spilling at elevation 750 ft. However, the lake is surcharged to 753 ft. for fish release water. (Cachuma water storage is based on Dec 2013 capacity revision)

Click on Site for Real-Time Readings	Spillway Elev. (ft)	Current Elev. (ft)	Max. Storage (ac-ft)	Current Storage (ac-ft)	Current Capacity (%)	Storage Change Mo.(ac-ft)	Storage Change Year*(ac-ft)
Gibraltar Reservoir	1,400.00	1,375.87	4,559	624	13.7%	0	-1,586
Cachuma Reservoir	753.**	725.18	193,305	119,845	62.0%	0	-23,930
Jameson Reservoir	2,224.00	2,213.36	4,848	3,607	74.4%	0	-681

As of April 1, the average precipitation for Santa Barbara County was 48% of normal for the water year. This year was categorized as a below normal year and is the driest that the county has experienced since 2014. Figure 1.1 shows Santa Barbara County Percent of Normal historical rainfall for water years 1980 through 2021.

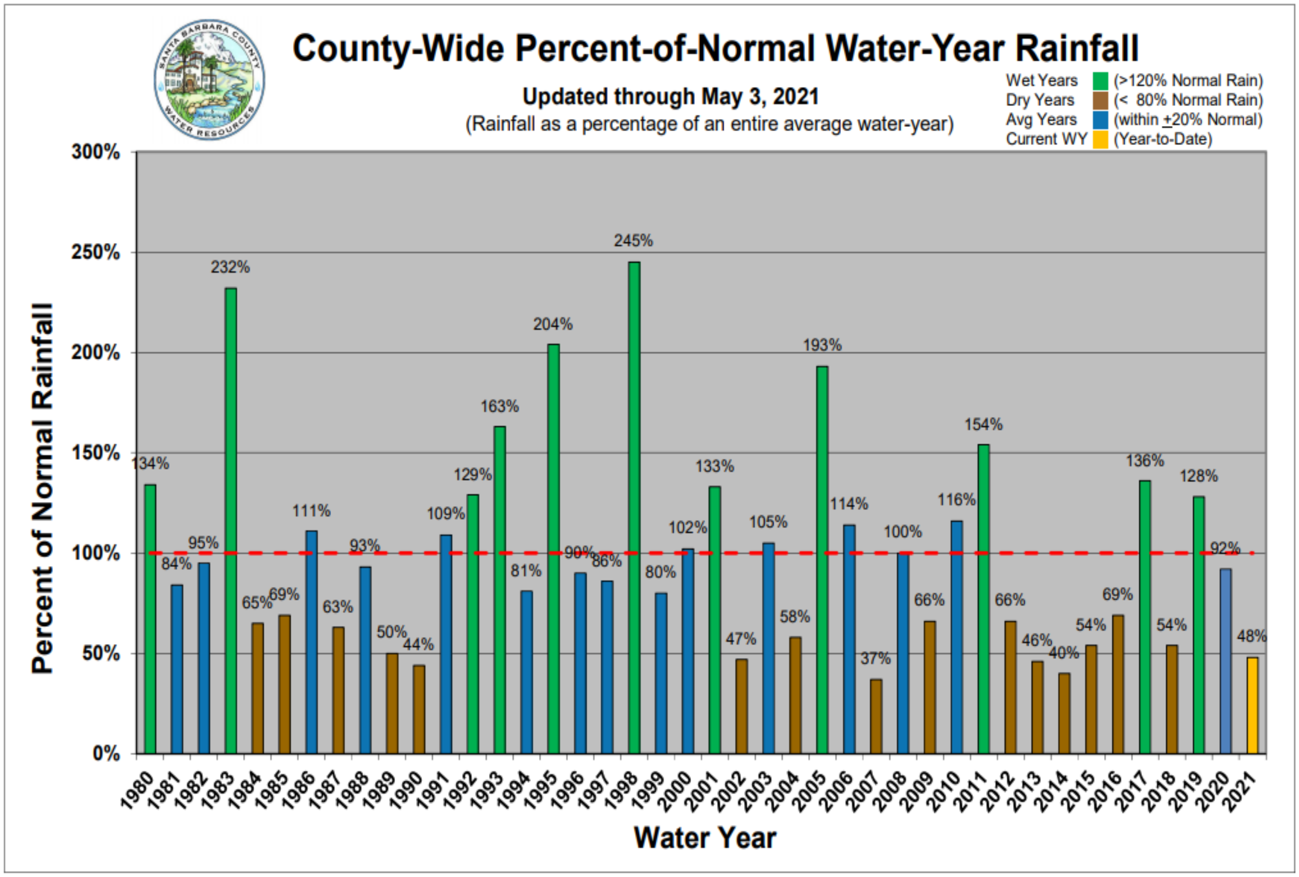

Figure 1.1 **Santa Barbara County percent of normal rainfall, water years 1980-2021 (Water Year 2021 through May 3rd).**

Figure 1.2 is a drought monitor comparison for December 1, 2020 and April 13, 2021. It represents a shift from abnormally dry conditions in early December to moderate drought conditions in mid April. As of April 13, 2021, the drought monitor images indicated that most of southern California ranged from moderate to severe drought conditions, while the northern part of the state also showed moderate to severe conditions. Nearly the entire state of California by mid April was experiencing some form of drought conditions, with the southern Sierras, towards southeastern California experiencing exceptional drought conditions.

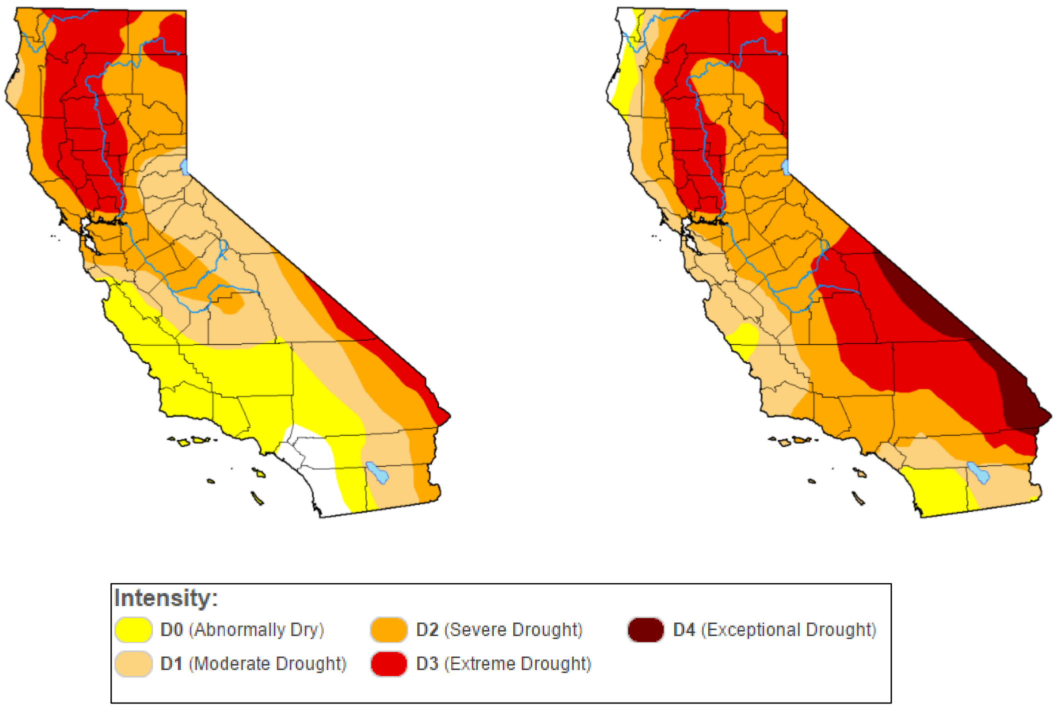

Figure 1.2 U.S. Drought Monitor Conditions for California for December 1, 2020 (left) and April 13, 2020 (right).

This report contains discussions on project operations, a short theory of cloud seeding, project design, equipment and personnel, and summaries and recommendations. A historical background of cloud seeding activities conducted in Santa Barbara County is provided in Appendix A. Table 1-2 is a list of all the acronyms that will follow in this report.

Table 1-2

Project Acronyms Descriptions

Acronym	Description
AFB	Air Force Base
AFWA	Air Force Weather Agency
AHOGS	Automated High Output Ground Seeding
ALERT Network	Automated Local Evaluation in Real Time
APCO	Advanced Process Control and Optimization
ARL	Air Resources Laboratory
CSU	Colorado State University
ENSO	El Nino Southern Oscillation
FAA	Federal Aviation Administration
FACE	Florida Area Cumulus Experiment
FSL	Forecast System Laboratory
HRRR	High Resolution Rapid Refresh
HYSPLIT	Hybrid Single Particle Lagrangian Integrated Trajectory (Model)
GMT	Greenwich mean time
ICE	Ice Crystal Engineering
NAWC	North American Weather Consultants
NCAR	National Center for Atmospheric Research
NEXRAD	Next Generation Radar
NOAA	National Oceanic and Atmospheric Association
NWS	National Weather Service
PDT	Pacific Daylight Time
PST	Pacific Standard Time
READY	Real-Time Environmental Applications and Display System
SBCWA	Santa Barbara County Water Agency
SLW	Supercooled Liquid Water
WMA	Weather Modification Association
WRF	Weather Research and Forecasting

2.0 THEORY OF CLOUD SEEDING FOR PRECIPITATION AUGMENTATION AND RESULTS OF PREVIOUS RESEARCH AND OPERATIONAL PROGRAMS CONDUCTED IN SANTA BARBARA COUNTY

Two theories have evolved concerning the potential to augment precipitation. 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, both 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 (colder than freezing) cloud droplets, would cause those droplets to freeze (Vonnegut, 1947). Supercooled cloud droplets 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.

2.1 <u>Precipitation Processes</u>

There are two basic mechanisms that produce precipitation: collision-coalescence and ice formation. The collision-coalescence process is defined as the growth of raindrops by the merging and/or colliding of cloud drops and small precipitation particles together. 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, as described in the Bergeron-Findeisen theory, consists of a process in which precipitation particles may form within a mixed cloud which are clouds composed of both ice crystals and liquid water drop. In such clouds the ice crystals will gain mass by sublimation at the expense of the liquid drops surrounding the ice crystals. Upon attaining sufficient weight, the ice crystal would fall to the ground as snow if the surface temperatures are at or below freezing, but would melt and fall as raindrops if the surface temperatures are warmer than freezing. Of interest to this discussion is the fact that cloud droplets often 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°C before they will freeze through a process known as homogeneous nucleation. This Bergeron-Findeisen 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 previous section, clouds often contain liquid cloud droplets at sub-freezing temperatures. These droplets are termed supercooled. The natural tendency is for these droplets to freeze, but to do so at temperatures warmer than -39°C they need to encounter an impurity. There are particles present in our atmosphere that possess the ability to cause these supercooled droplets to freeze; they are known as freezing nuclei or ice nuclei. Research has demonstrated that certain natural particles (for example, soil particles, and a certain type of bacteria) in the atmosphere serve as freezing nuclei. The conversion of a supercooled water droplet into an ice crystal is referred to as nucleation. It is known that the nucleating 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°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°C (Dennis, 1980). Some more recently developed seeding formulations show nucleation at temperatures as warm as -4°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°C or colder these same nuclei can serve as 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 cloud 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 compared to condensation-freezing nucleation, which can be quite rapid, on the order of one to a few minutes.

2.3 Impacts of Silver Iodide Seeding

Since a scarcity of natural ice nuclei commonly exists in the atmosphere at temperatures in the range of -5 to -15°C, many clouds may be inefficient in converting 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 cloud as either snow or rain. Rain is produced by the melting of such snowflakes when they fall through warmer air near the ground. This increase in efficiency is usually referred to as a *static* seeding effect.

In the process of converting supercooled cloud droplets into ice crystals, additional heat is added to the cloud due to the release of the 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 Association (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.

2.4 Santa Barbara II Research Program

There was an early research program conducted in Santa Barbara County, termed Santa Barbara I, which was conducted from 1957-1960 and was sponsored by various organizations including the State of California, The University of California, Santa Barbara and Ventura counties, the National Science Foundation, the U.S. Weather Bureau and the U.S. Forest Service. This program employed randomized seeding of storm periods using ground-based silver iodide solution generators. Results from this research program indicated increases of 45% but were not statistically significant. Further information about this program can be found in Appendix A of this report. A second research program conducted in the county was known as the Santa Barbara II program, which was conducted during the winter seasons of 1967 to 1973. Santa Barbara II was conducted in two primary phases. Phase I consisted of the release of silver iodide from a ground site located near 2,600 feet MSL in the Santa Ynez Mountains northwest of Santa Barbara. These silver iodide releases were made as convection bands passed overhead. The releases were conducted on a random seed or no-seed decision basis in order to obtain baseline non-seeded, natural, rainfall information for comparison. A large network of recording precipitation gauges was installed for the research program (Figure 2.1). The amount of precipitation that fell from each seeded or non-seeded convection band was determined at each precipitation gauge location. Average convection 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 to the non-seeded band precipitation.

Ratios greater than 1.0 are common in Figure 2.2. A ratio of 1.50 would indicate a 50 percent increase in precipitation from seeded convection bands. This was proven to be statistically significant unlike Santa Barbara I. The reasoning for one being statistically significant and the other result not, can be found in Appendix B. The high ratios in southwestern Kern County are not significant in terms of amounts of additional rainfall since the convection 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.

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 2.3 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 convection band precipitation was increased over a large area using this ground-based seeding approach.

In a similar experiment, phase II employed an aircraft to release silver iodide (generated by silver iodide - acetone wing tip generators) into the convection bands as they approached the Santa Barbara County coastline west of Vandenberg Air Force Base. The convection bands to be seeded were also randomly selected. Figure 2.4 provides the results. Again, a large area of higher precipitation amounts is indicated in seeded convection bands compared to non-seeded convection 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 Air Force Base (for example, west of the ground-based release point).

A study of the contribution of convection band precipitation to the total winter precipitation in Santa Barbara County and surrounding areas was conducted in the analysis of the Santa Barbara II research program. This study indicated that convection bands contributed approximately one-half of the total winter precipitation in this area (Figure 2.5). If it is assumed that all convection bands could be seeded in a given rainy season and that a 50 percent increase was produced, the result would be a 25 percent increase in total rainy season precipitation if we assume the convection bands would have contributed one half of the rainy season's rainfall. Two NAWC reports (Thompson et al., 1988 and Solak et al., 1996) provided a more precise quantification of the optimal seasonal seeding increases that might be expected at Juncal and Gibraltar Dams of 18-22%, respectively, from seeding convection bands.

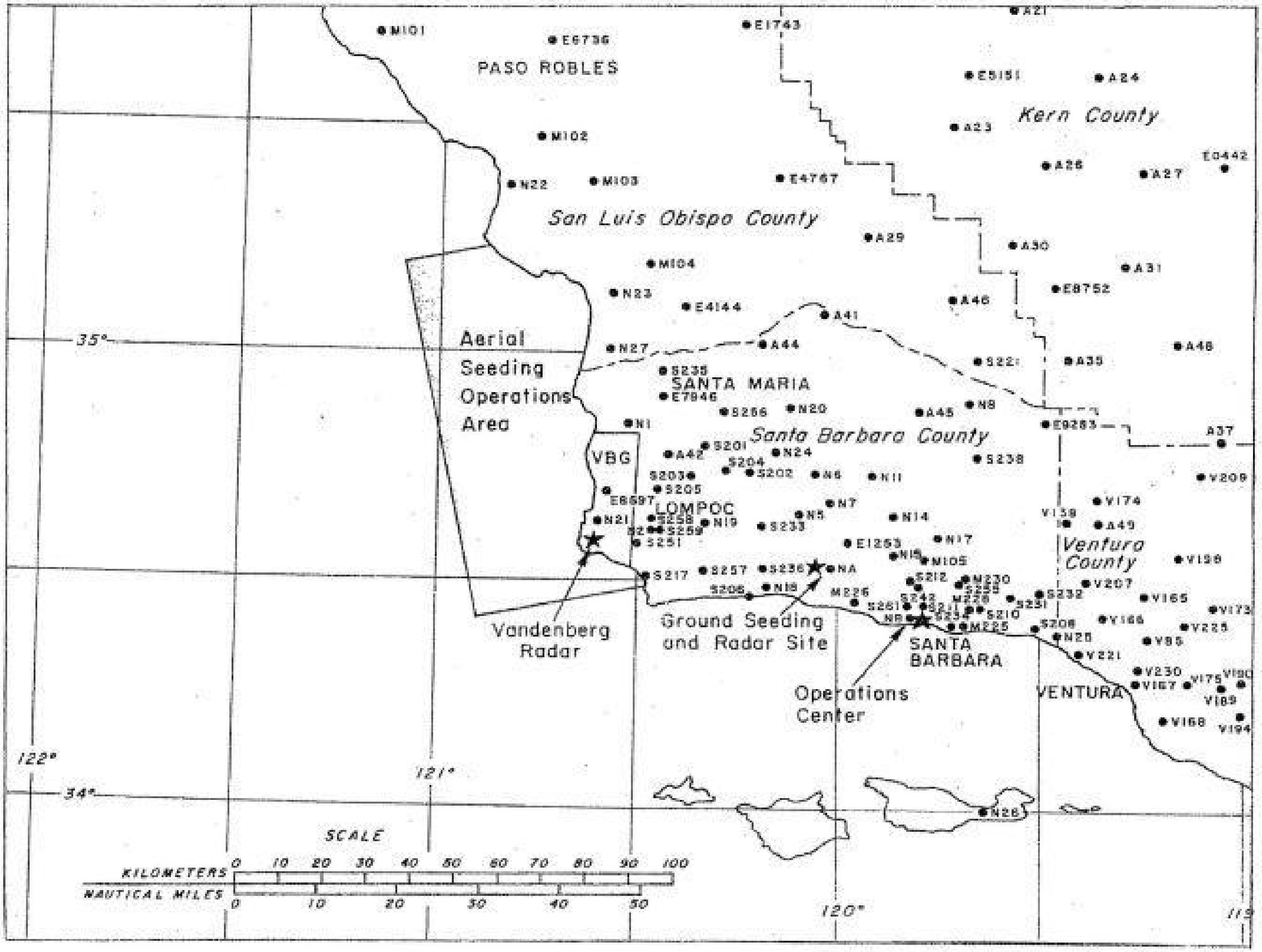

Figure 2.1 Santa Barbara II project map with rain gauge locations, radar and seeding sites.

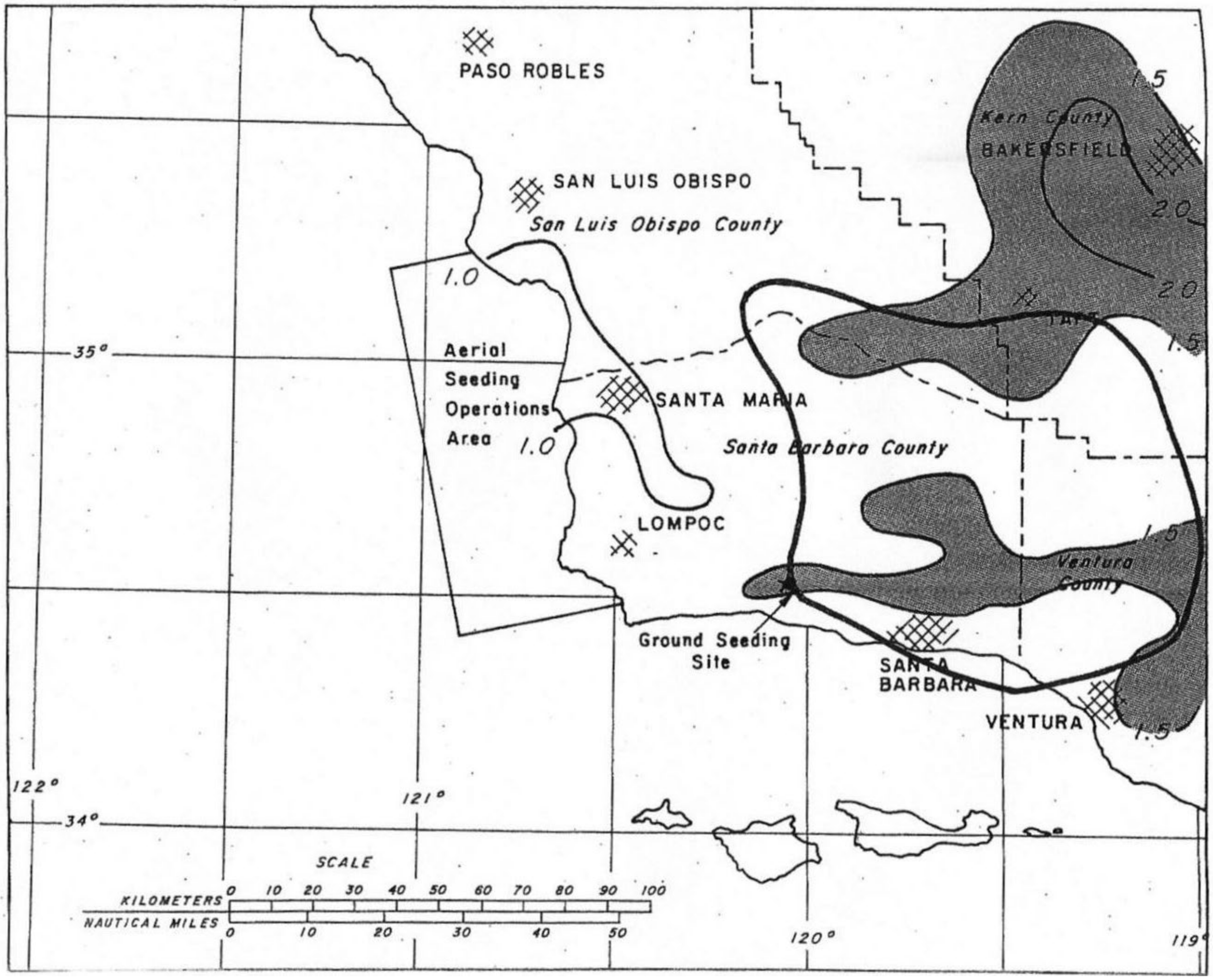

Figure 2.2 Seeded/Not-Seeded Ratios of band precipitation for Phase I.

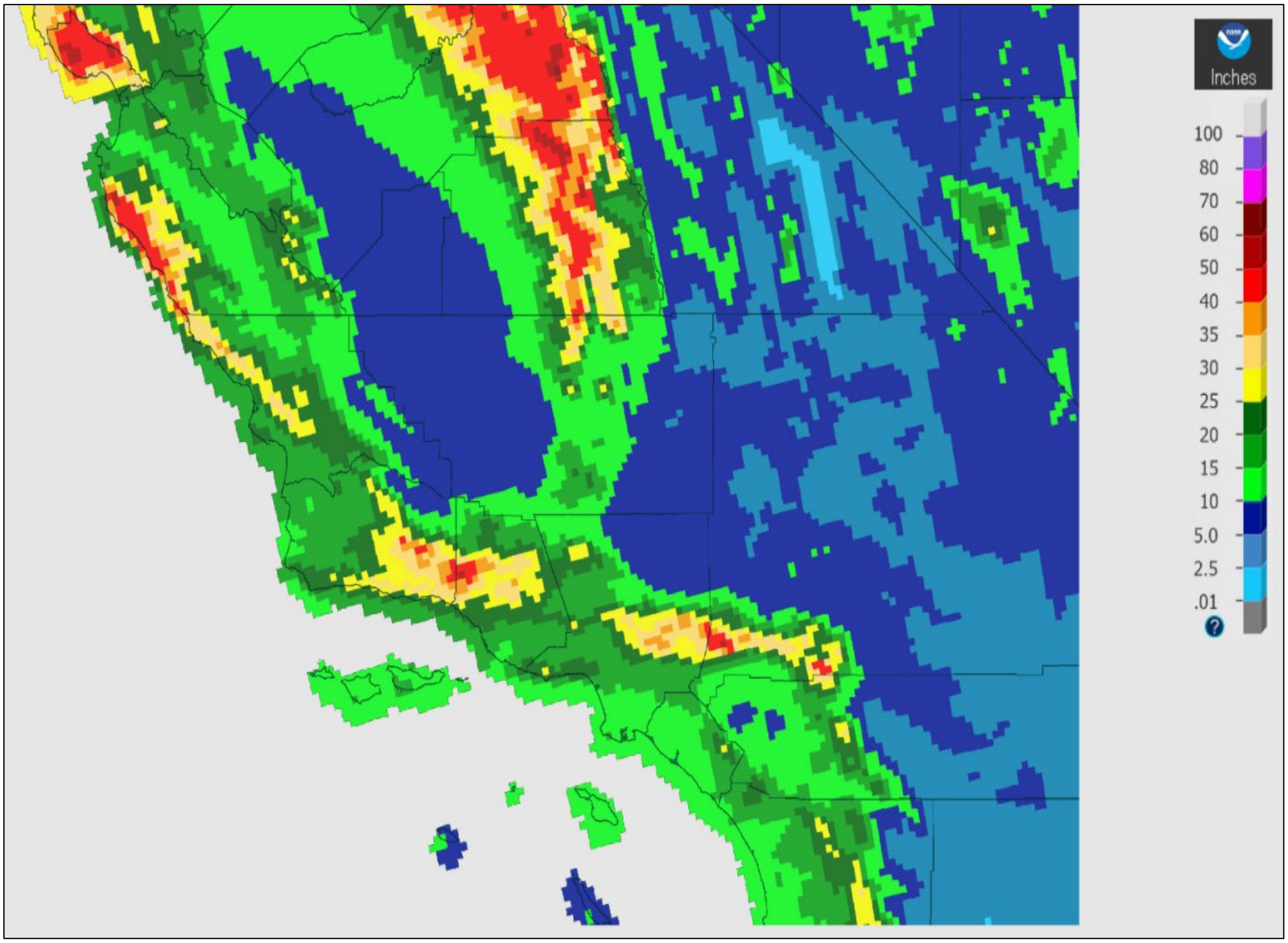

Figure 2.3 Annual average precipitation (inches), Southern California 1980-2010.

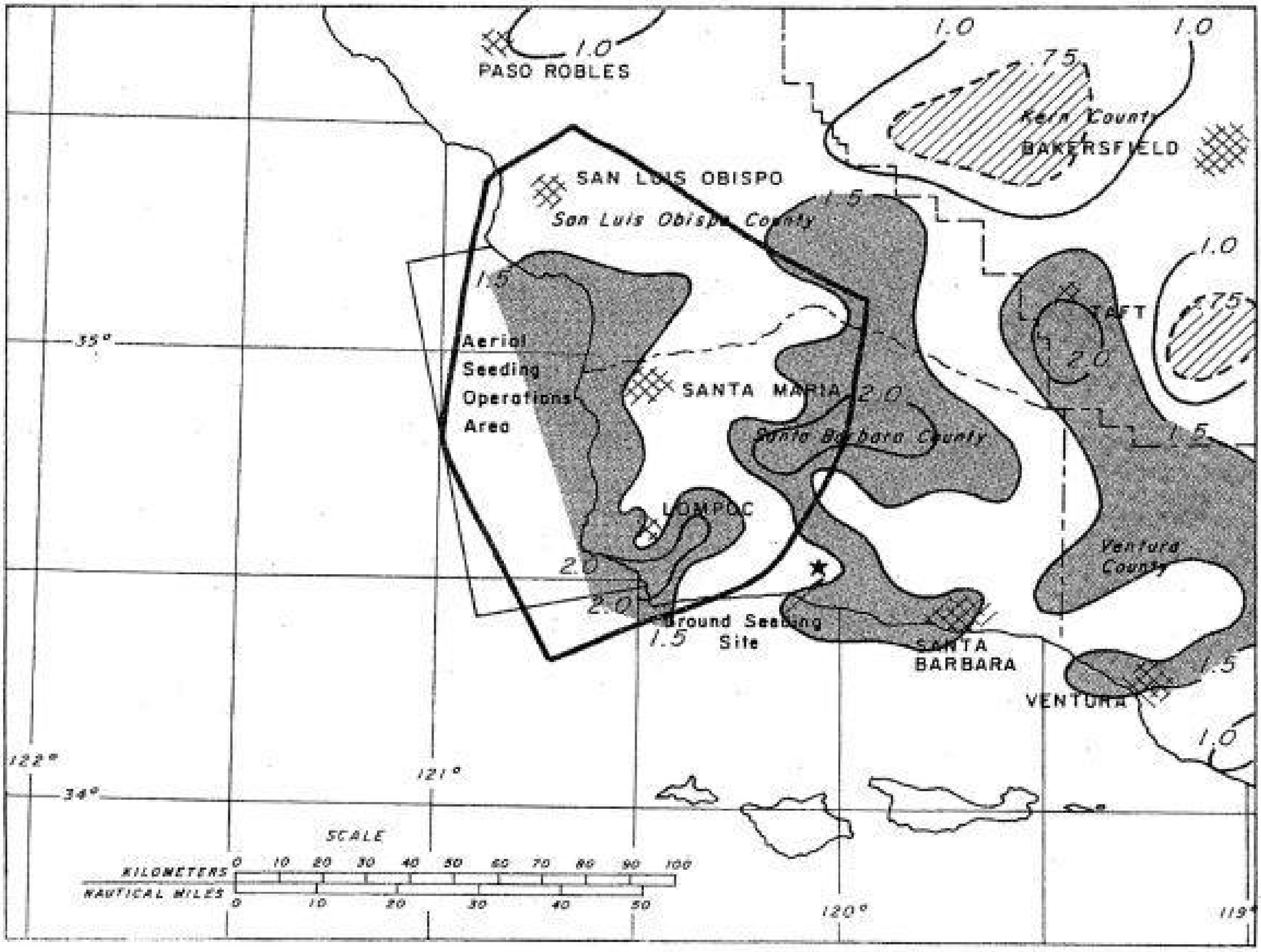

Figure 2.4 Seeded/Not-Seeded ratios of band precipitation for Phase II aerial operations, 1970-74 seasons.

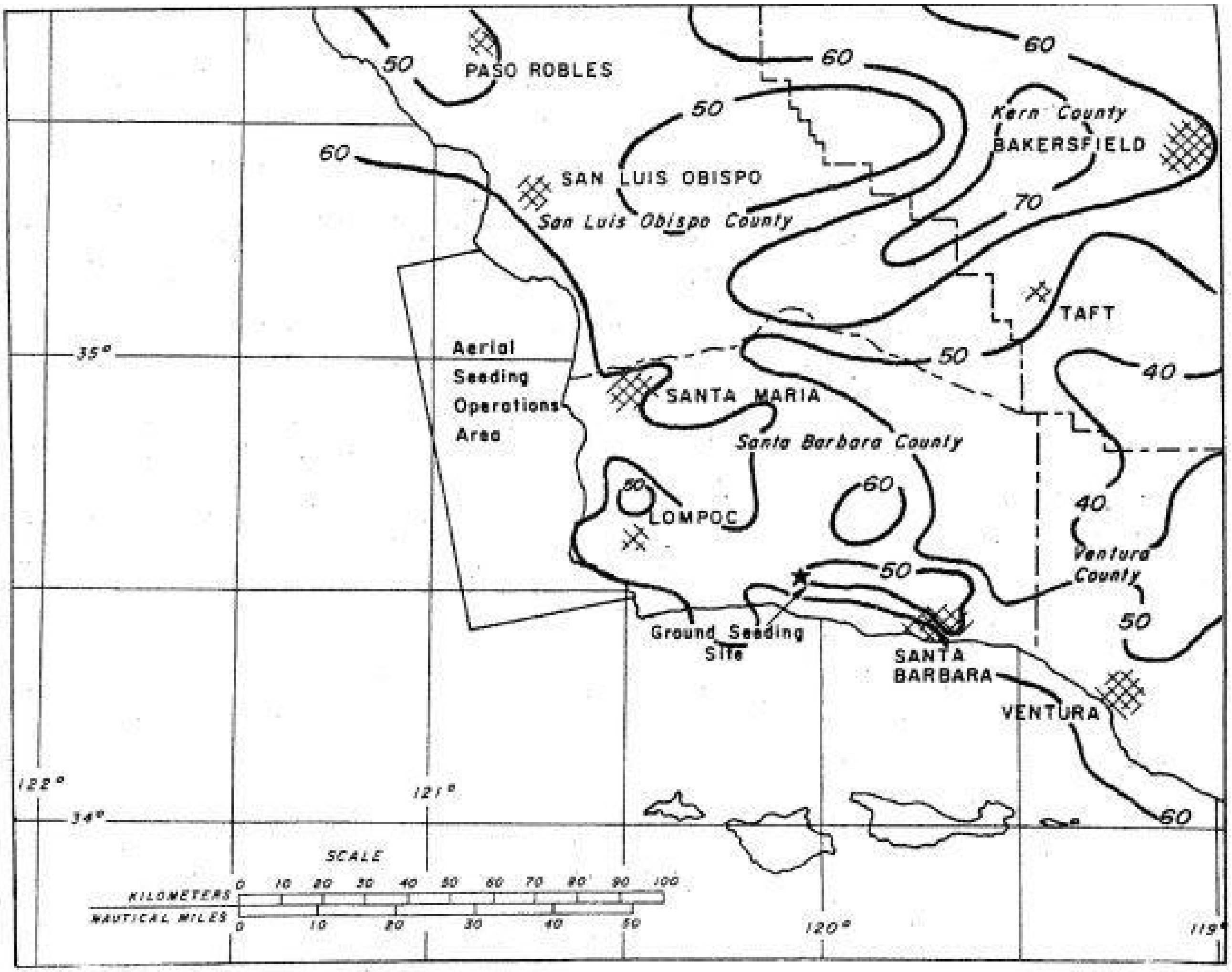

Figure 2.5 Approximate percentage of winter precipitation occurring in convection bands, 1970-74 seasons.

For illustration purposes, Figure 2.6 provides a sequence of six radar images of a convection band as it moved into Santa Barbara County on April 11, 2010. The radar images are from the Vandenberg AFB radar site. Table 2-1 provides 30 minute interval rainfall values observed at Orcutt during the passage of this convection band. The highest 15-minute rainfall total (not shown in the table) was 0.35 inches between 1725 and 1740 PDT during the passage of the heaviest portion of the band, corresponding to the time period between the 2nd and 3rd images in the sequence. Short- duration rainfall rates peaked at close to 2 inch per hour for a brief period around 1730 PDT. Rainfall rates then averaged around a quarter inch per hour or less during the remainder of the event (after about 1800 PDT).

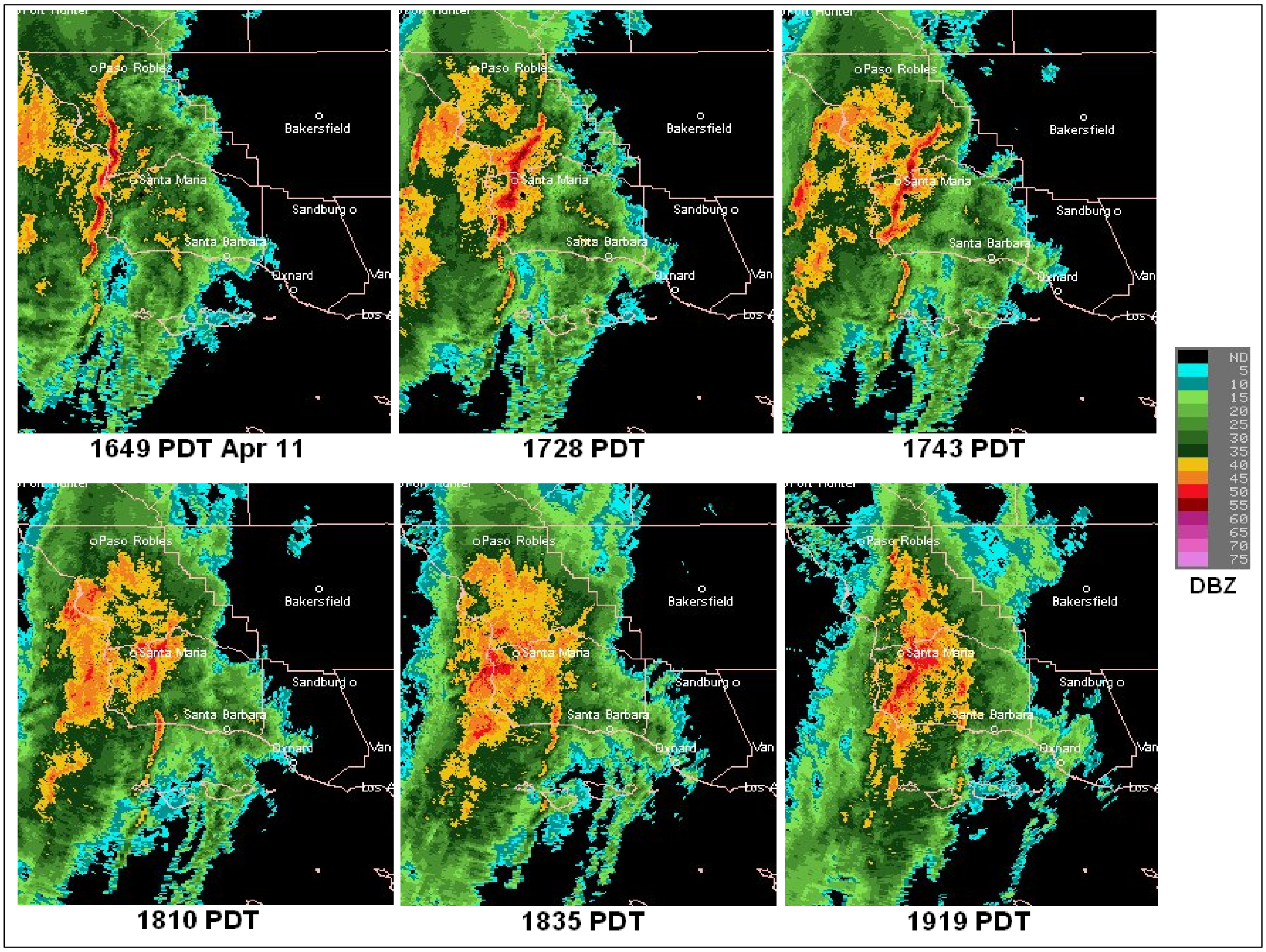

Figure 2.6 Frontal convective band passing over Santa Barbara County on April 11, 2010.

Table 2-1
Short Duration Rainfall Amounts at Orcutt During Storm Event in Figure 2.6

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

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 rainy season precipitation. In addition, research has indicated that these bands contain supercooled liquid cloud 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 a general north to south fashion (for example, northeast to southwest, northwest to southeast) 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 on occasion. 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.

3.0 PROJECT DESIGN

The winter cloud seeding program was conducted over portions of northern Santa Barbara and southern San Luis Obispo counties for the Huasna-Alamo Target area (Twitchell Reservoir drainage). This area is depicted in Figure 3.1. The objective of the program was to seed all suitable storm systems affecting the target area that contained organized convective bands, unless precluded by previously established suspension criteria, which are listed in Section 5.0.

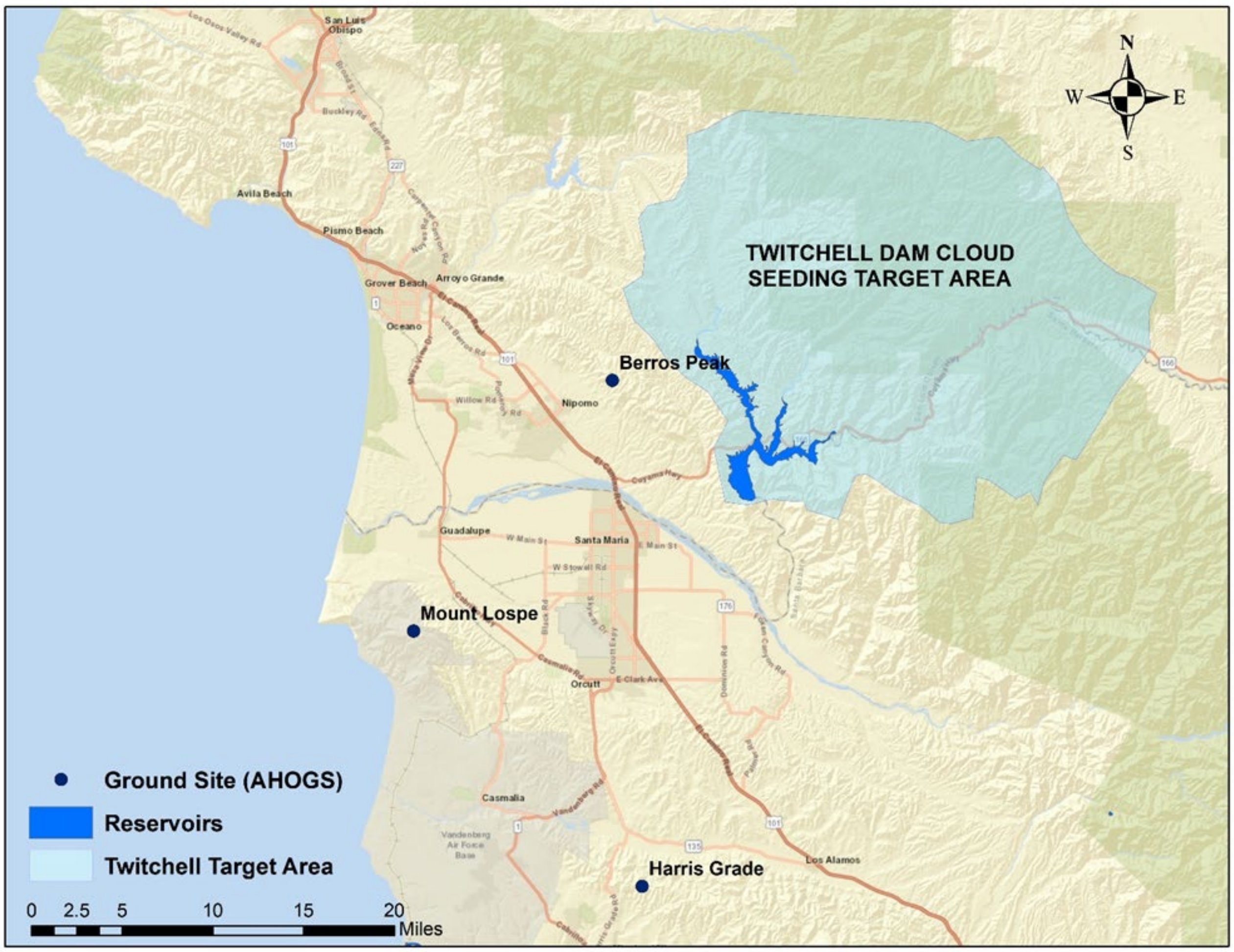

Figure 3.1 Project area and ground-based high-output flare site locations

Table 3-1 provides some generalized seeding criteria that NAWC uses to help determine whether an approaching storm contains suitable conditions for seeding.

Table 3-1
Generalized Seeding Criteria

- Organized convective band approaching the area.
- 700 mb (approximately 10,000 feet) temperature colder than -4° to -5° C for ground seeding operations. If warmer temperatures are present, aircraft seeding may be viable.
- 700 mb wind directions favorable for transport of the seeding materials over the target areas.
- Cloud top temperatures colder than or at -5° C.
- No suspension criteria met.

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 (for example, that research results from one location are transferable to the operational program's target area). The Santa Barbara area has a unique advantage in this respect since a successful winter research program was conducted during the winters of 1967-1973 within Santa Barbara County. The research program was known as Santa Barbara II, which was summarized in Section 2.4.

As a consequence of the above, NAWC believes the best project design for a winter cloud seeding program in Santa Barbara County and southern San Luis Obispo County to be one that replicates, as much as possible, the design of the Santa Barbara II Research Program, since it documented the successful results of randomized seeding experimentation and analysis. In fact, the combination of the research program's phase I (ground-based) and phase II (airborne) seeding modes should constitute the optimized method for capitalizing on the seeding potential for the area. NAWC's project design was based upon this approach.

Three AHOGS sites were used to seed suitable convection bands as they passed over these sites with consideration given to targeting of the effects of seeding, and to seeding suspension criteria. These sites were located at Mt. Lospe, Berros Peak and Harris Grade, which have all been used during previous seasons.

NAWC initially (1982-1985 seasons) used this high-output ground-based pyrotechnic seeding approach in the operational Santa Barbara program following the completion of the Santa Barbara II research program, but this seeding mode was discontinued since the manufacture of high-output flares (400 grams of silver iodide each) was discontinued. 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 (between -4 to -10°C or –12°C). High-output silver iodide generators were flown on the aircraft and 400-gram output ground 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) flares beginning with the 2001-2002 program. The pyrotechnic flares used at the AHOGS sites emit fast-acting silver iodide complexes during a burn time of approximately four minutes. **These flares are referred to as 150-gram flares but this weight includes all the components of the flare (e.g., oxidizer, reduction agent, binder etc.). The amount of silver iodide in the flare has been determined to be 16.2 grams.** These flares are manufactured by Ice Crystal Engineering (ICE) located in Fargo, North Dakota.

The output of these ICE flares has been tested at the Colorado State University Cloud Simulation Laboratory during the 1970s. Table 3-2 provides the results of this testing. These flares exhibited activity up to temperatures of -4°C, which is considered very desirable since activity at these warmer temperatures can result in the creation of more artificially generated ice crystals at lower altitudes in the convective bands. A couple of advantages can result:

- Ground releases of seeding material can activate more quickly since the seeding plumes will rise to the -4°C level sooner than the -6 to -8°C level which may have been the case with earlier generation flares.

- Conversion of cloud water droplets to ice crystals at the -4°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 further discussion on this).

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>. It was therefore concluded that nuclei produced by these flares were operating by the condensation-freezing mechanism as discussed in Section 2.0. This is considered to be an advantage over the earlier generation flares that are likely operated by the contact nucleation process, which is much slower. It implies that nearly all of the seeding material that reaches temperatures of -4°C within target clouds should quickly produce ice crystals. The contact nucleation flares, due to the slow nature of the process, could result in some of the seeding material not activating 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 3-2
CSU Cloud Chamber Test Results for Ice Crystal Engineering Flare

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

The current ICE flare was compared to the earlier LW-83 flare based upon tests conducted at the CSU Cloud Simulation Laboratory. Figure 3.2 provides a visual comparison of the nucleating characteristics of the ICE and the LW-83 flares. The figure demonstrates that the ICE flare is more effective in the warmer temperature regions of -4 to -10°C. 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.

Figure 3.2 demonstrates that the ICE flare can produce more ice crystals per gram of seeding material in these critical temperature regions (as much as two orders of magnitude higher at -4°C) than the older LW-83 flare, although the latter flare contained more seeding material.

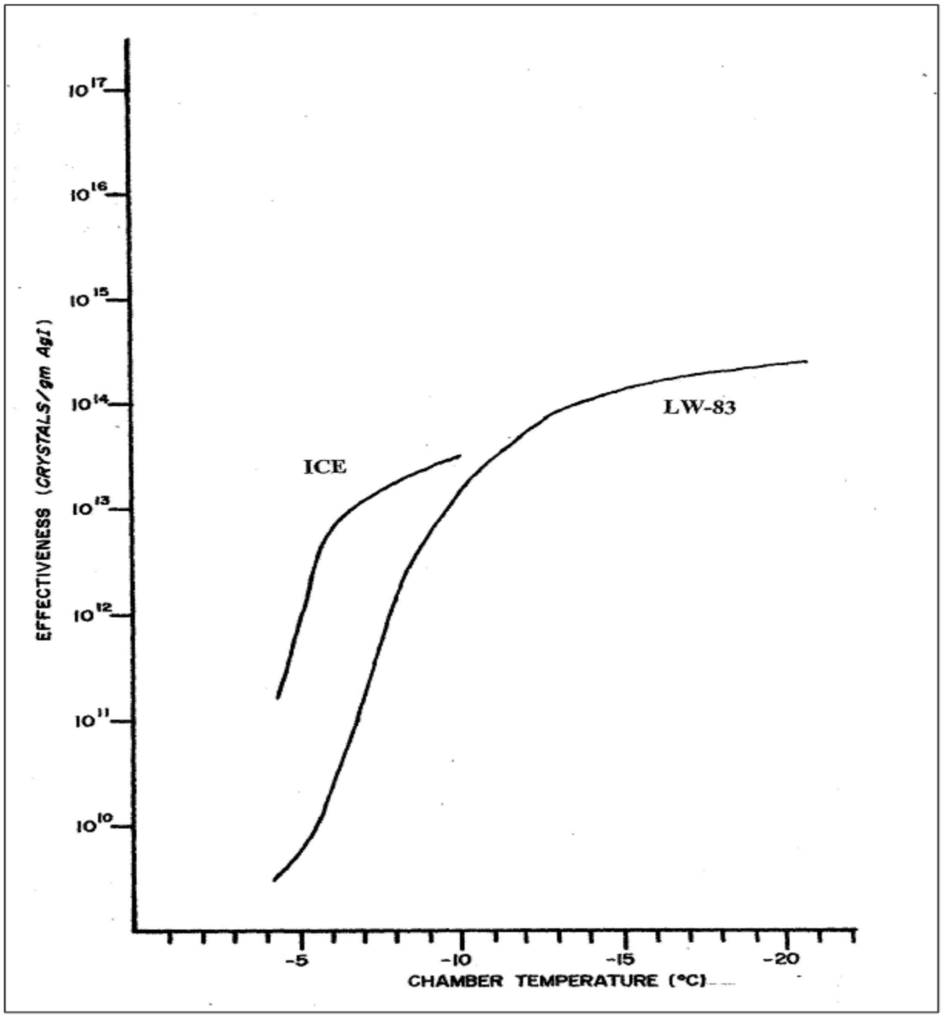

Figure 3.2 Comparison of effectiveness of the LW-83 versus the ICE burn-in-place flare, CSU Cloud Chamber results

Table 3.3 shows historical program information for the county of Santa Barbara for the last nine years. This table shows that the seasonal period can be adjusted per the client's needs and can be designed to fit various hydrological and budgetary circumstances.

Table 3-3
Santa Barbara County Historical Program Information

Operational Season	Length of Season (months)	Ground Program	Airborne Program
2010-2011	4.5	Nov. 15-Mar. 31	Nov. 15-Mar 31
2011-2012	4.5	Dec. 1 – Apr. 22[1]	N/A
2012-2013	3.5	Dec. 1 – Mar. 15[2]	N/A
2013-2014	5	Nov. 15- Apr. 15	Dec. 15-Mar. 15
2014-2015	5	Nov. 15- Apr. 15	Jan. 1 – Mar. 31
2015-2016	6	Nov. 1 – Apr. 30	Dec. 1 – Mar. 31
2016-2017	6	Nov. 1 – Apr. 30[3]	Jan. 1 – Mar. 31
2017-2018	5	Nov. 15 – Apr. 15[1]	N/A
2018-2019	5	Nov. 15 – Apr. 15[1]	N/A
2019-2020	4.5	Dec. 1 – Apr. 15[1]	N/A
2020-2021	4	Dec. 1 – March 31[1]	N/A

[1] Program only conducted for the Huasna-Alamo Target area

[2] Season shortened due to the likelihood of no significant runoff occurring. No aircraft were included due to large burn areas present in Santa Barbara County.

[3] The Huasna-Alamo target area began Nov. 1 and the Upper Santa Ynez began Nov. 15.

4.0 EQUIPMENT, PROCEDURES AND PERSONNEL

Each operational cloud seeding program relies upon a mix of suitable equipment, customized procedures and qualified personnel. These elements were blended into a comprehensive Operations Plan that was customized specifically for operations of the Santa Barbara program for the 2020-2021 winter season. Various components of this plan are discussed below.

4.1 Weather Radar

The Vandenberg AFB radar site has been utilized for the operation of the cloud seeding program since 2001. It provides information on precipitation location and intensity, as well as wind speed and direction within the precipitation echoes and a large array of additional products. The radar step-scans through 14 different elevation angles in a 6-minute period. The maximum range for the detection of precipitation echoes is 143 miles from the radar. The NWS provides all the necessary support for the radar: operation, calibration, spare parts, and maintenance.

An upgrade to the Vandenberg AFB NEXRAD radar was completed during the 2011-2012 winter season. This upgrade consisted of adding a dual polarization capability. This upgrade greatly enhances NEXRAD radars by providing the ability to collect data on the horizontal and vertical properties of hydrometeors (e.g., rain, hail) and non-weather (e.g., insect, ground clutter) targets. Four new products were provided from this upgrade during this past season: Correlation Coefficient, Differential Reflectivity, Specific Differential Phase and Hydrometeor Classification. In the context of the Santa Barbara seeding program this upgrade provided the opportunity for a project meteorologist to be able to determine if supercooled liquid water (SLW) was present using these specialty products and compare it to icing reports.

4.2 AHOGS Ground-Based Seeding Systems

The Automated High Output Ground Seeding Systems (AHOGS) allow 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 convection rain bands as they track into and across the project area under different wind flow regimes.

Each AHOGS site is controlled via a modem and can be connected via the internet where the LoggerNet software is installed. This software allows the user to manage the flare seeding operations and allows monitoring and reporting of AHOGS site status information, such as flare inventory and battery voltage. The project 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-minute intervals, beginning at any selected time.

NAWC utilized three custom AHOGS sites for the 2020-2021 winter season, to affect the Huasna-Alamo target area. These sites are designated as Mt. Lospe, Harris Grade and Berros Peak. NAWC believes higher elevation sites to be more effective since the base of the convective bands may not reach lower elevations during their passage over the target area. Such conditions could result in the lack of transport of the seeding agent into effective regions within the bands. Location is important since the effects of seeding will generally occur to the east through north of the site location. The three sites were selected as ones that would offer potential targeting of seeding effects in the Huasna-Alamo target area under different lower-level wind flow regimes commonly experienced with the passage of convective bands over Santa Barbara County. Table 4-1 provides location and elevation information for the AHOGS sites.

Table 4-1
AHOGS Site Locations

Location	Latitude (N)	Longitude (W)	Elevation (ft.)
Mt. Lospe	34.897	-120.595	1570
Harris Grade	34.730	-120.413	1204
Berros Peak	35.062	-120.437	1610

These systems were designed for intensive seeding of convection bands using high-output pyrotechnic flares. Each AHOGS consists of the following primary onsite components:

- Two flare masts, which hold a total of 32 fast-acting seeding flares.
- Spark arrestors that enclose each flare.
- A control mast with 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.

NAWC, working with Advanced Process Control and Optimization (APCO) of Salt Lake City, developed an updated design of this system in the summer of 2015 for another southern California program. This updated design included:

- Ethernet/digital controls.
- A Campbell Scientific CR 1000 to replace the earlier CR 10 data loggers.
- Platform peripheral communications were upgraded to Ethernet from older RS232 serial format.
- A video camera, which can be activated through the internet, was added to the central control mast which allows viewing of the flare masts in real-time; a useful feature to confirm that a flare that has been programmed to burn actually does ignite. If not, the project meteorologist can burn another flare.
- Improved photovoltaic panels, voltage regulators and battery storage was added to the control platform.

NAWC installed four of these newly designed units for the Santa Barbara program during the 2016-2017 winter season, replacing the older units at the Mt. Lopse and Harris Grades sites. The newer system was already in use when the Berros Peak site was established. Figures 4.1 and 4.2 provide photos from one of the video cameras that show seeding flares burning in daytime and nighttime conditions.

The pyrotechnic flares used at the AHOGS sites produce high-output, fast-acting silver iodide complexes during a burn time of approximately 3-4 minutes. Additional information regarding these flares is provided in Section 3.0. NAWC upgraded the AHOGS sites for the 2005-2006 winter season through the addition of spark arrestors placed over each flare. The spark arrestors were developed during the fall of 2005. They are stainless steel cylinders with a large number of small holes drilled through the cylinders' walls. The spark arrestors were designed to eliminate any concerns about sparks, produced during flare combustion, falling to the ground. Even though the cloud seeding program is conducted during the winter season, there can still be periods when the ground cover can be dry, such as at the start of the program in the fall or during a dry spell that occurs during the operational period. Figure 4.6 shows a close up of the spark arrestors and Figure 4.7 shows a flare burning inside a spark arrestor.

Figure 4.1 Flare burning at an AHOGS site during daytime conditions

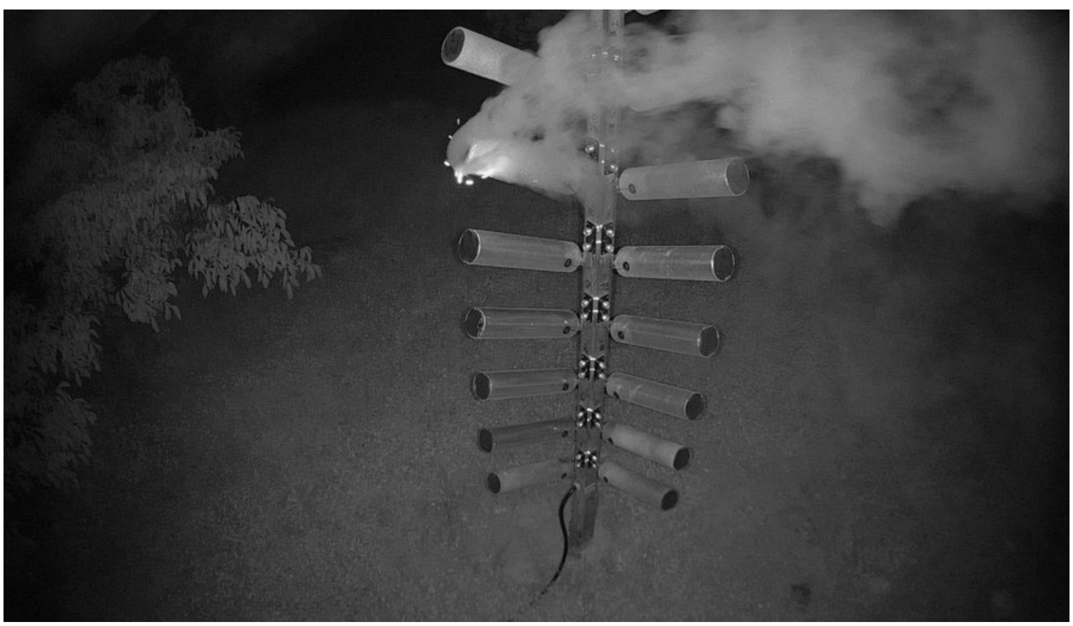

Figure 4.2 Flare burning at an AHOGS site during nighttime conditions

The video cameras are very useful during seeding operations since they allow the project meteorologist to verify the firing of flares. If a malfunction were to occur, the project meteorologist could program another flare to fire. Photos of each site used during the 2019-2020 winter season can be seen in Figures 4.3 – 4.5.

Figure 4.3 Photo of the Mt. Lospe AHOGS site

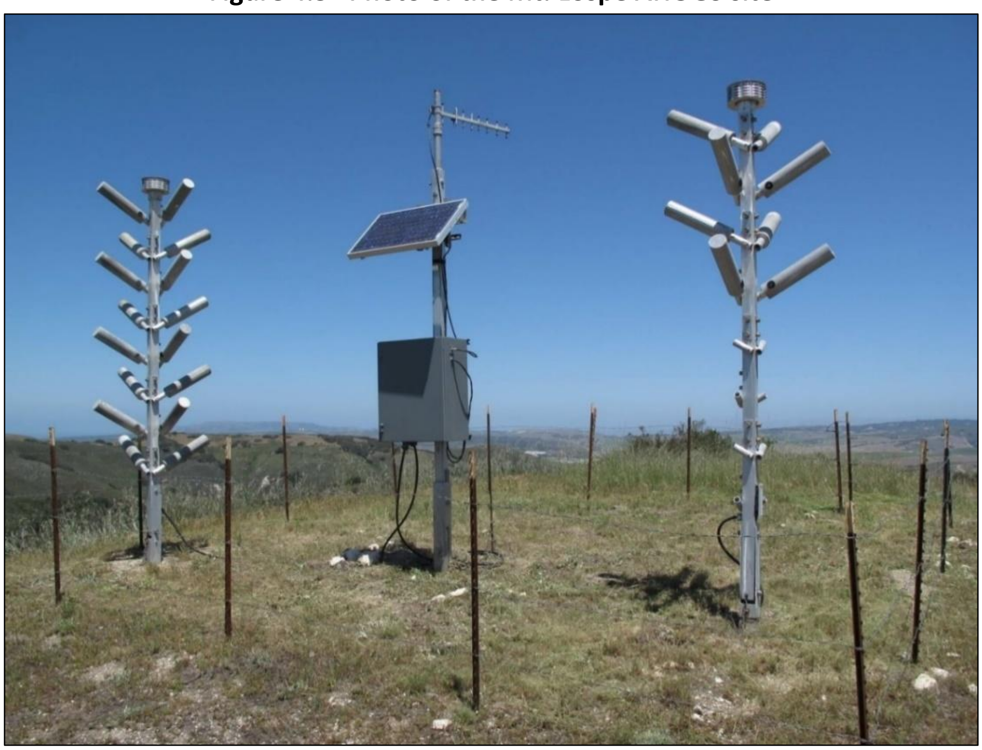

Figure 4.4 Photo of the Harris Grade AHOGS site

Figure 4.5   Photo of the Berros AHOGS site

Figure 4.6   Close-up of spark arrestors

Figure 4.7 Flare burning inside a spark arrestor

4.3 Operations Center

NAWC's corporate headquarters in Sandy, Utah served as the operations center for the December 1, 2020 – March 31, 2021 operations period. The project meteorologist's computer contained the LoggerNet software necessary to control the three AHOGS sites. Weather radar information from the NWS NEXRAD site at Vandenberg AFB California was used to assist in decision-making. Data from this site was available at approximately 6-minute intervals through a variety of online sources.

4.4 Weather Forecasts and Meteorological Data Acquisition

NAWC project meteorologists were responsible for the determination of when seedable conditions were present and whether seeding suspension criteria were met. Coordination between NAWC's project meteorologist and Mr. Matthew Scrudato of the Santa Barbara Water Agency typically occurred before and after each potential seeded event and sometimes during these events. NAWC's project meteorologists were also responsible for archiving relevant weather data (for example, local NEXRAD radar displays, satellite photos and rainfall data) from each event. Examples are shown in Section 5.0, which discusses last winter's operations.

A variety of weather information is available via the internet that was used to forecast approaching storms, observe weather conditions during storms as they passed through Santa Barbara County and document conditions of interest like criteria relating to suspension criteria. Some of these useful products include:

- Upper-air data, including important levels at 850, 700, 500 and 250 mb.
- Rawinsonde data including pressure, temperature and wind observations which are plotted throughout the atmosphere.
- Radar and surface data which allow the meteorologists to view important parameters before and during seeding operations.
- Hourly observed precipitation data from ALERT networks in Santa Barbara and San Luis Obispo counties, including streamflow data.
- Satellite imagery including visible, infrared, and water vapor presentations updated at intervals ranging from 5 minutes to one hour.

4.5 Seeding Procedures

NAWC's conceptual model of the dynamics of the convection bands is that they are similar to convective bands that can occur in other parts of California during winter storms and other parts of the U.S. when a frontal structure is involved. NAWC believes that the primary low to mid-level inflow to these bands is along the leading edge of the bands. The inflow regions, usually along the leading edges of convection bands, are the areas containing stronger updrafts. These are also the development and accumulation zones of supercooled liquid cloud droplets. Consequently, this is the desired region for the introduction of the seeding material. This would mean that flares burned at the ground sites would be timed to occur as the leading edge of the bands, as determined by the Vandenberg AFB NEXRAD radar, approached the ground sites. Low-level winds are considered in terms of targeting of seeding effects as well as the avoidance of seeding over areas that meet any suspension criteria. The HYSPLIT model, discussed in Section 6.0 was also used in real time to help predict the plume dispersion from flares burned.

4.6 Suspension Criteria

Suspension criteria were developed jointly between the Agency and NAWC personnel to serve as safeguards to avoid seeding during situations of extreme weather or adverse hydrologic conditions. Previously, special criteria had been developed and implemented following large fire events within the target areas. Since 1989, different types of suspension criteria for this project have been adopted and amended annually as needed. Cloud seeding suspension criteria were invoked whenever the National Weather Service (NWS) issued a severe storm, or flood warning that affected any part of the project area. Appendix B contains the suspension criteria for the 2020-2021 winter season. Seeding suspension criteria were monitored during some of the heavier precipitation events, but ultimately, the heavier precipitation event periods did not coincide with seeding operations since they did not meet NAWC's generalized seeding criteria (Table 3-1), thus no seeding suspensions occurred during the operational season.

4.7 Personnel

The following agencies and personnel were responsible for the conduct of the 2020-2021 cloud seeding program.

Santa Barbara County Flood Control &Water Conservation District and Water Agency

Mr. Matthew Scrudato, Senior Hydrologist and Project Administrator
Mr. Matt Young, Water Agency Manager
Mr. Tom Fayram, Water Resources Deputy Director

North American Weather Consultants

Mr. Garrett Cammans, President
Ms. Stephanie Beall[2], Project Manager/Meteorologist
Mr. David Yorty[3], back-up Project Meteorologist
Mr. Tom Segura, Local Equipment Technician

[2] Ms. Stephanie Beall is a Certified Operator by the Weather Modification Association.
[3] Mr. David Yorty is a Certified Manager and Operator by the Weather Modification Association.

5.0 OPERATIONS

The location of the seeding target area, the Huasna-Alamo, is shown in Figure 5.1. Ground seeding sites were operational at Mt. Lospe, Berros Peak and Harris Grade for the four month period of December 1, 2020 through March 31, 2021 for the Huasna-Alamo target area. Ground seeding locations are provided in Figure 5.1. Additional information on the design of the project was provided in Section 3.0.

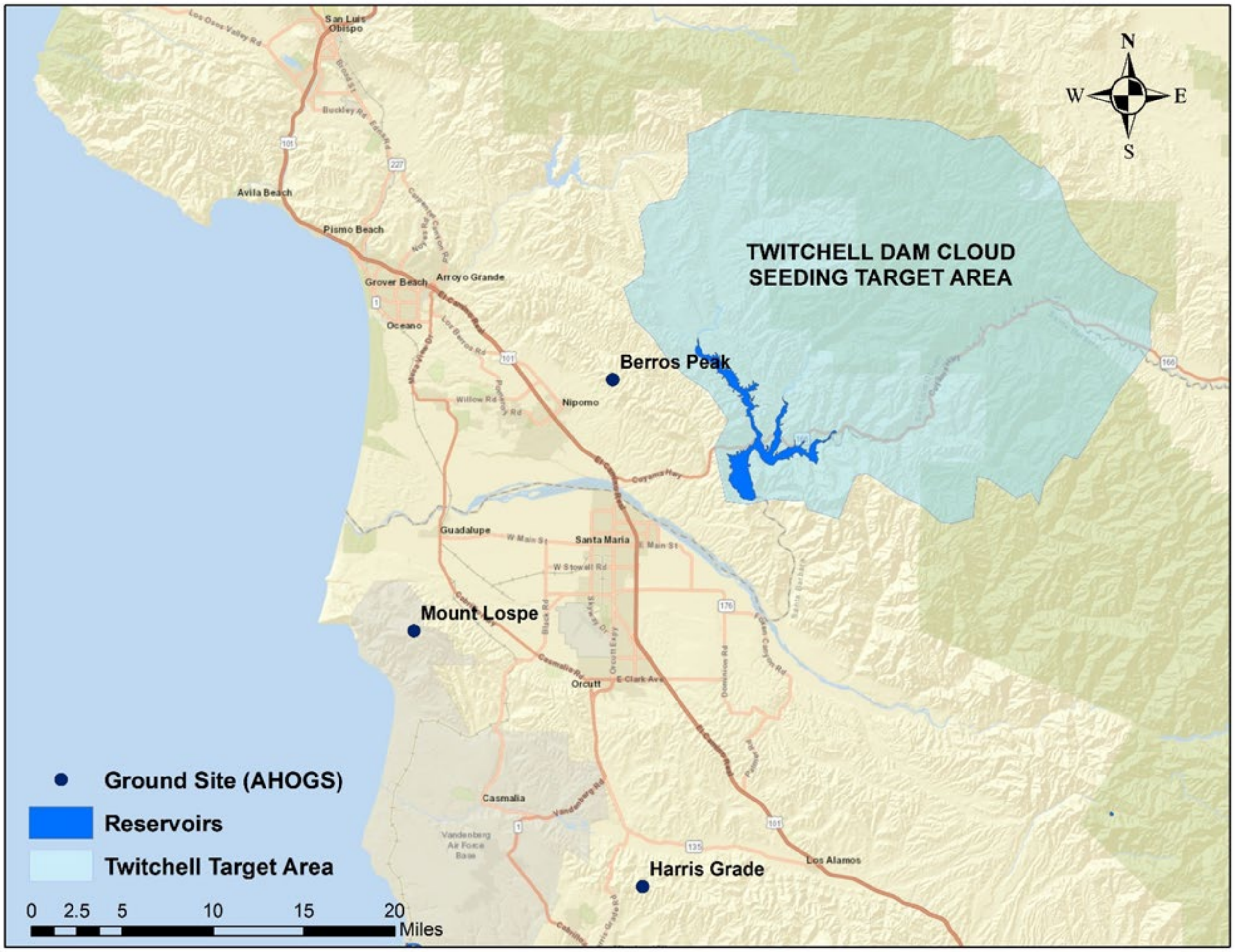

Figure 5.1 Project Area and AHOGS site locations

All operations were conducted in accordance with established suspension criteria, which were developed for a variety of situations, such as high intensity rainfall, flood warnings and streamflow discharge. Suspension criteria can be found in Appendix B.

The 2020-2021 winter season was characterized by was a weak La Nina phase of the El Nino Southern Oscillation (ENSO). The weak La Nina phase is not predictive of a particular precipitation pattern, i.e., it does not especially favor either an above or below normal water year. Figure 5.2 shows the precipitation percent of average for January through March of 2021 for the contiguous United States. Below normal precipitation was common not only along the Central Coast, but over most of the state of California. Only a few locations north of the Central Coast and into extreme northwestern California saw near normal precipitation. Most of the West Coast and Great Basin saw near to below normal precipitation values, while in the northern Rockies and Central Plains above normal values were observed, mostly due to an active spring storm track, that allowed several closed low type systems to linger there. Table 5-1 shows the evolution of the ENSO 3.4 region index throughout the 2020-2021 winter season. A value of -0.5 or less indicates La Nina conditions present and a value of +0.5 or more indicates that El Nino conditions are present. Values between -0.5 and +0.5 are considered neutral. The observed values this season were indicative of the La Nina ENSO phase, as shown in the table.

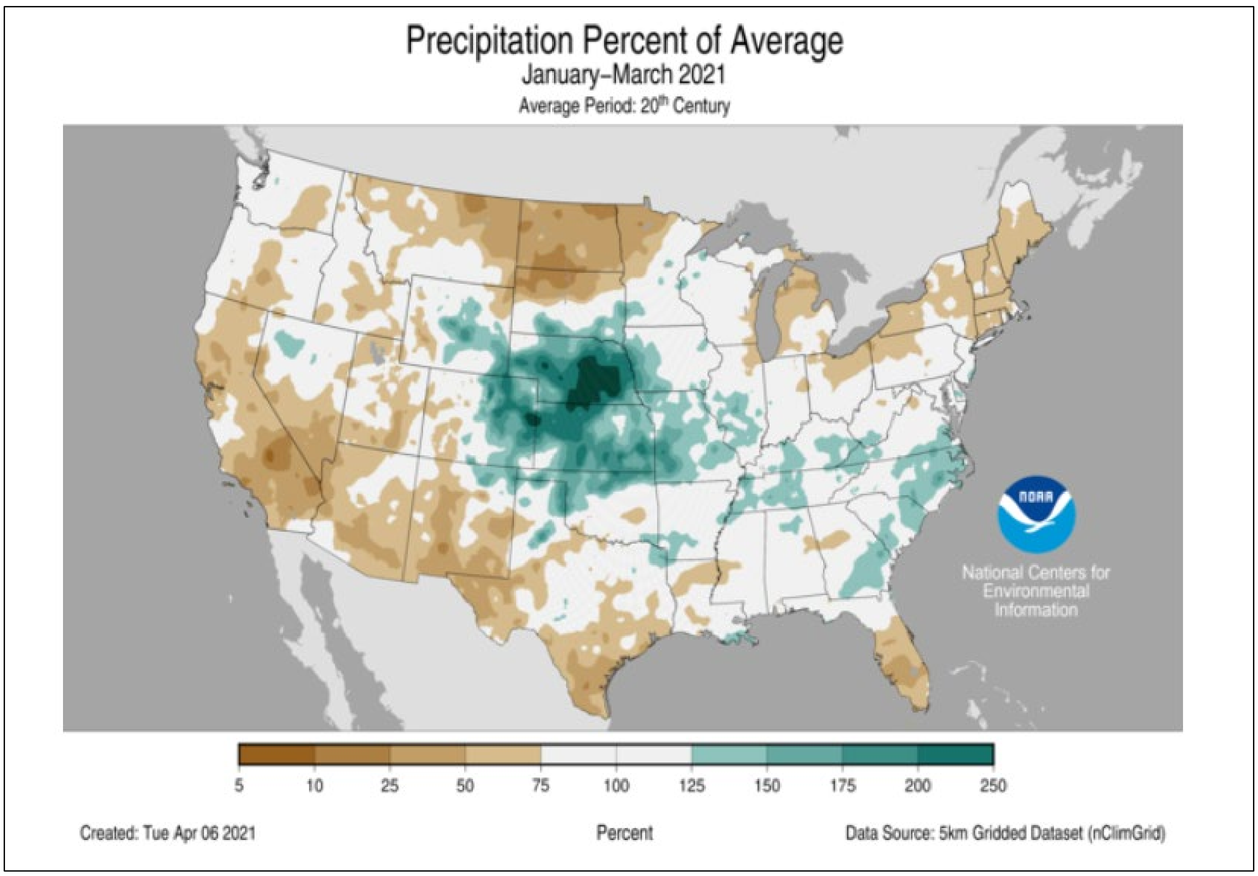

Figure 5.2 **Percent of average precipitation January 2021 – March 2021 for the contiguous United States**

Table 5-1
December 2020 – April 2021 ENSO Values

December - February	January - March	February - April
-1.0	-0.9	-0.8

5.1 Summary of the 2020-2021 Winter Season Rainfall

Santa Barbara County rainfall for the 2020-2021 season was far below normal, which was drier than the 2019-2020 winter season. Countywide percent of normal on May 1 was 92% during the 2020 Water Year and dipped to 48% during the 2021 Water Year. Above normal precipitation occurred in January, with the December, February and March periods experiencing below normal precipitation, particularly in February.

December brought below normal conditions to Santa Barbara County with only marginal precipitation amounts falling over the county. There was one storm that impacted the area near the end of the month, which contributed most of the monthly precipitation to the area. December 2020 percent of normal precipitation was 69%.

January proved to be the wettest month of the 2021 Water Year, with a number of systems affecting Santa Barbara County. Most of January remained dry however, with only the last week of the month contributing to 100% of the monthly precipitation and the seeding operations for the Twitchell watershed. Monthly percent of normal for January was 132%, providing much needed rainfall to the start of the rainy season.

February was the driest month of the 2020-2021 winter season, with monthly precipitation totals only 5% of normal for the county. Generally warm and dry conditions were the case, with many sites not receiving any measurable precipitation during the month. Coincidentally, February 2021 was nearly as dry as the historically dry February of 2020.

March proved to be wetter than February, but not by much. Dry conditions continued throughout most of March, with a monthly percent of normal around 44% for the county. Even with the general lack of precipitation, operations did occur around the second week of the month. The seeding program concluded on March 31, 2021.

Table 5-3 provides rainfall statistics as of April 16, 2021, two days after project completion. The countywide rainfall for the season was 48% of normal as of April 16, 2020. The cumulative percentage of average for the county's 2021 Water Year to date was 2% on December

1, 12% by January 1, rising to 40% by February 1, 40% on March 1 and 47% as of April 1. Figures 5.3-5.8 show a month by month glace at percent normal maps for the county of Santa Barbara.

Table 5-2
Seasonal Rainfall and Percentage of Normal through April 1, 2021

Santa Barbara County - Flood Control District

130 East Victoria Street, Santa Barbara CA 93101 - 805.568.3440 - www.countyofsb.org/pwd

Rainfall and Reservoir Summary

Updated 8am: 4/1/2021 **Water Year: 2021** **Storm Number: NA**

Notes: Daily rainfall amounts are recorded as of 8am for the previous 24 hours. Rainfall units are expressed in inches.
All data on this page are from automated sensors, are preliminary, and subject to verification.
*Each Water Year (WY) runs from Sept 1 through Aug 31 and is designated by the calendar year in which it ends
County Real-Time Rainfall and Reservoir Website link: ➢ http://www.countyofsb.org/hydrology

Rainfall	ID	24 hrs	Storm 0day(s)	Month	Year*	% to Date	% of Year*	AI
Buellton (Fire Stn)	233	0.00	0.00	0.00	8.54	57%	51%	
Cachuma Dam (USBR)	332	0.00	0.00	0.00	10.51	60%	53%	
Carpinteria (Fire Stn)	208	0.01	0.00	0.01	4.52	29%	26%	
Cuyama (Fire Stn)	436	0.00	0.00	0.00	3.62	54%	47%	
Figueroa Mtn. (USFS Stn)	421	0.00	0.00	0.00	8.37	44%	39%	
Gibraltar Dam (City Facility)	230	0.00	0.00	0.00	10.63	44%	40%	
Goleta (Fire Stn-Los Carneros)	440	0.00	0.00	0.00	9.14	55%	50%	
Lompoc (City Hall)	439	0.00	0.00	0.00	10.68	81%	73%	
Los Alamos (Fire Stn)	204	0.00	0.00	0.00	8.41	61%	55%	
San Marcos Pass (USFS Stn)	212	0.00	0.00	0.00	14.17	45%	42%	
Santa Barbara (County Bldg)	234	0.00	0.00	0.00	7.31	44%	40%	
Santa Maria (City Pub.Works)	380	0.00	0.00	0.00	7.16	60%	54%	
Santa Ynez (Fire Stn /Airport)	218	0.00	0.00	0.00	8.31	58%	53%	
Sisquoc (Fire Stn)	256	0.00	0.00	0.00	6.31	47%	42%	

County-wide percentage of "Normal-to-Date" rainfall : 53%

County-wide percentage of "Normal Water-Year" rainfall : 47%

County-wide percentage of "Normal Water-Year" rainfall calculated assuming no more rain through Aug. 31, 2021 (End of WY2021).

AI (Antecedent Index / Soil Wetness)
6.0 and below = Wet (min. = 2.5)
6.1 - 9.0 = Moderate
9.1 and above = Dry (max. = 12.5)

Reservoirs

Reservoir Elevations referenced to NGVD-29.
**Cachuma is full and subject to spilling at elevation 750 ft.
However, the lake is surcharged to 753 ft. for fish release water.
(Cachuma water storage is based on Dec 2013 capacity revision)

Click on Site for Real-Time Readings	Spillway Elev. (ft)	Current Elev. (ft)	Max. Storage (ac-ft)	Current Storage (ac-ft)	Current Capacity (%)	Storage Change Mo.(ac-ft)	Storage Change Year*(ac-ft)
Gibraltar Reservoir	1,400.00	1,375.87	4,559	624	13.7%	0	-1,586
Cachuma Reservoir	753.**	725.18	193,305	119,845	62.0%	0	-23,930
Jameson Reservoir	2,224.00	2,213.36	4,848	3,607	74.4%	0	-681

(Data from the Santa Barbara County Flood Control District)

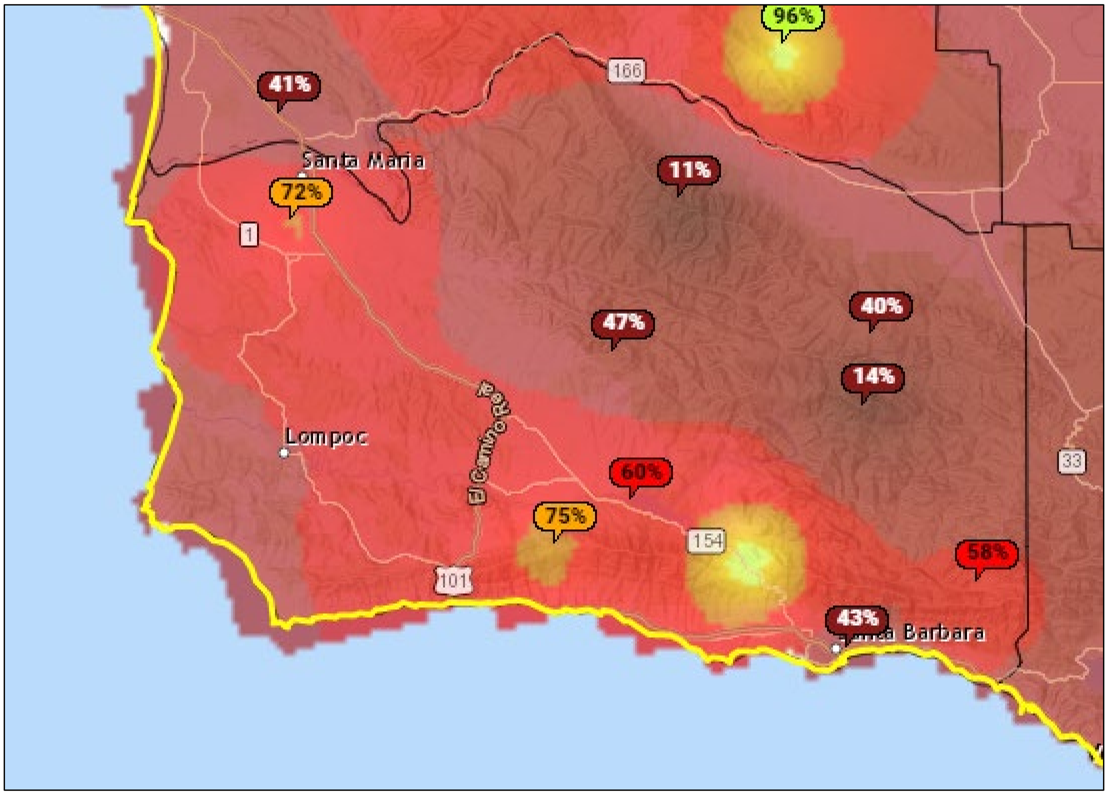

Figure 5.3 December 2020 Percent of Normal Precipitation

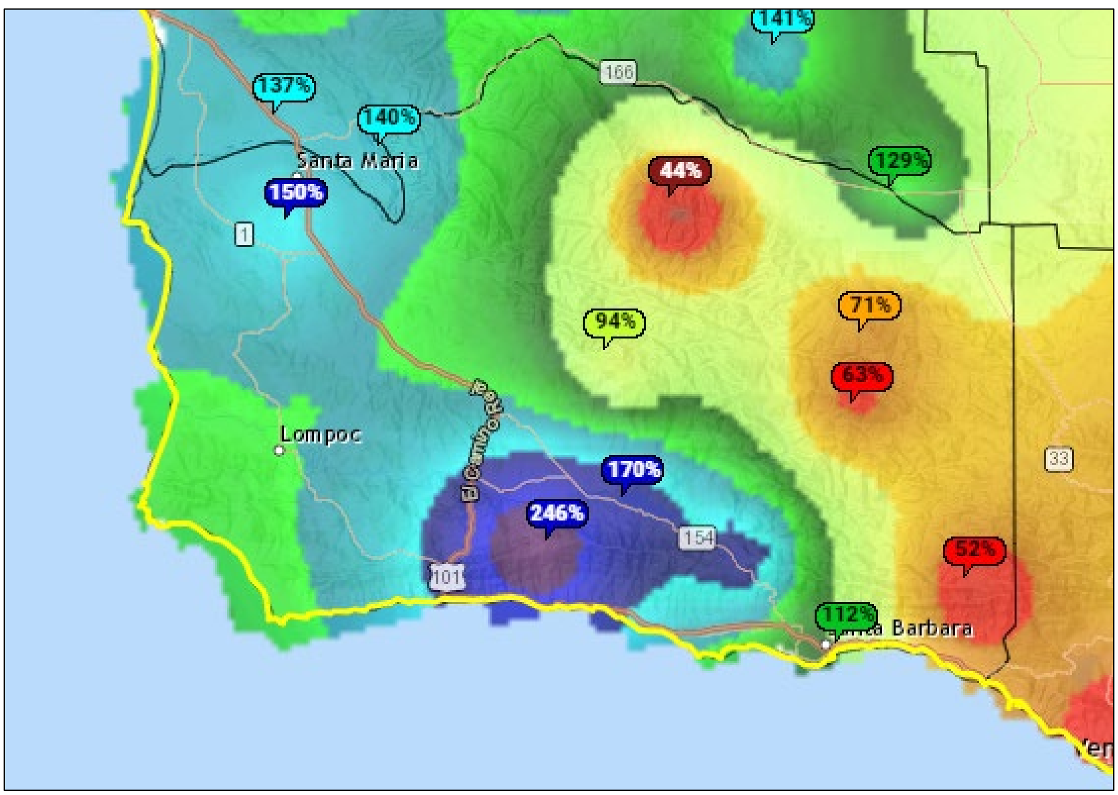

Figure 5.4 January 2021 Percent of Normal Precipitation

Figure 5.5 February 2021 Percent of Normal Precipitation

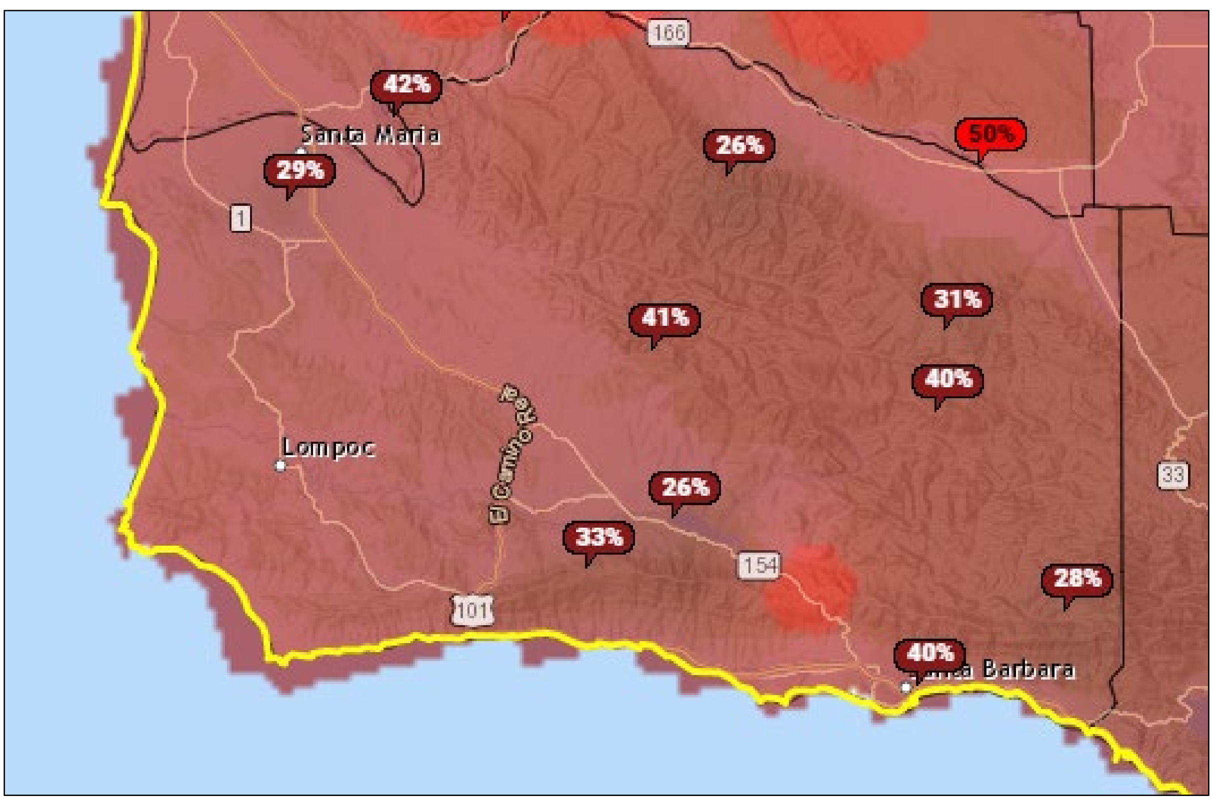

Figure 5.6 March 2021 Percent of Normal Precipitation

Figures 5.7-5.9 provide graphical depictions of rainfall events for the period of December 1, 2020 through March 31, 2021, for three different sites in and near the Huasna-Alamo target area. Note that the scale on the x-axis of each site is different, depending on how much rainfall was received during the given period.

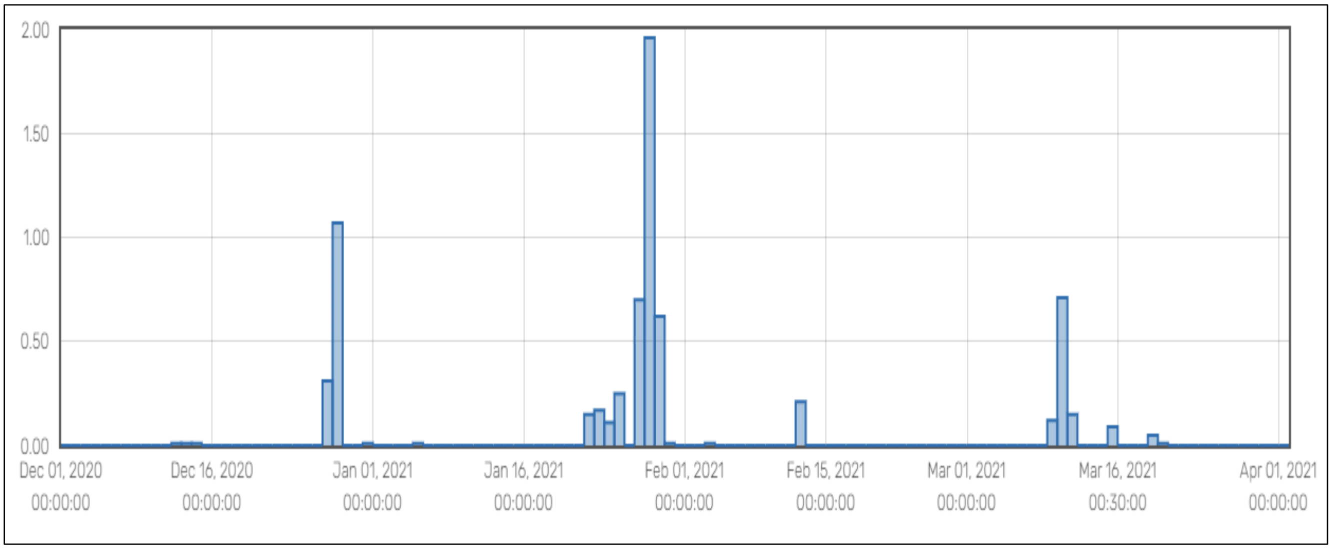

Figure 5.7 Santa Maria Daily Rainfall (8 am to 8 am) – December 1, 2020 to April 1, 2021

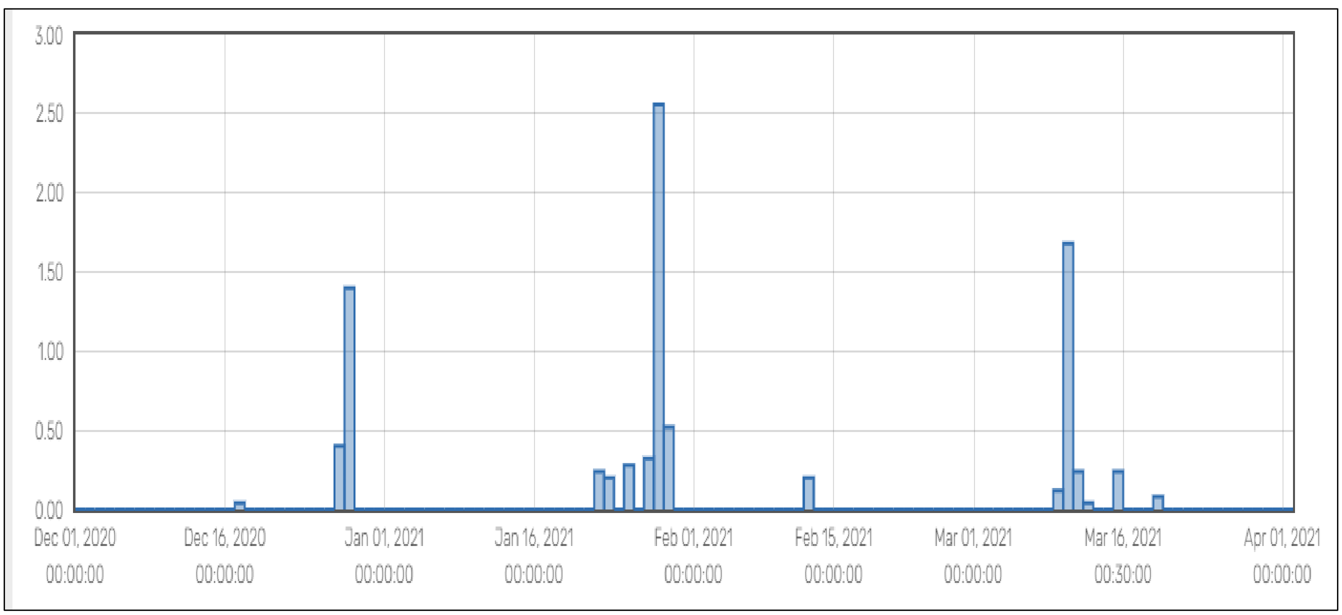

Figure 5.8 Bald Mountain Daily Rainfall (8 am to 8 am) - December 1, 2020 to April 1, 2021

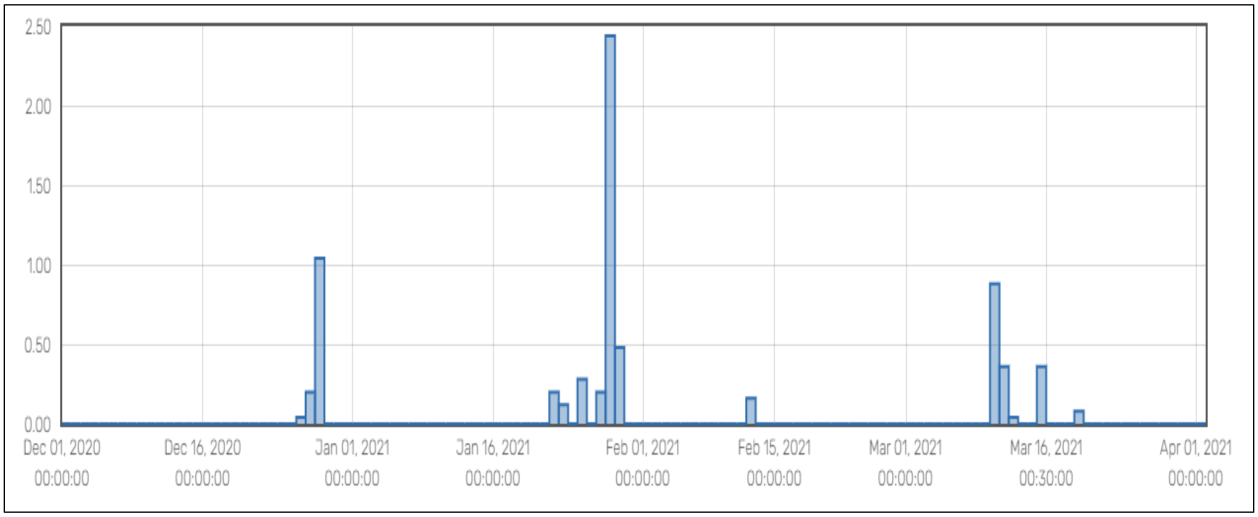

Figure 5.9 Shell Peak Daily Rainfall (8 am to 8am) – December 1, 2020 to April 1, 2021

5.2 Hydrologic Conditions During the 2020-2021 Winter Season

In Figure 5.10, it can be seen that during most of the winter season, little to no run occur from the Hausna River near Arroyo Grande. The only period where some runoff was actually measured was around January 30, which makes sense, as this is when the most significant and continuous period of precipitation occurred over the target area. More information regarding this active period can be found in Section 5.4.

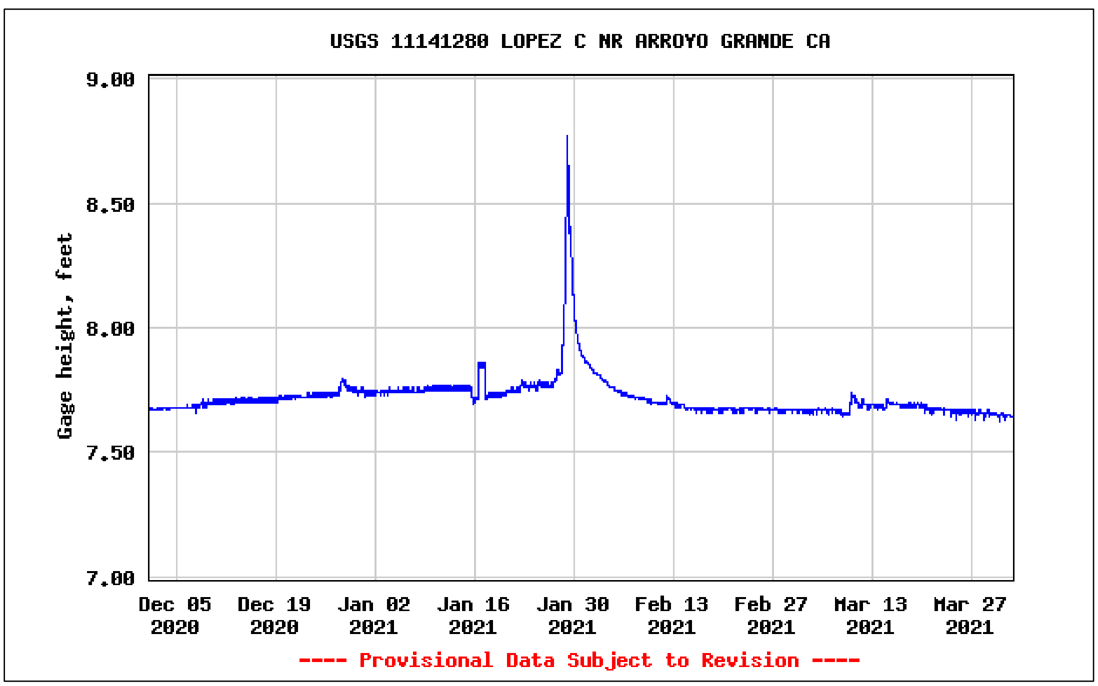

Figure 5.10 Streamflow at the Huasna River from December 1, 2020 to April 1, 2021

5.3 Summary of Seeding Operations

The contract period ran from December 1, 2020 – March 31, 2021 for the Huasna-Alamo target area. Seeding was conducted on eight separate days during the 2020-2021 season. Table 5-3 summarizes the ground-based seeding operations for the season. A total of 89 flares were successfully burned at the three ground sites, releasing an estimated 1,424 grams of silver iodide. Individual operational periods are discussed in more depth in Section 5.4.

Table 5-3
2020-2021 Ground-Based Seeding by Location and Firing Time

Date	Mt. Lospe	Berros Peak	Harris Grade	Storm Total
December 27, 2020	2000, 2015, 2025, 2035(2)	--	2040, 2050, 2110, 2125, 0025	16
December 28, 2020	0630(2)	0645, 0655, 0745, 0800, 0905	0710, 0800, 0845, 0900	11
January 22, 2021	--	1145, 1200		2
January 24, 2021	--	1850 (2), 1900, 1020 (3), 1045(2), 1105 (2), 1115 (3) **(12 total)**	1020(2)	14
January 28, 20211	--	0515, 0530(2), 1330, 1345	0450 (2), 0500(2), 1115 (2), 1130 (2), 1150 (2), 1210 (2), 1350 (2)	33
January 29, 2021	--		1110(2)	2
March 9, 2021	2137(2), 2150(2),	2212, 2220, 2222	--	7
March 10, 2021	0037(2), 0050, 0905(2)	0100, 0115, 0920, 1505	--	9
Total Flares	**16**	**28**	**45**	**89**

5.4 Storm Events of the 2020-2021 Winter Season

This section describes the storm events that affected the Huasna-Alamo project area during the 2020-2021 operational period. A general discussion of the meteorology accompanying each event is given, followed by a description of the seeding operations (if any). Wind directions, when provided, are always reported in the direction from which the wind is blowing (e.g., a southerly wind means the wind is blowing from the south toward the north). Wind speeds are usually reported in nautical miles per hour (knots), with 1 knot equal to 1.15 miles per hour. Figures shown in the storm summaries may include the following:

1) Satellite images; infrared (IR), water vapor (WV), or visible. Infrared images provide information during both the day and night which primarily consists of the cloud top temperatures. Water vapor can be useful when determining where upper level dry or moist air exists, and visible satellite images can be helpful for observing cloud structure.

2) National Weather Service NEXRAD radar images, showing reflectivity values associated with precipitation near the times when seeding occurred. 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 radar through the Doppler feature, which is part of the NEXRAD design. Plots of winds with height in 1000-foot increments are available with a 6-minute time resolution from NEXRAD radars. These displays are called Velocity Azimuth Displays (VAD).

3) 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, providing temperature and moisture profiles and convection 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° C or colder during seeded periods since silver iodide becomes effective as a seeding agent between -4°C and -5°C. The closer the height of the -5°C level is to the ground seeding sites, the quicker a seeding effect will begin to be produced in the convection elements embedded in the convective bands. These convective elements transport the seeding material vertically from the ground seeding sites to colder temperatures aloft.

December 27-28, 2020

A large-scale, cold core area of low pressure moved towards the Central Coast by midday on the 27th. The low moved inland, and a robust convective band impacted the county between 2000 and 2200 PDT (Figure 5.11). Temperatures were in a favorable range prior to the band moving into the target area, with observations showing 700 mb temperatures around -4°C at 1600 PDT. Additional cooling occurred as the band moved into the region, as it was associated with a surface cold front. Winds were southwesterly as the low was still to the west of the region during the evening of the 27th and into the morning of the 28th. Seeding occurred with this band during the late evening hours. The first band was the most robust of all four bands that would be seeded, with lightning noted on radar offshore and over Lompoc at times during its passage. Three additional bands moved through the area on the 28th, with the last band moving through the area around 0900 PDT. This last band (Figure 5.12) was associated with the trough axis moving through the area, and subsequently, winds shifted to the west/northwest. The two middle bands early on the 28th were weaker than the first band on the 27th and the last one (on the 28th), but still provided seeding opportunities. Temperatures by 0400 PDT on the 28th at 700 mb had cooled to -10°C, with a large amount of the cloud depth being below freezing and radar vertically integrated liquid data (VIL) showed a large amount of supercooled liquid water (SLW) was available for seeding operations. A total of 22 flares were dispersed throughout this 24 hour period over two days, from all three ground sites.

Operational note: The radar website, WeatherTap, was down for the entire duration of seeding activities. Other websites were available for use during operations that provided radar data including Velocity Azimuth Display (VAD), which displays how winds change over time and can help during operations as they change. The radar images shown in these figures depict convective cell motion as inferred from the radar data. Images for this seeding day will be included below but will be different due to the outage of WeatherTap website.

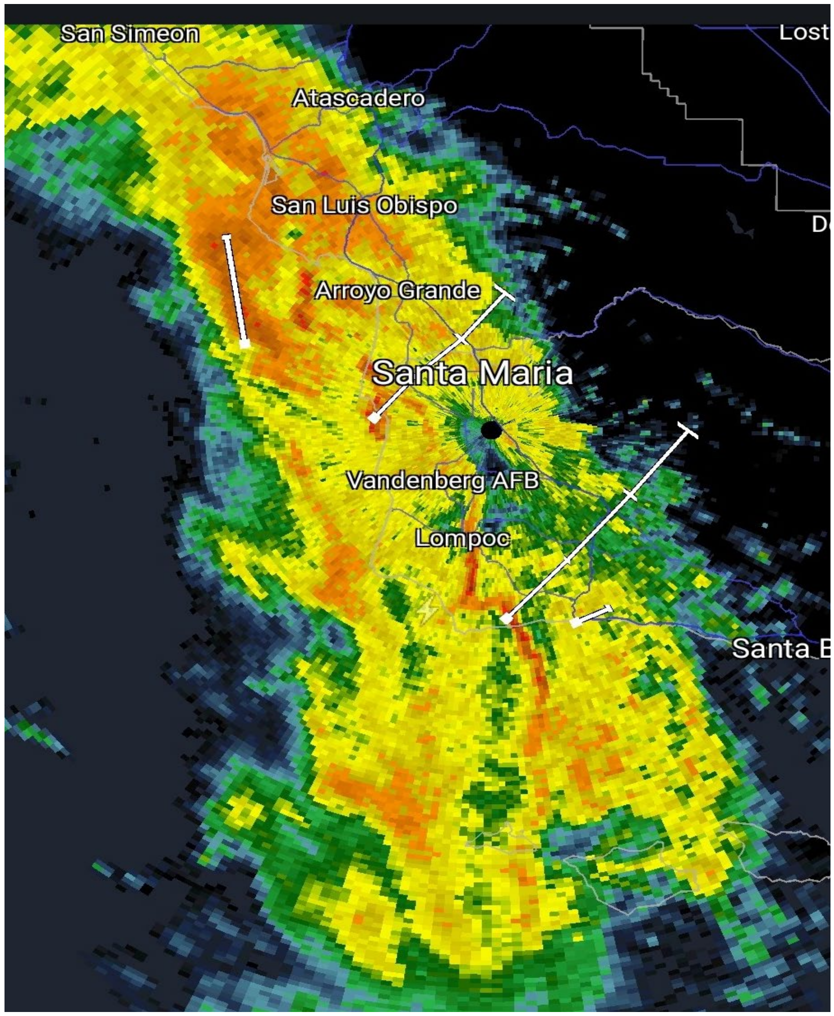

Figure 5.11 Base Reflectivity on December 27, 2020 at 2053 PST

Figure 5.12 Base Radar Reflectivity on December 28, 2020 at 0735 PST

__January 22, 2021__

A potent closed low was poised off the northern California coast during the morning hours of the 22nd. Temperatures were around -2°C at 700 mb and cooled throughout the day as the low moved inland over Central California. A band approached the county (Figure 5.13) around 1100 PST with relatively warm temperatures, but atmospheric conditions were deemed to be conducive for seeding. South/southwesterly flow was present as the band passed through the area (Figure 5.14). The band did move through quickly, so only a limited amount of seeding was conducted. The band produced precipitation amounts between 0.20-0.30 inches in and around the operational area. A total of 14 flares were dispensed from two ground sites.

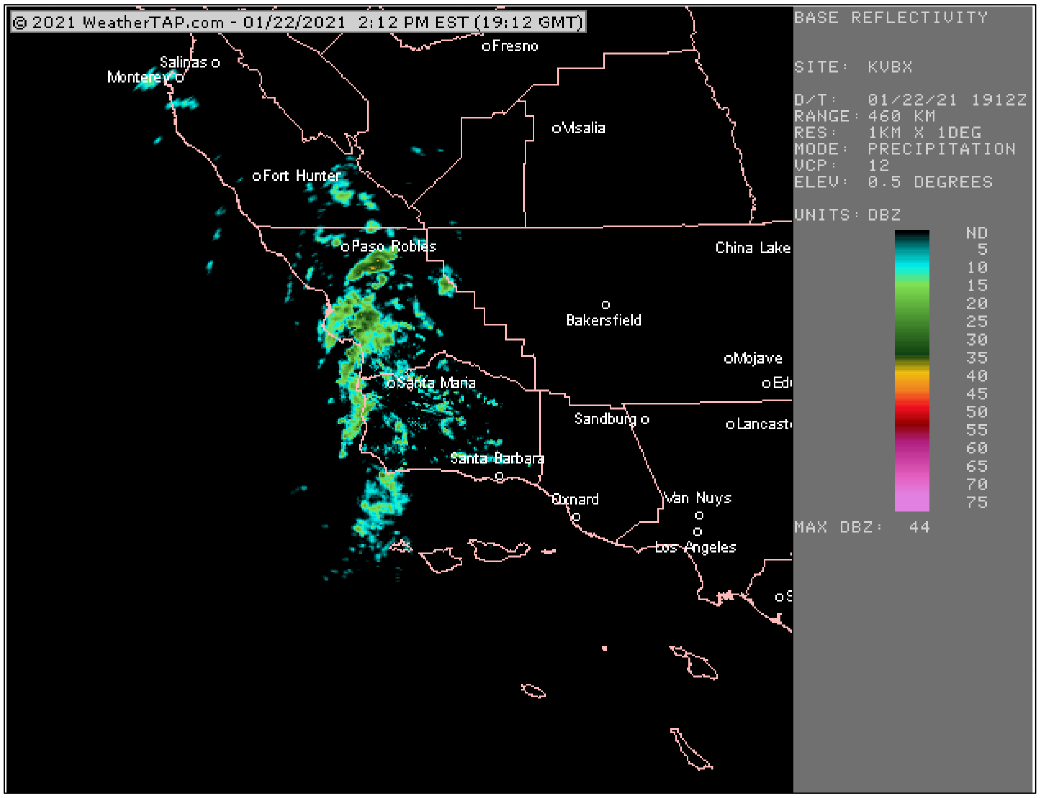

Figure 5.13 Base Reflectivity on January 22, 2021 at 1112 PST

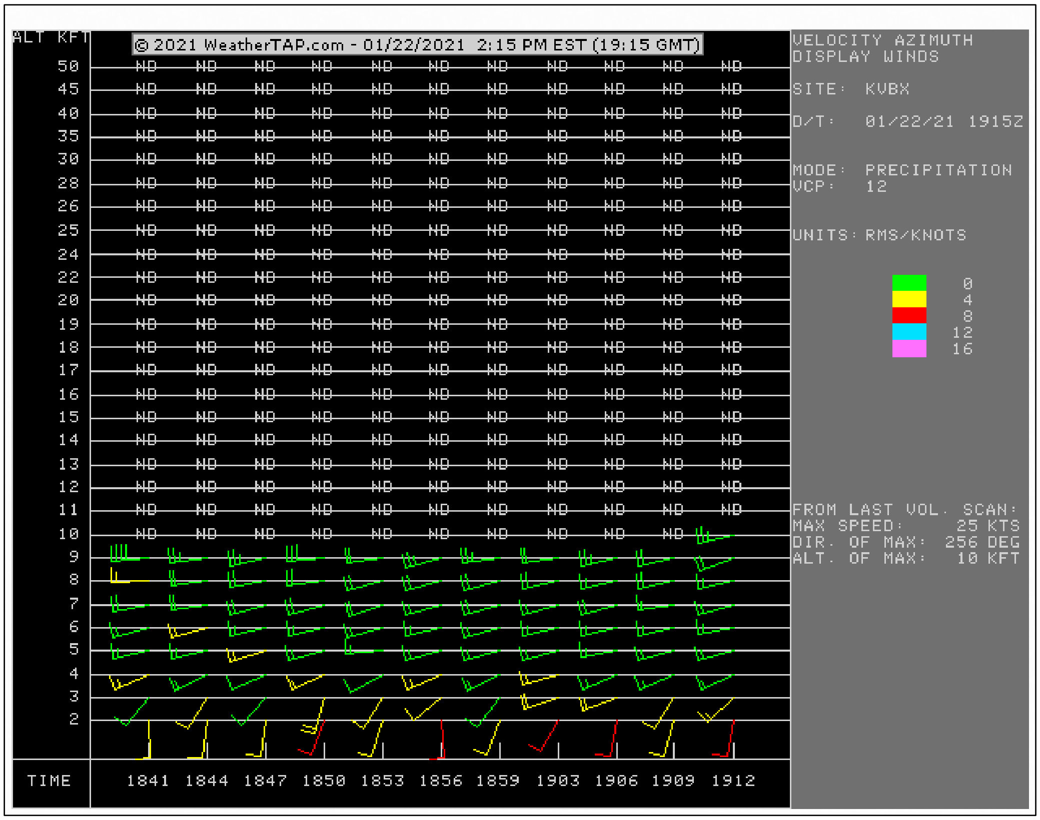

Figure 5.14 Velocity Azimuth Wind Display on January 22, 2021 at 1115 PST

<u>January 24, 2021</u>

Three convective bands affected the area on this day as low pressure was located over northern California. This system allowed for sufficient moisture and dynamics to progress southward into southern California, which gave rise to these convective bands. The first band was weak and was not seeded, but the secondary and third bands were seeded, as they exhibited excellent radar presentation and reasonable precipitation amounts as they moved from west to east across the county. The second band affected the area between 1800 and 1900 PST (Figure 5.15) and provided a seeding opportunity, as temperatures at 700 mb were around -8°C and winds were northwesterly (Figure 5.16). The Berros Peak site was used to target this band. Another band moved through the area between 2030 and 2130 PST (Figure 5.17) with southwesterly flow, becoming westerly (Figure 5.18) as it passed through the county. A total of 14 flares were fired from one ground site during this seeding period. Precipitation amounts between 0.25-0.50 inches were observed during this storm period.

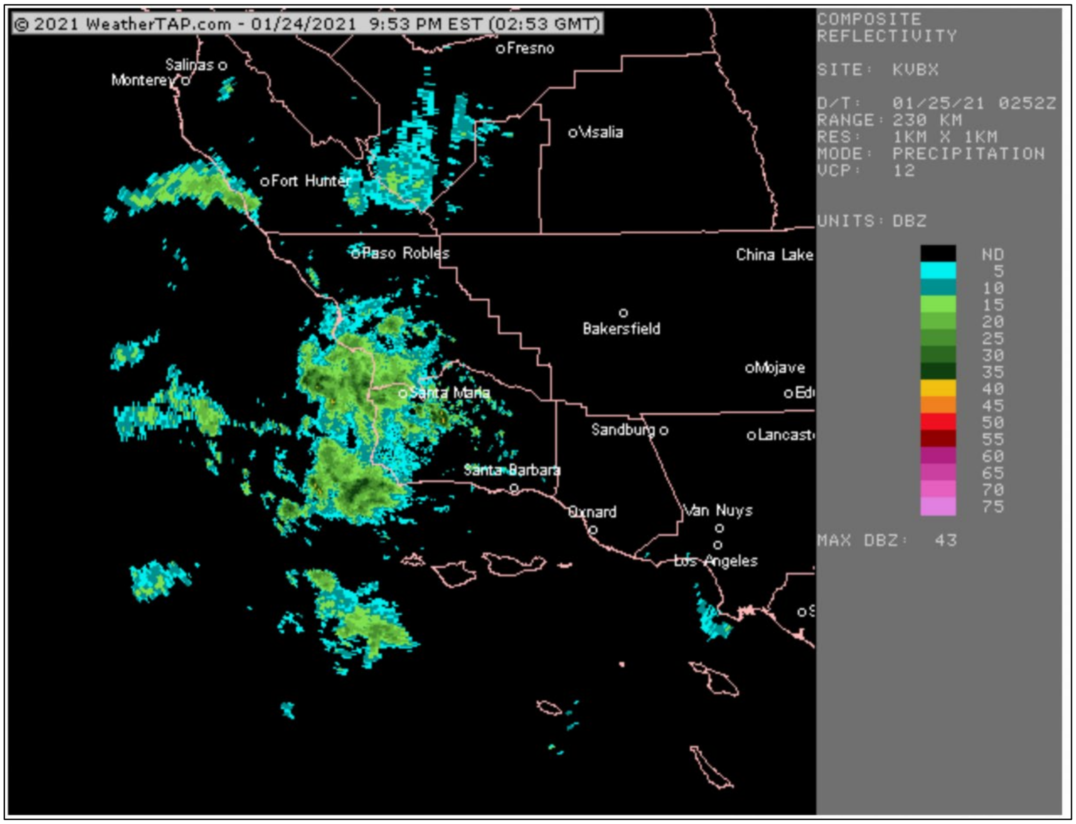

Figure 5.15 Composite Reflectivity on January 24, 2021 at 1852 PST

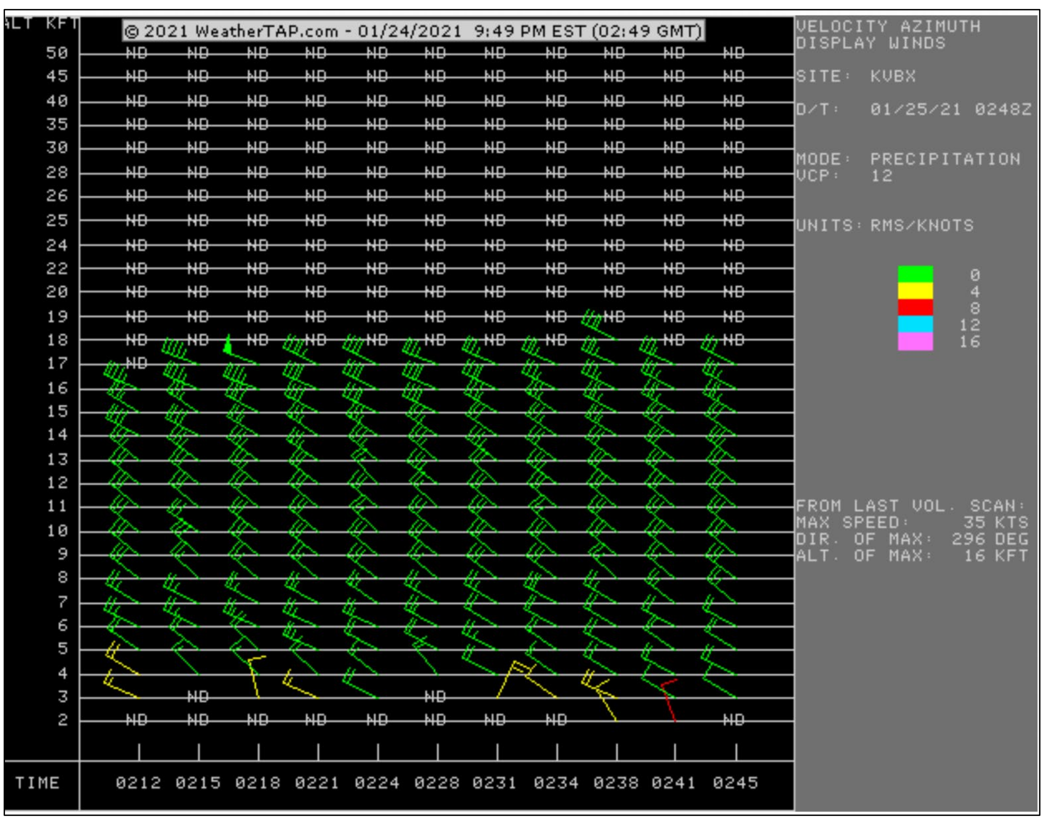

Figure 5.16 Velocity Azimuth Wind Display on January 24, 2021 at 1852 PST

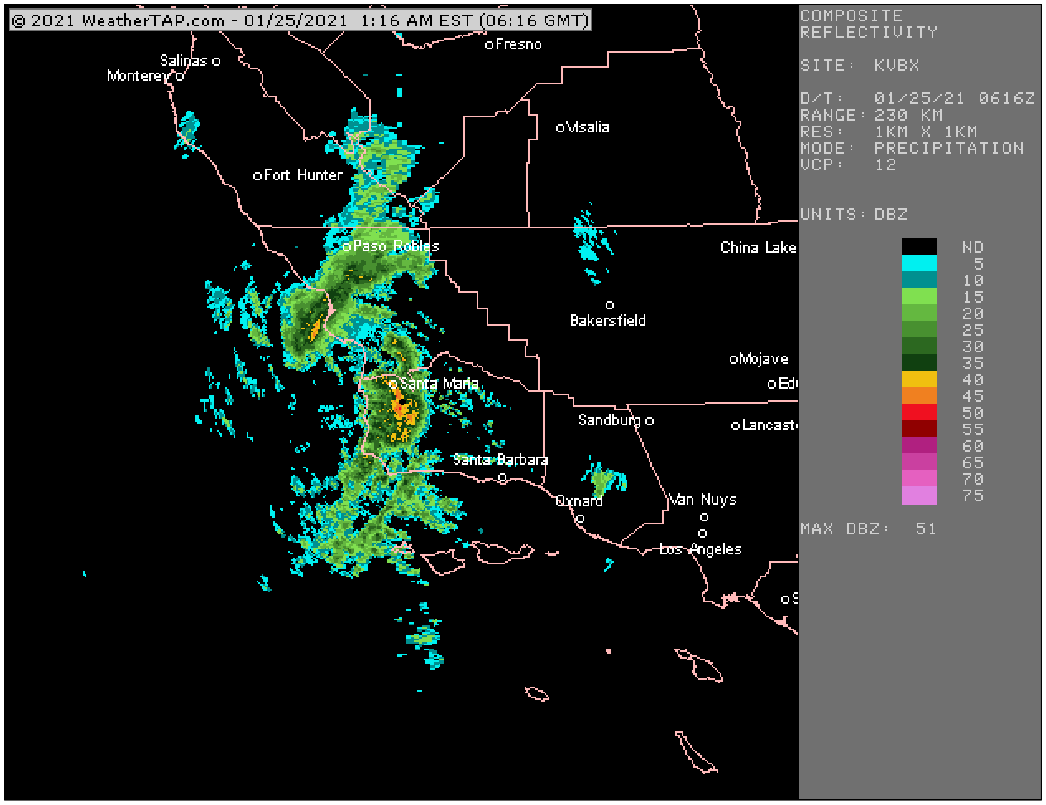

Figure 5.17 Composite Reflectivity on January 24, 2021 at 2216 PST

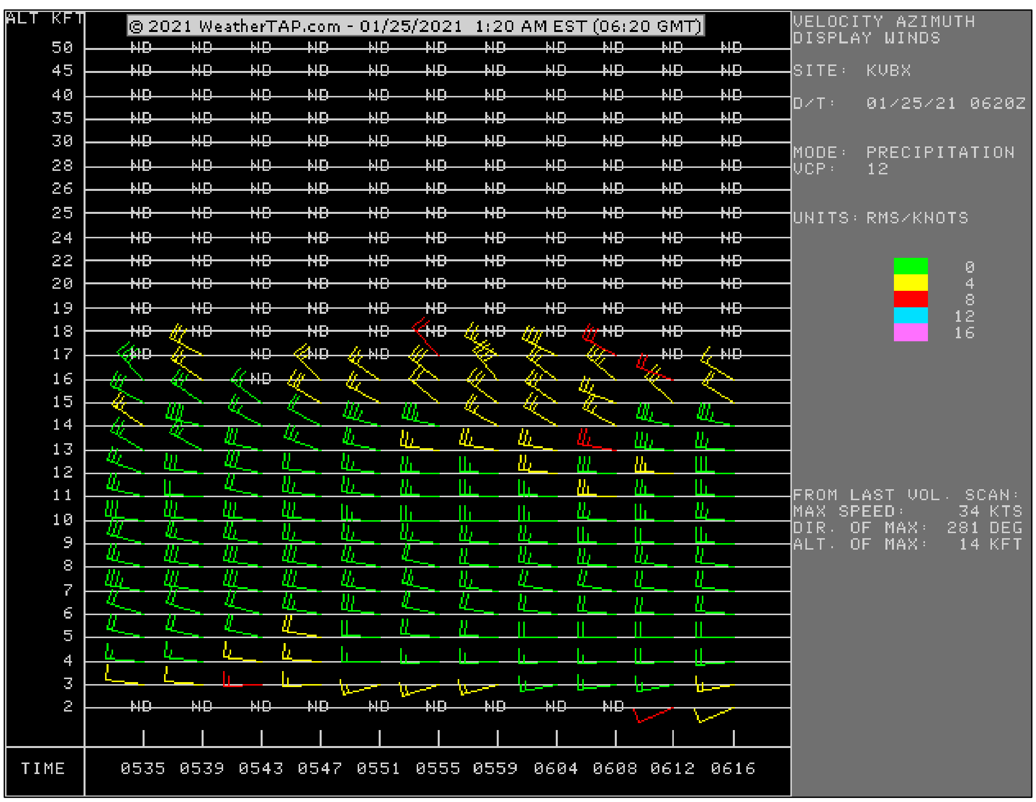

Figure 5.18 Velocity Azimuth Wind Display on January 24, 2021 at 2216 PST

January 28, 2021

A large-scale area of low pressure hovered off the coast of California for a few days beginning on January 27th. This slow moving low and trough provided a multiday rain event for the area. The early portion of the storm was not seeded due to the height of the cloud tops, relative to the freezing and -5°C level, which indicated that not much supercooled liquid water was present. However, during the latter part of the storm, when the trough moved inland and allowed a surface cold front to slowly move across the area, colder air moved into the lower and mid-levels which brought a more favorable environment for seeding operations. The first band that impacted the county occurred between 0400 and 0500 PST, and only a few flares were fired as this leading band was very thin (Figure 5.19) with the initial landfall of the rain shield. Another reason why this band wasn't optimal for seeding was due to very strong winds (Figure 5.20) which would likely carry the material too far downwind before nucleating.

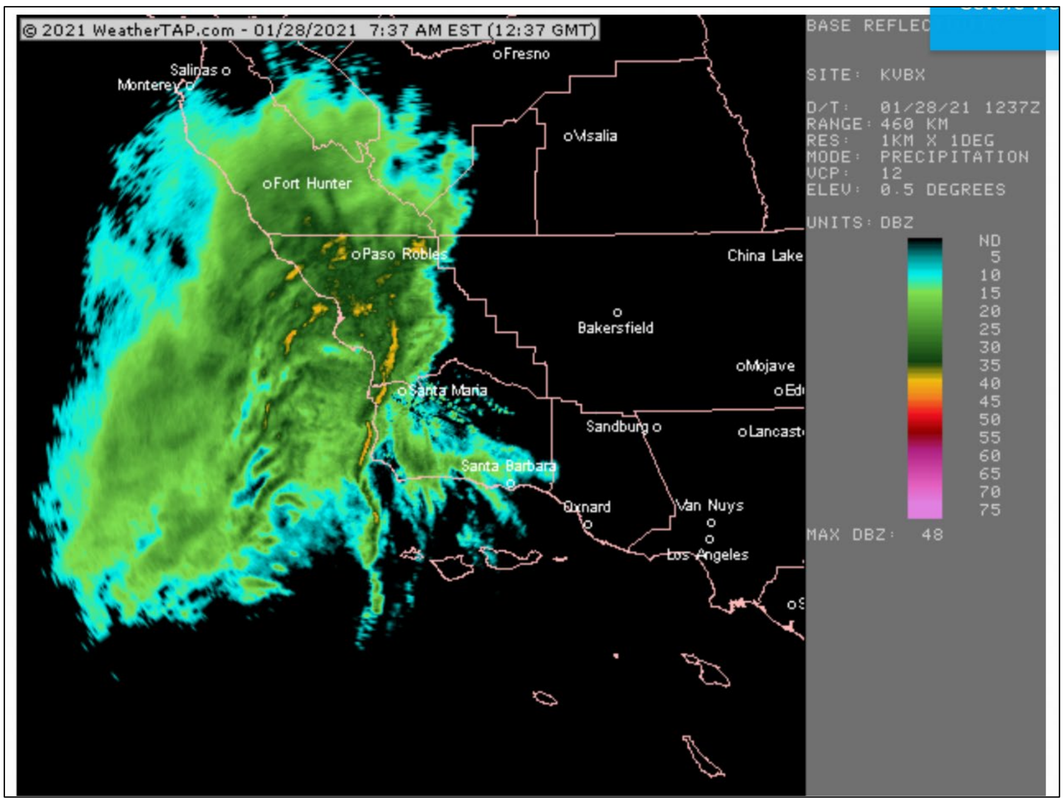

Figure 5.19 Base Reflectivity on January 28, 2021 at 0437 PST

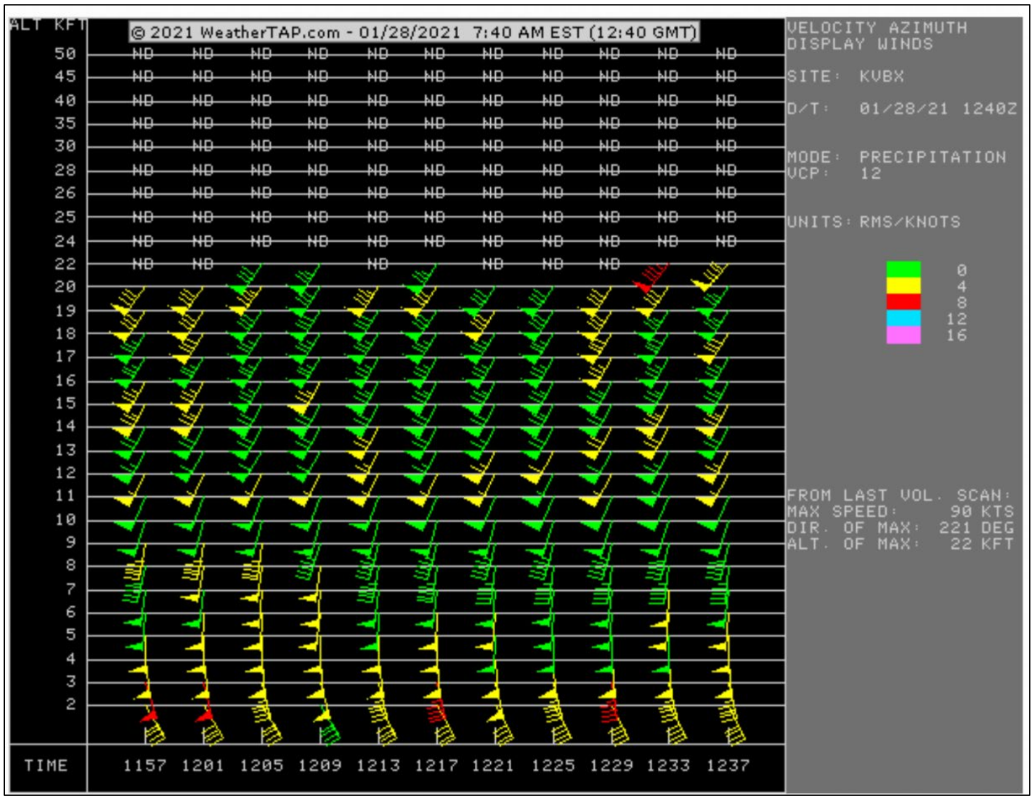

Figure 5.20 **Velocity Azimuth Wind Display on January 28, 2021 at 0440 PST**

A more ideal convective band impacted the county later in the day on the 28th, between 1100 and 1400 PST, as the band was more convective, along with a more desirable flow regime being in place. Temperatures were slightly colder than the event seeded earlier in the day, with 700 mb temperatures around -10°C. The band had excellent radar presentation, with a very defined, robust convective band (Figure 5.21) moving across Santa Barbara County. As mentioned above, wind regimes were favorable for transport of the seeding material (Figure 5.22), with light to moderate southwesterly flow from the surface up to 5,000 feet, where the winds became stronger and had a more southerly component. A total of 33 flares were dispensed from two ground sites during both band passages. 24 hour rainfall totals ranged between 1.50 and 2.0 inches.

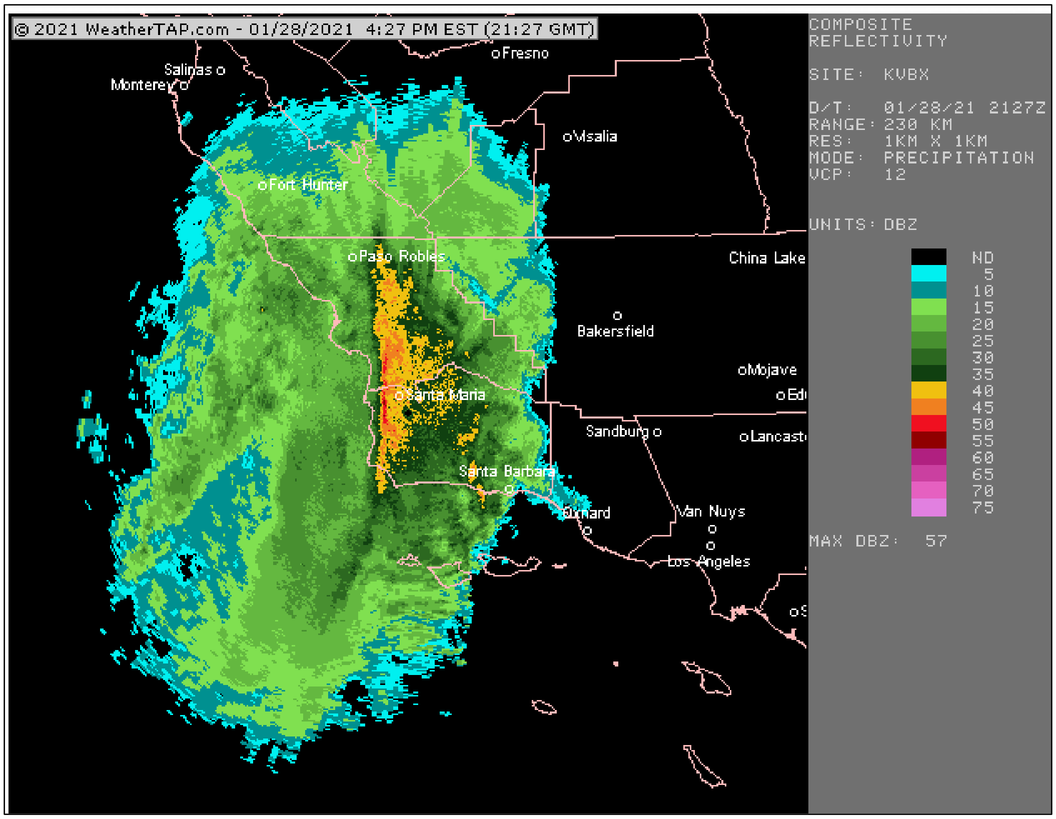

Figure 5.21 Composite Reflectivity on January 28, 2021 at 1330 PST

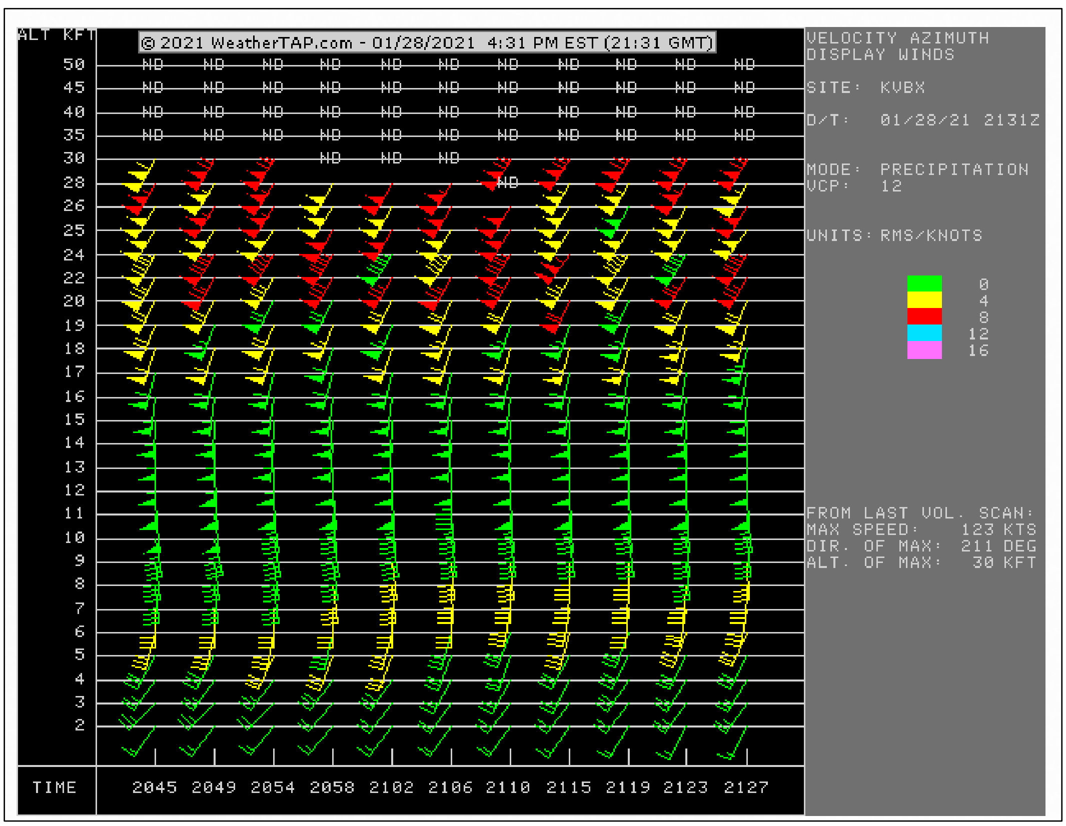

Figure 5.22 Velocity Azimuth Wind Display on January 28, 2021 at 1331 PST

January 29, 2021

The same low/trough that brought the wet period to the county on the 28th continued to impact the area overnight and into the 29^{th}, with the trough axis to the east of the area on the morning of the 29^{th}. The precipitation that fell overnight was associated with a warm rain process, as 700 mb temperatures were around -3°C and the top of the band was generally below this height (?) . However, the morning sounding on the 29^{th} showed temperatures had cooled to around -10°C at 700 mb and a disorganized convective band (Figure 5.23) moved through the county between 1100 and 1200. Only a few flares were fired on the band, as it looked rather weak as it moved into county. Winds were southerly at the surface and southwesterly above 4,000 feet (Figure 5.24). A total of two flares were fired from Harris Grade during this storm period. Observed rainfall amounts were between 0.10-0.30 inches. Three-day rainfall totals showed about 3.30 inches falling at the Twitchell Reservoir site.

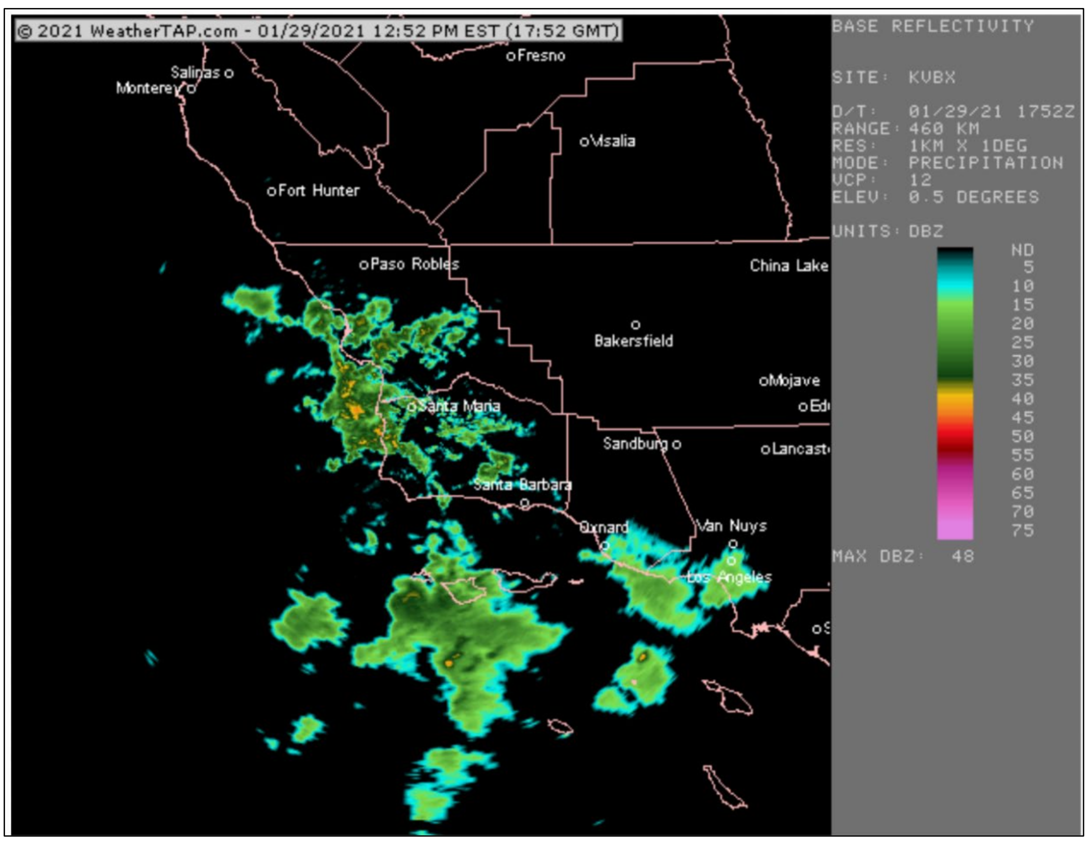

Figure 5.23 Base Reflectivity on January 29, 2021 at 1000 PST

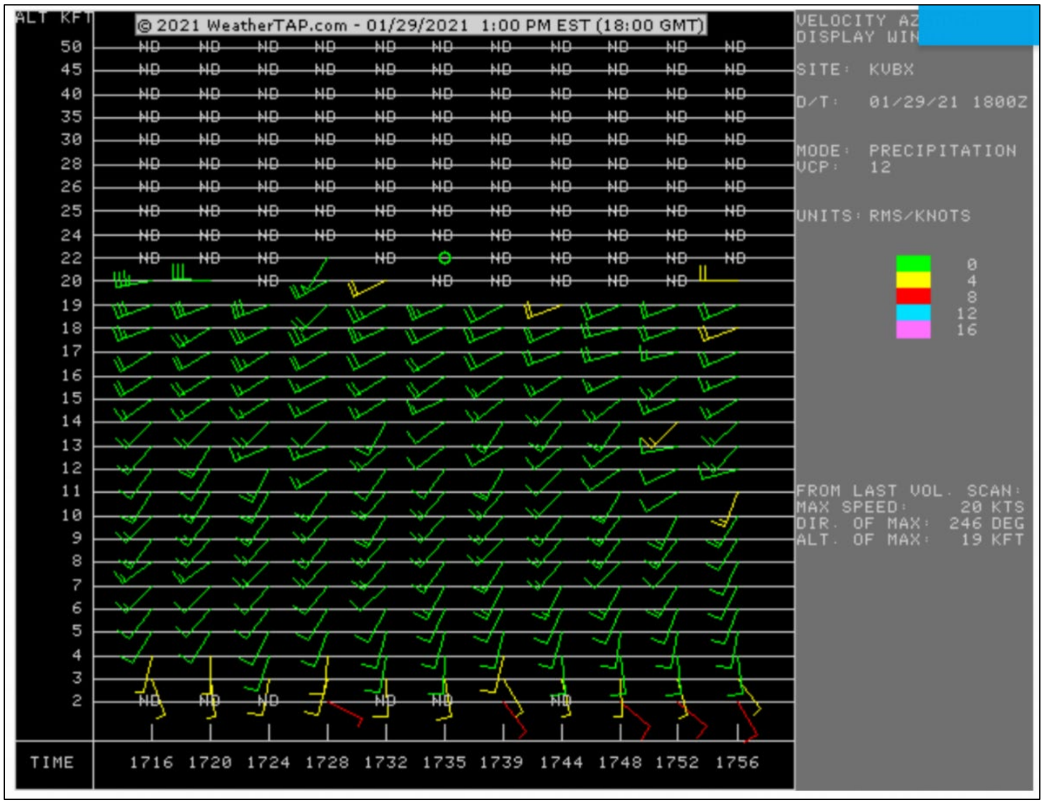

Figure 5.24 Velocity Azimuth Wind Display on January 29, 2021 at 1000 PST

<u>March 9-10, 2021</u>

A closed low was located off the northern California coast with the low center containing rather robust convection. There were three seeded bands that were associated with this low, as it slowly moved into California. The first band was seeded between 2100 and 2300 PST (Figure 5.25) on March 9. The band was impacting locations north of the area earlier in the day, with modest rainfall totals observed, but did not affect the Twitchell Watershed until around 2100 PST. Temperatures were around -9°C when seeding operations began. Winds were moderately strong and southerly near the surface becoming more southwesterly with height (Figure 5.26).

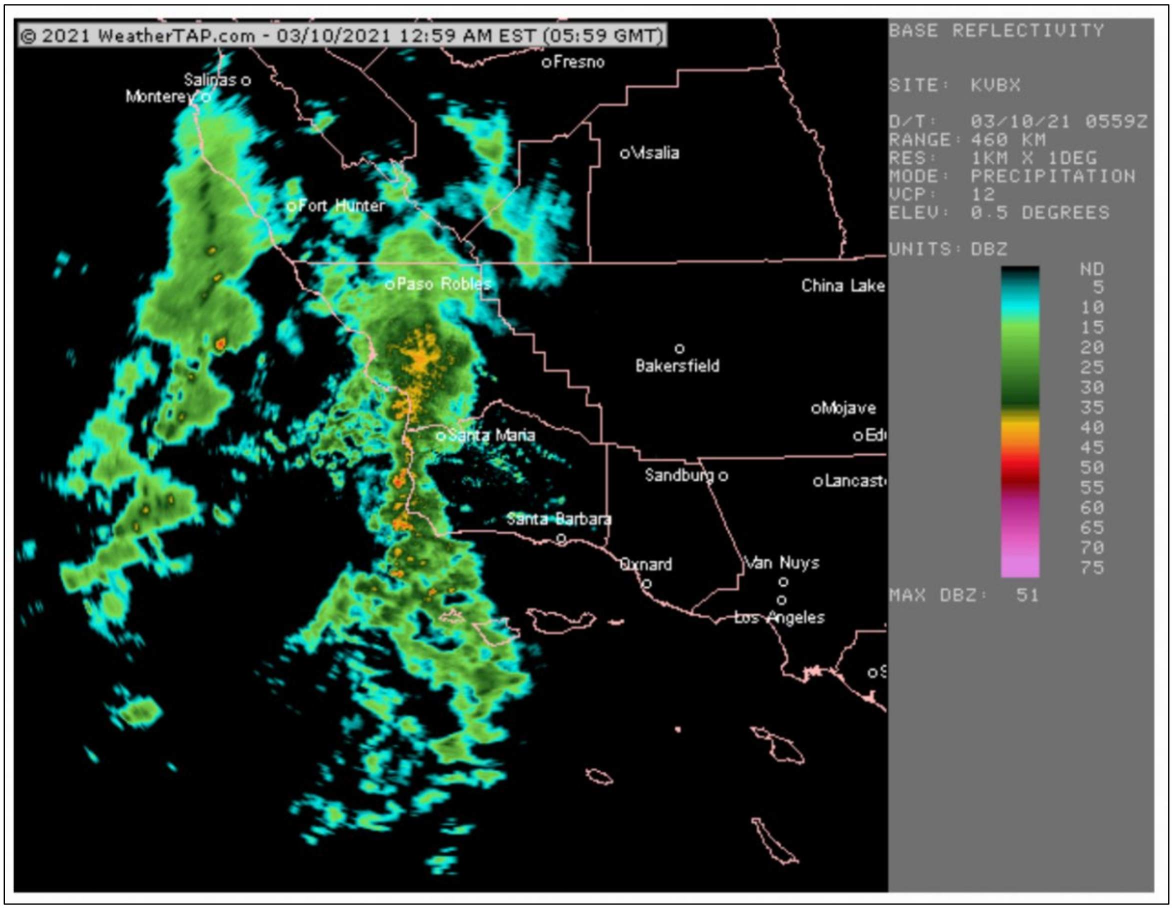

Figure 5.25 Base reflectivity on March 9, 2021 at 2159 PST

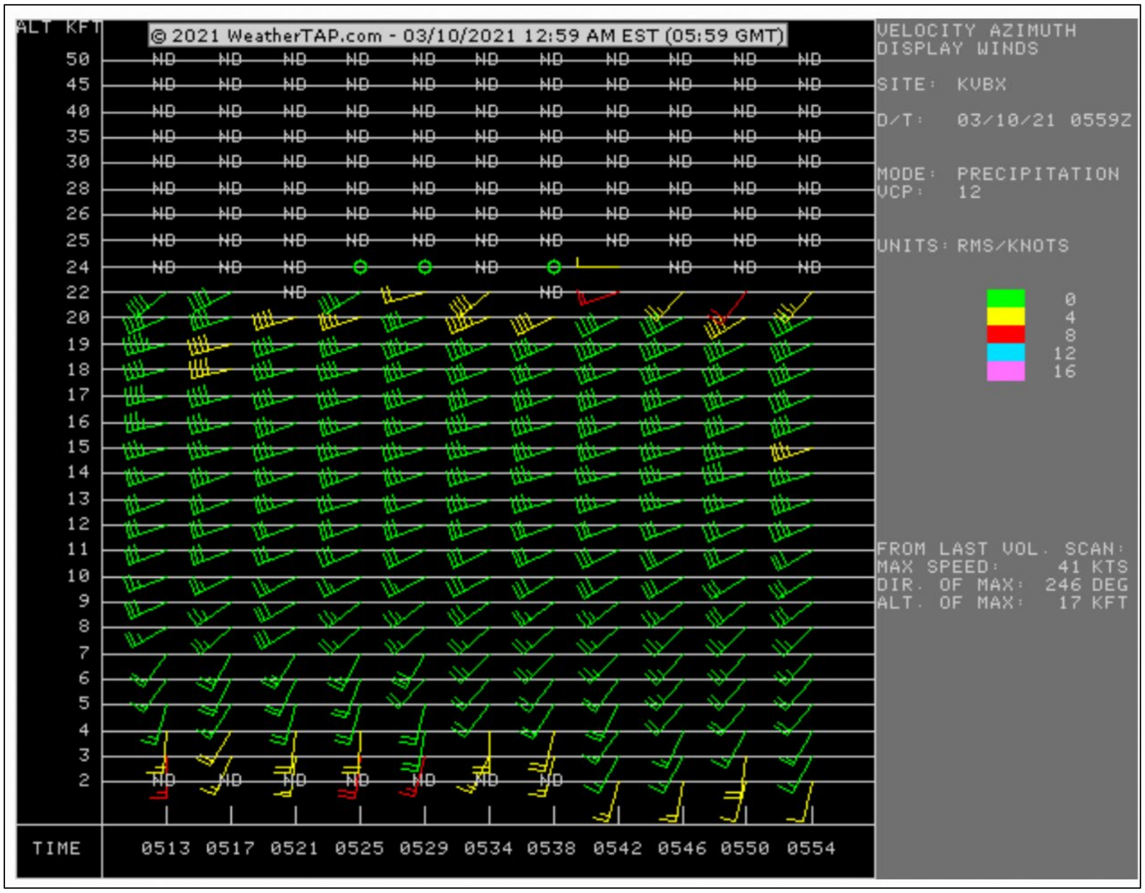

Figure 5.26 VAD wind profile on March 9, 2021 ending at 2154 PST

Shortly after midnight on the 10th, another band affected the area and seeding was conducted. It was a bit more robust than the first band and exhibited higher intensity precipitation (Figure 5.27). Winds were about the same as the previous band (Figure 5.28), with 700 mb temperatures remaining around -9°C.

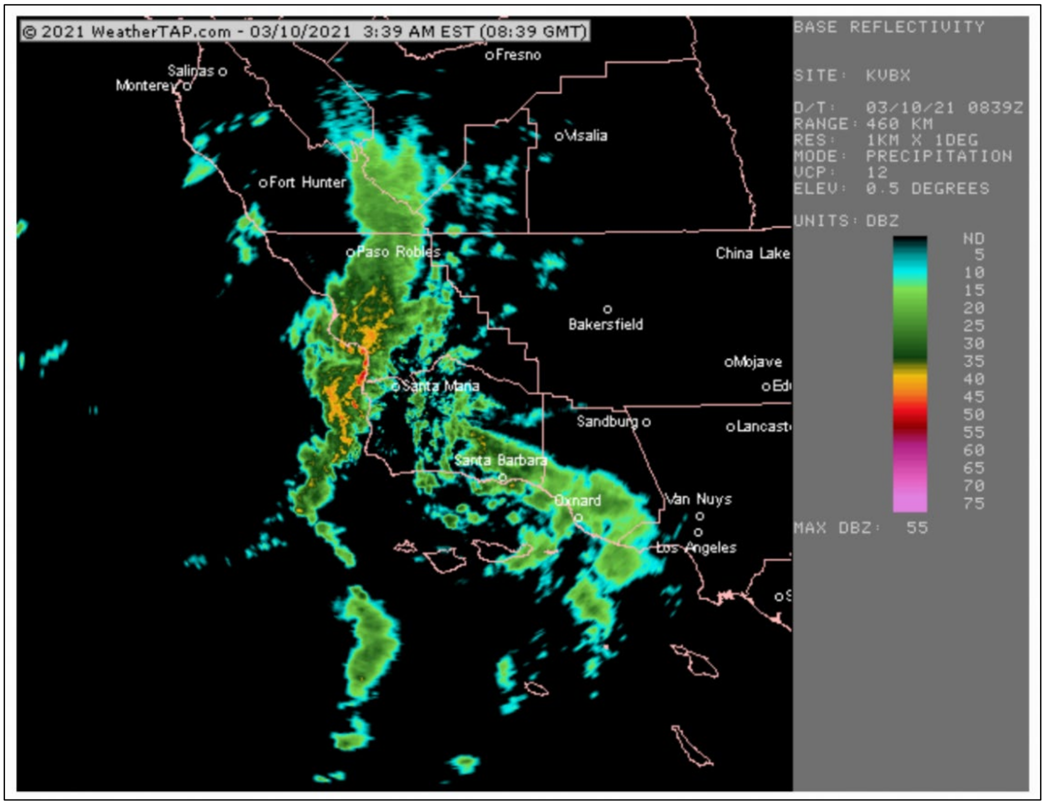

Figure 5.27 Base Reflectivity on March 10, 2021 at 0039 PST

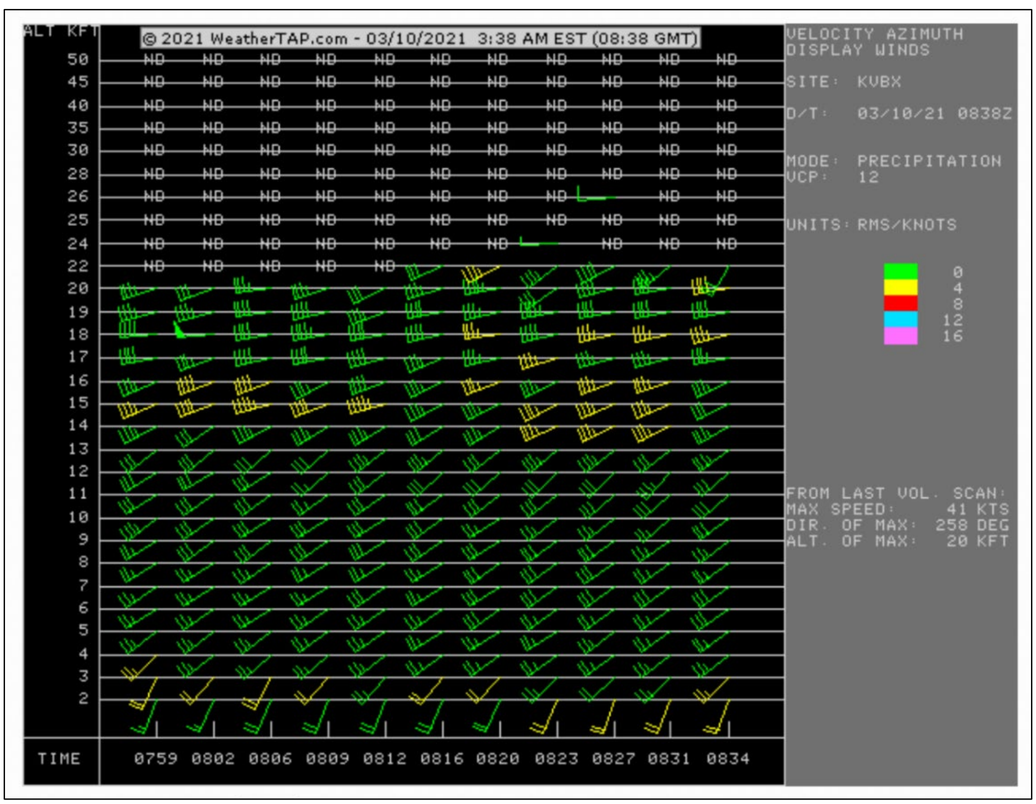

Figure 5.28 VAD wind profile on March 10, 2021 ending at 0034 PST

6.0 COMPUTER MODELING

NAWC utilized specialized computer models in the conduct of this program. These models were 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). Some model data was archived on NAWC computers while significant amounts of other data are archived and available on the internet.

In previous winter seasons, NAWC had used the standard National Oceanic and Atmospheric Administration (NOAA) atmospheric models: North American Model (NAM), High Resolution Rapid Refresh (HRRR) and Global Forecast System (GFS) in forecasting seedable events and associated parameters of interest (e.g., temperatures, winds, precipitation). NAWC continued to use the NAM and GFS models, especially for longer range forecasts. A more sophisticated model was used for shorter range forecasts, 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, convection bands and a variety of other parameters of interest in conducting the cloud seeding operations.

The HYSPLIT model, developed by NOAA, provides forecasts of the transport and diffusion of either ground or aerial releases of a material, which in our case would be silver iodide particles. NAWC first utilized predictions from the HYSPLIT model to assist in making seeding decisions during the 2012-2013 winter season. NAWC has continued its use of the HYSPLIT model since that time. The WRF and HYSPLIT models will be discussed separately in the following.

6.1 WRF Model

The Weather Research and Forecasting (WRF) Model is a 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 (NOAA), the National Centers for Environmental Prediction (NCEP), the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (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, mathematics, and data assimilation contributed by the research community.

NAWC utilized NOAA's Earth Systems Research Laboratory's HRRR version of the WRF model during the winter 2019-2020 season. This model has a 3-km grid spacing compared to the more standard grid model spacing of 12-km (NAM model), plus it is re-initialized every hour using the latest radar observations. The NAM and GFS models are currently re-initialized every six hours. Hourly forecast outputs from the HRRR model are available for a variety of parameters out to 18 hours. Table 6-1 provides a summary of some forecast parameters of interest in conducting the cloud seeding program.

Table 6-1
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.
Maximum 1 km above ground level reflectivity	Forecast 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 (5,000 feet) wind direction are useful in determining if and when wind directions may go out of bounds in regards to suspension criteria.
700-mb temperature	NAWC uses this level, which is near 10,000 feet MSL, to indicate whether silver iodide will activate. Temperatures colder than -5°C are desirable at this level.

Parameter	Application
700-mb 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°C) or if perhaps too cold (-25°C) to produce positive seeding effects.

Figure 6.1 is a ten-hour forecast from the HRRR model of composite radar reflectivity over the southwestern U.S., valid at 1600 PDT, March 25, 2012. This model predicted a west-east oriented convective band over Santa Barbara County associated with an upper closed low located off the coast of Santa Barbara County. This HRRR forecast agrees well with the radar image in Figure 6.2, which is the Vandenberg AFB composite radar reflectivity display valid at 1530 PDT March 25. Figure 6.3 provides a ten-hour forecast of the one-hour accumulated precipitation over California valid from 1500-1600 PDT March 25, 2012. This forecast also seemed to verify. For example, the HRRR forecast indicated approximately 0.10 inches of precipitation in the Sudden Peak vicinity. Figure 6.4 provides hourly precipitation values from Sudden Peak, which indicates 0.20 inches of precipitation fell from 1400-1500 PDT, about an hour earlier than forecast. Examination of the rainfall at Santa Maria indicated that the band apparently rotated northward with 0.11 inches from 1500-1600 PDT being observed there, about an hour earlier than predicted (Figure 6.5). The precipitation that was forecast to occur over Santa Barbara County during this period was associated with a convective band that did develop and that was seeded from between 1400 and1500 PDT.

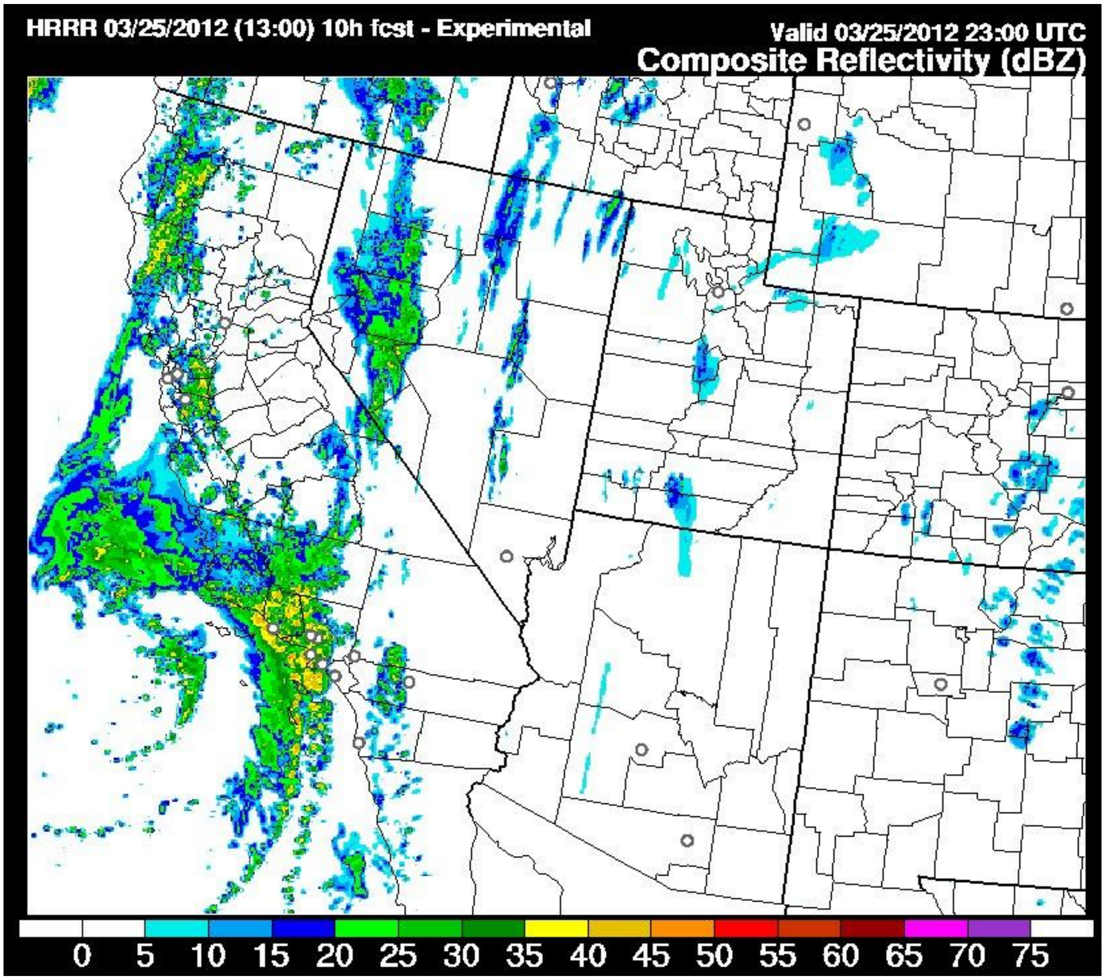

Figure 6.1 HRRR Model Ten-Hour forecast of Composite Radar Reflectivity - valid at 1600 PDT on March 25, 2012

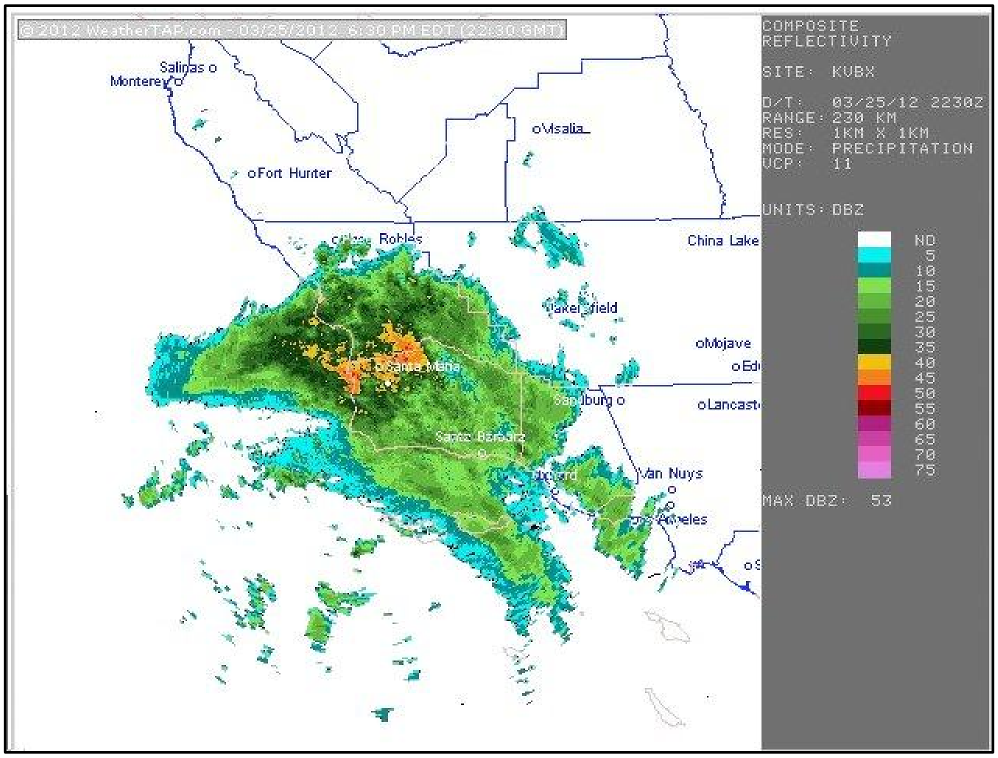

Figure 6.2 Vandenberg AFB Composite Radar Reflectivity valid at 1530 PDT, March 25, 2012

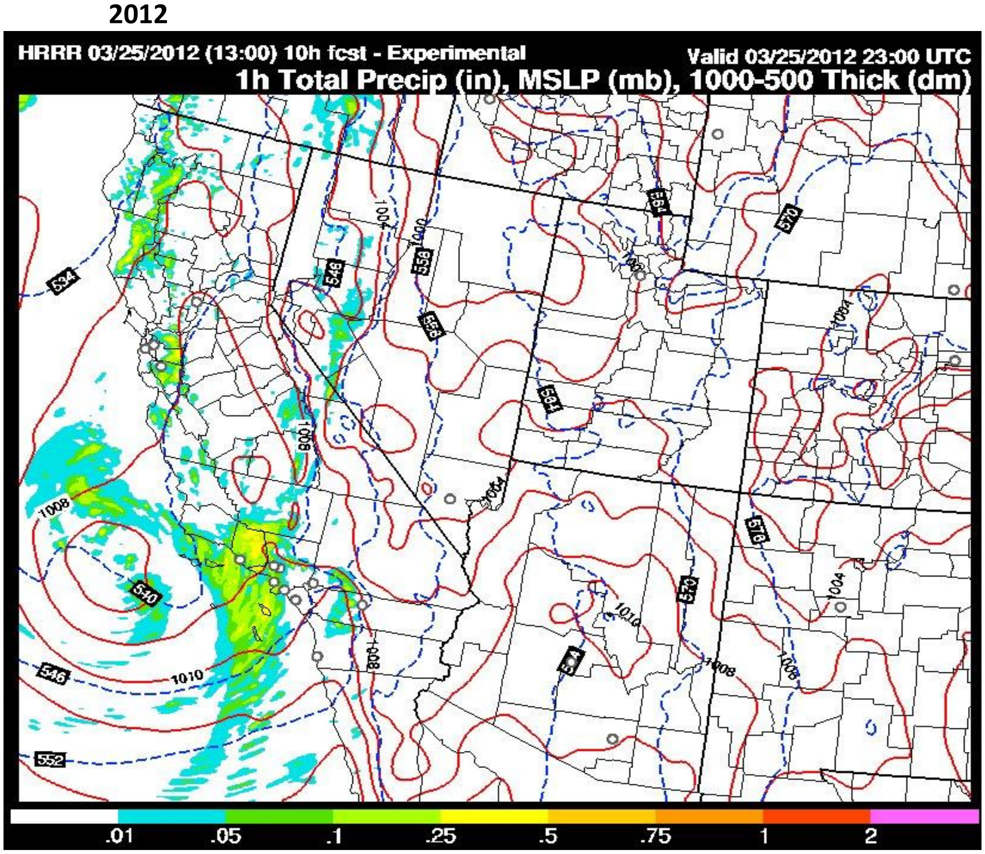

Figure 6.3 HRRR Model Ten-Hour Forecast of One-Hour Precipitation from 1500-1600 PDT March 25, 2012

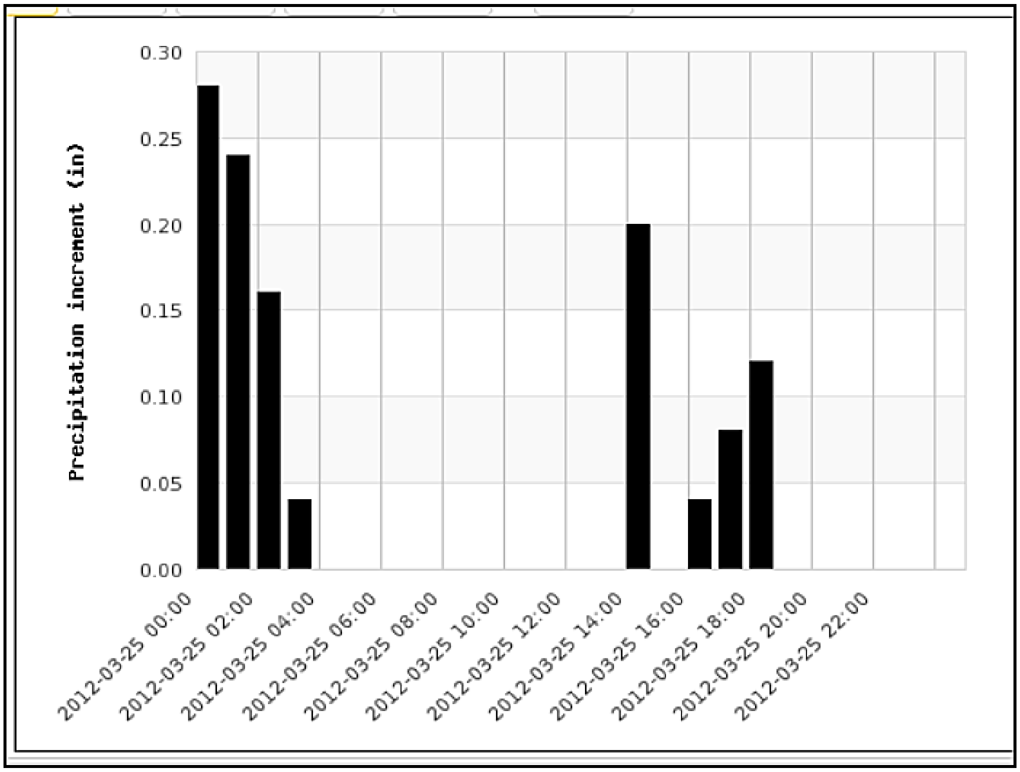

Figure 6.4 Observed Hourly Precipitation at Sudden Peak, March 25, 2012

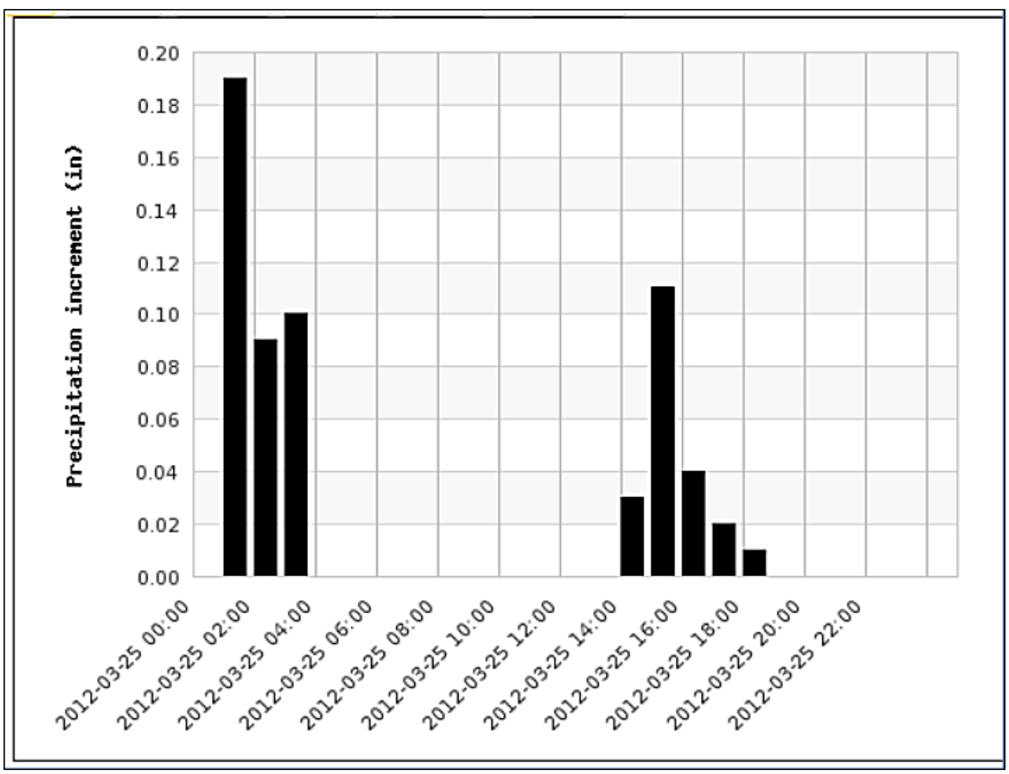

Figure 6.5 Observed hourly precipitation at Santa Maria, March 25, 2012

Based on the design of the program (Section 3.0), which is focused on seeding convective bands, and the seeding techniques as described in Section 4.6, it can be seen that forecasts of convective band locations are useful for the ground-based seeding sites. Final seeding decisions for ground-based sites can be made using real-time radar information indicating when a convective band is approaching a seeding site. These convective band forecasts become more useful in airborne operations to provide lead time in filing flight plans and subsequent seeding aircraft take-off times to coincide with convective band passages. The precipitation type forecasts (Figure 6.3) are also useful when considering suspension criteria.

6.2 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.

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 turbulence component.

NAWC has utilized the HYSPLIT model to predict the transport and diffusion of silver iodide seeding material in real-time during potentially seedable storm situations in Santa Barbara County. The model can also be run after the fact using archived NAM model data, which is available back to 2007. Figure 6.6 provides HYSPLIT model output for one ground seeded event during the 2020-2121 season.

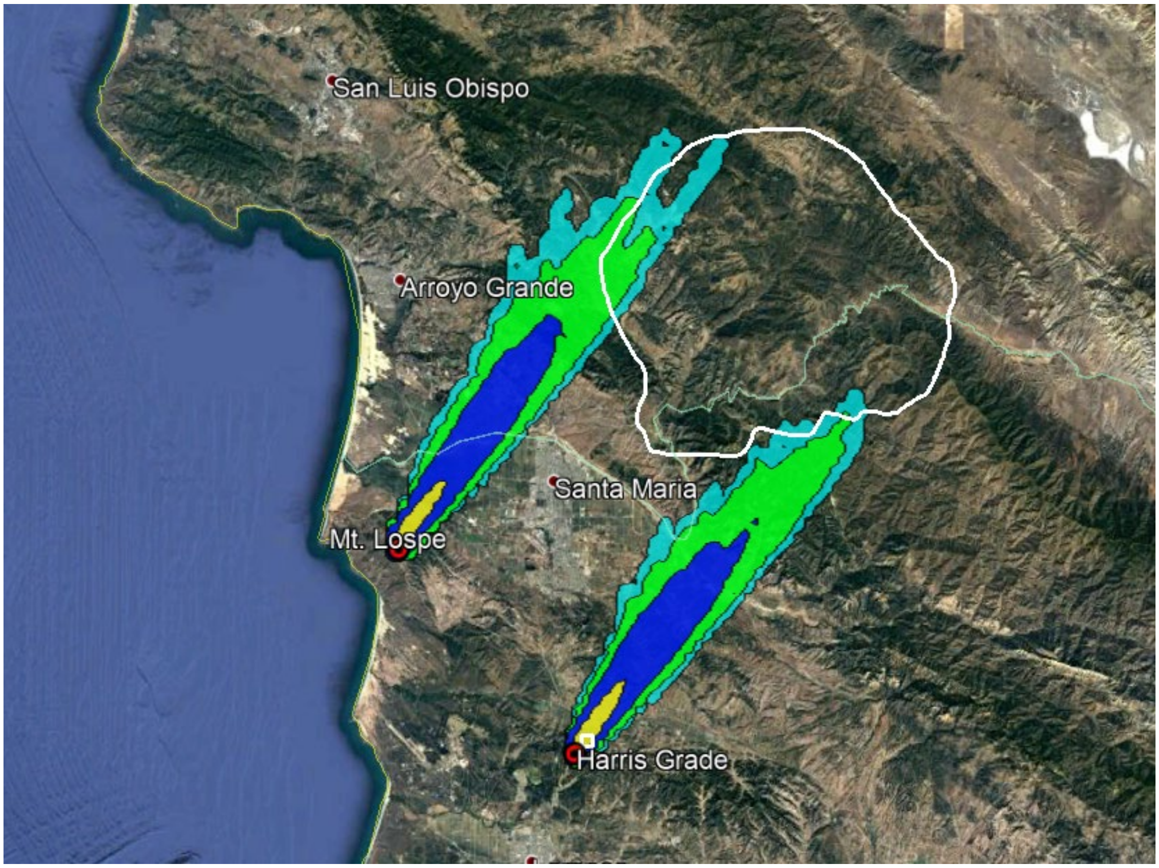

Figure 6.6 HYSPLIT Model output for seeding operations on December 28, 2020

The colors in Figure 6.6 represent the concentration of the seeding material in the plume, with the highest concentrations shown in yellow followed by dark blue, green and aqua representing lesser concentrations near the edges of the plume.

The depiction provided in Figure 6.6 is of the transport of the seeding plumes during a seeding day this season. The seeding material needs to interact with the convective bands forming ice crystals, which grow into snowflakes and melt into rain drops as they pass through the freezing level. These processes occur as the band moves downwind in time. The HYSPLIT plume depictions are of the initial transport and diffusion phase of the plumes and are not modeling or depicting the nucleating process, or precipitation due to seeding. Seeding for the storm period featured in Figure 6.6 took place from the Mt. Lospe and Harris Grade sites. The HYSPLIT model plume forecasts were used in making seeding decisions when the winds were questionable or otherwise uncertain to the meteorologist.

Another useful tool in avoiding seeding impacts in areas identified in the suspension criteria is the vertical wind displays from the Vandenberg AFB NEXRAD radar.

Figure 6.7 provides an example from an event during the 2020-2021 season. The vertical distribution of winds at 1,000 foot intervals are displayed over approximately a one-hour period in six-minute time steps. NAWC has frequently used the winds at the 850-mb level (approximately 5,000 feet MSL) as an indicator of the mean direction that a seeding plume would initially be transported. For example, in Figure 6.7 winds were mostly southwesterly throughout the column. This wind profile suggests favorable conditions from most of the ground sites on this seeding day.

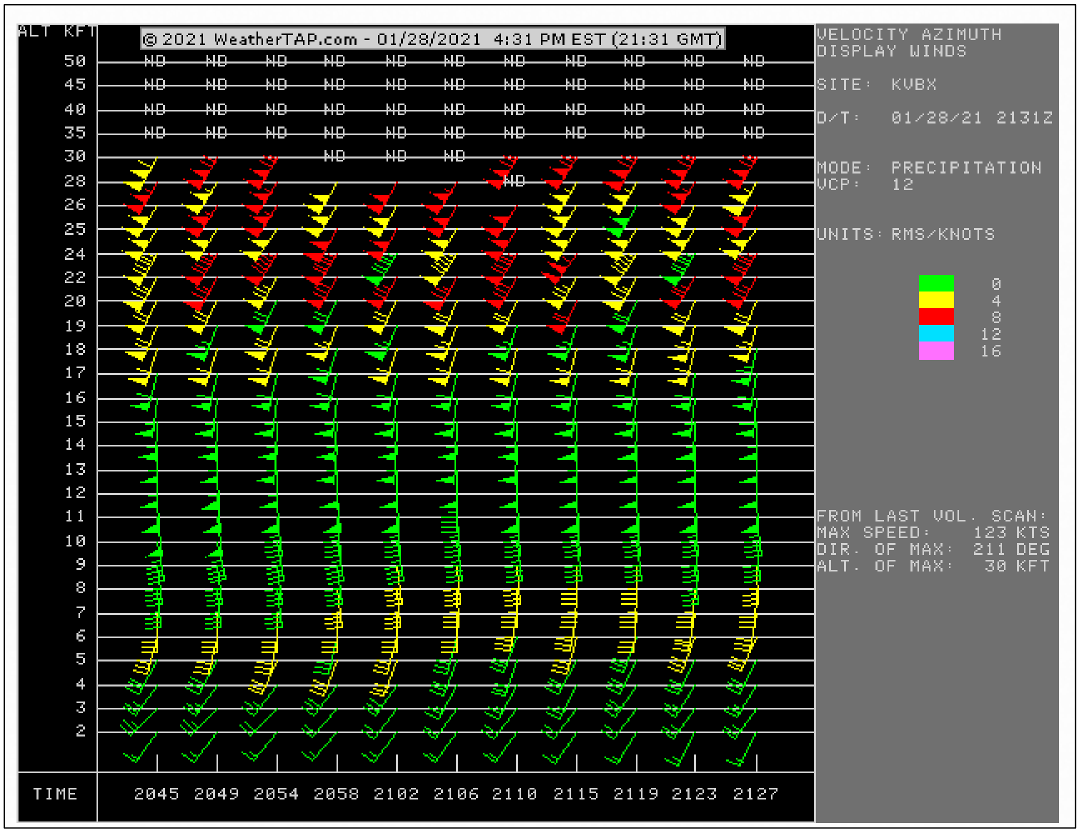

Figure 6.7 **Velocity Azimuth Wind Display on January 28, 2021 at 1331 PST**

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APPENDIX A

BACKGROUND ON CLOUD SEEDING IN SANTA BARBARA COUNTY

There is a long history of cloud seeding programs being conducted in Santa Barbara County. Some of these have been research programs, while others have been operational programs. The research programs have been conducted to better understand winter storm systems that impact Santa Barbara County and also to attempt to evaluate the potential impacts of cloud seeding, especially in terms of any additional rainfall that can be attributed to the cloud seeding activities. Some of these research programs employed randomization techniques whereby approximately one-half of the seedable events were deliberately left unseeded in order to provide data for comparison with the seeded events. Operational programs have been conducted with the primary objective being to maximize the amount of rainfall produced through the cloud seeding activities. As a consequence, randomization is typically not employed on operational programs since the goal is to produce the maximum impact, not to demonstrate that cloud seeding “works” or to document the amount of the cloud seeding increases. Programs in the County date back to the early 1950's which were the result of the pioneering work done in the field of weather modification in the late 1940's by Drs. Vincent Schaefer and Bernard Vonnegut.

Table 1 provides a summary of the research programs conducted in Santa Barbara County. There were also some early operational programs conducted in the 1950's and a later program in 1978. The 1978 program was conducted due to drought conditions. The design of the current program is based upon the results obtained from the Santa Barbara research program Phase I and II. Table 2 provides a summary of some of the earlier operational programs.

Table 1
Summary of Santa Barbara Research Programs

Name	Time Period	Study Area	Sponsor(s)	Design	Results
Santa Barbara I	1957-1960	Higher Elevations of Santa Barbara and Ventura Counties	State of California, University of California, Santa Barbara County, Ventura County, National Science Foundation, U.S. Weather Bureau, U.S. Forest Service	Randomized seeding using ground based silver iodide generators	Indications of a 45% increase, but results were not statistically significant (Neyman, et al, 1960) (Elliott, et al, 1962)
Water Balance of Orographic Clouds	1960-1963	Santa Ynez and San Gabriel Mountain Ranges	National Science Foundation	Analysis of Precipitation and Rawinsonde data during winter storms	Approximately one quarter of the orographically produced condensate fell as precipitation in the two mountain areas. More precipitation is produced in unstable versus stable air masses
Convection Band Study	1960-1963	Santa Barbara County	National Science Foundation	Analysis of Precipitation and Rawinsonde data during winter storms	The discovery that convection bands are a common feature of winter storms. Bands 20-40 miles wide centered some 30 to 60 miles apart Elliott and Hovind, 1964

Santa Barbara II: Phase I	1967-71	Santa Barbara County	Naval Weapons Center, China Lake, California	Randomized seeding of winter convection bands from a single ground site using high output silver iodide flares	Increases in convection band precipitation as high as 50%, several sites statistically significant Brown et al, 1974
Santa Barbara II: Phase II	1970-1974	Santa Barbara County	Naval Weapons Center, China Lake, California	Randomized seeding of winter convection bands using aircraft	Increases in convection band precipitation as high as 100%, several sites statistically significant Brown et al, 1974

Table 2 Summary of Earlier Santa Barbara Operational Programs

Time Period	Target Area	Sponsor	Design	Results
1950-1953, 1955	South Coast, Santa Ynez Basin, Cuyama Valley	Santa Barbara County Water Agency	Ground Based Silver Iodide Generators	Estimated 1.35 to 5.09-inch increases for 1955 program
1978	North-east portion of Santa Barbara County	Santa Barbara County	Ground based, high output silver iodide flares	Estimated increases of approximately 40%

The Santa Barbara County Water Agency (Agency) completed a number of tasks during 1981 designed to reactivate cloud seeding activities within the County. These tasks included: 1) preparation of a Negative Declaration Statement (#81-ND-87), 2) conducting a public hearing (December 10, 1981), and 3) obtaining a Weather Resource Management permit from the California Department of Water Resources. North American Weather Consultants (NAWC) was awarded an initial contract from the Agency (dated January 11, 1982) to conduct an operational cloud seeding program during the remainder of the 1982 winter season. Periodic contracts were awarded to NAWC by the Agency to continue these operational programs in a nearly continuous fashion through the 1997 Water Year.

Atmospherics, Inc. of Fresno, California was awarded a contract to conduct an operational program during the 1998 Water Year. Weather Modification, Inc., of Fargo, North Dakota, was awarded a contract by the Agency to conduct operational programs for the 1999 through 2001 Water Years. NAWC, under contract with the Agency, resumed its conduct of operations for the County during the winter of 2001-2002. This program utilized a revised project design based upon the highly successful results of earlier research conducted by NAWC (e.g., Santa Barbara II phase I and phase II experiments). The Agency renewed NAWC's contract to conduct the cloud seeding operations for the 2002-03 winter season. The Agency released an RFP for another three-year program during the early summer of 2003. NAWC was awarded this contract, which resulted in operations being conducted during the 2003-2004, 2004-2005 and 2005-2006 rainy seasons. The revised design, originally implemented during the 2001-2002 rainy season, was utilized in conducting these programs. The Agency released another RFP for a three-winter program during the spring of 2007. NAWC was again selected to perform this work, which would include both ground and airborne seeding. A large fire impacted substantial portions of the upper Santa Ynez watershed during the summer of 2007 (the Zaca fire). As a consequence, the Agency decided that no cloud seeding would be conducted during the 2007-2008 winter season in the Upper Santa Ynez watershed. The Agency decided to conduct a program designed to only affect the Twitchell watershed. The Agency expanded the program for the 2009-2010 program to include both the Huasna-Alamo and Upper Santa Ynez watersheds although restrictions were in place to avoid seeding impacts in some recent burn areas (La Brea, Jesusita, Gap and Tea fires). The Agency released another RFP for a three-winter program during the summer of 2011. NAWC was again selected to perform this work, which would include both ground and airborne seeding. Only ground seeding was conducted during the 2011-2012 and 2012-2013 rainy seasons. The Agency released another RFP for a three-winter program during the summer of 2014. NAWC was again selected to perform this work, which would include both ground and airborne seeding for the 2014-2015 through the 2016-2017 rainy seasons. Table 3 provides a summary of NAWC operations for the 1981 through 2017 period.

Research has demonstrated that properly conducted cloud seeding programs offer an environmentally safe and cost-effective means of augmenting precipitation from winter storms. NAWC conducted a study for the Santa Barbara County Water Agency (Thompson and Griffith, 1987), which assessed the precipitation augmentation potential from seeding wintertime cloud bands moving over Santa Barbara County. That assessment covered a sixty-one (61) year period (1920-1980). A follow-on study (Solak, et al., 1996) covered the period from 1981 through 1994, applying the same analysis methods. A key conclusion of these studies was that, under average conditions, seasonal precipitation could be optimally enhanced by 18 to 22 percent at Juncal and Gibraltar Dams through seeding of all appropriate precipitation bands from October through April. Seasonal increases of that magnitude could add as much as 4.5 to 5.0 inches of precipitation to the average seasonal total. Realizing the importance and benefit of this additional rainfall, the water purveyors of Santa Barbara County, under the administrative leadership of the County's Water Agency and/or the Flood Control District have sponsored a cloud seeding program in all water years since 1982, with the exception of 1985-1986 and 2007-2008. The 1985-1986 and 2007-2008 programs were canceled due fires which produced large burn scars in the project areas, which, in turn, created concerns about the potential for excessive erosion and mudslides.

Availability of fresh water in adequate supplies is obviously of paramount importance. Local precipitation has been the major source of water for most areas of California. As part of Santa Barbara County's water resource development and management strategies, cloud seeding operations have been routinely utilized to augment natural precipitation, helping to stabilize annual fresh water supplies. Cloud seeding for precipitation enhancement has been shown to be an effective tool, which carries a very attractive long-term benefit/cost ratio.

Table 3
Historical Operational Cloud Seeding Periods in Santa Barbara County, Water Year 1982 to Present

OPERATIONAL PERIOD	TARGET AREA	REMARKS
Jan 15-Apr 15, 1982	Santa Barbara County except South Coast	Airborne seeding, weather radar support provided by Vandenberg Air Force Base. Ground based pyrotechnic flare firing at Tranquillion Park.
Dec 1, 1982-Jan 26, 1983	Santa Barbara County except South Coast	Airborne and ground based pyrotechnic seeding suspended in late January due to heavy rainfall and Lake Cachuma approaching capacity.
Mar 1, 1984-Apr 30, 1984	North County	Airborne seeding and ground based pyrotechnic seeding.
Nov 1, 1984-Apr 30, 1985	Santa Barbara County except South Coast	Airborne seeding and ground based pyrotechnic seeding.
1985-1986		No program due to burn areas in San Luis Obispo and Ventura Counties
Nov 1, 1986-Mar 31, 1987	Santa Barbara County except South Coast	Airborne seeding. Ground based pyrotechnic seeding replaced with two ground-based silver iodide generators (Mt. Lospe and Sudden).
Nov 1, 1987-Mar 31, 1988	Santa Barbara County except South Coast	Airborne seeding. Implementation of remotely controlled ground-based silver iodide generators began (Mt. Lospe). The use of a computerized targeting model (GUIDE) began.
Nov 1, 1988-Apr 30, 1989	Santa Barbara County except South Coast	Provision of a project specific weather radar was initiated. Airborne seeding. Four manual generator sites (Gaviota, La Cumbre, Sudden, Graham Ranch) and one remote site (Mt. Lospe). Dedicated weather radar.
Nov 1, 1989-Apr 30, 1990	Santa Barbara County except South Coast	Airborne seeding. Four manual generator sites and one remote site. Special project suspension criteria developed for lower Santa Ynez River flow below Bradbury Dam. Dedicated weather radar.

Nov 1, 1990-Apr 30, 1991	Santa Barbara County except South Coast	Special targeting criteria adopted for Painted Cave burn area. Lower Santa Ynez flow suspension criteria continued. Airborne seeding. Three remotely controlled ground generators (Sudden, La Cumbre and Graham Ranch). One ground based manual site (Gaviota). Dedicated weather radar.
Nov. 1, 1991-Apr 21, 1992	Santa Barbara County except South Coast	Targeting restrictions continued for Painted Cave burn area plus Santa Ynez River flow. Airborne seeding. Four remotely controlled and one manually operated ground-based silver iodide generators. Dedicated weather radar.
Dec. 1, 1992-Mar 31, 1993	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Cachuma Reservoir spilled for the first time since the 1982-83 winter season. Santa Ynez River flow restrictions continued. New suspension criteria for Twitchell Reservoir inflow adopted. Provision made for acquisition of weather satellite information. Dedicated weather radar.
Dec. 17, 1993-Apr 18, 1994	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Targeting restrictions imposed for the Marre burn area. Santa Ynez River flow and Twitchell Reservoir inflow restrictions continued. Airborne seeding. Six remote generators. Dedicated weather radar.
Nov. 15, 1994-Mar 24, 1995	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Targeting restrictions continued for the Marre burn area. Santa Ynez River flow and Twitchell Reservoir inflow restrictions continued. Airborne seeding. Six remote generators. Cachuma spilled. Dedicated weather radar.
Dec. 14, 1995 - Mar. 13, 1996	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Targeting restrictions for Marre burn area removed. Santa Ynez River flow and Twitchell Reservoir inflow restrictions continued. Continued airborne seeding. 6 remote and 2 manual generators. Dedicated weather radar.
Dec. 9, 1996 - Mar. 22, 1997	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Santa Ynez River flow and Twitchell Reservoir inflow restrictions continued. Airborne seeding. Six remote generators. Two manual generators. Dedicated weather radar.
Nov. 15, 1997-Apr. 30, 1998	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Work performed by Atmospheric, Inc. of Fresno, California. Program onset delayed, operated Jan. 1-Feb. 1, 1998. Program suspended on Feb. 2, 1998 and terminated Mar. 15, 1998 (extremely wet watersheds)

OPERATIONAL PERIOD	TARGET AREA	REMARKS
Dec. 15, 1998-Mar. 31, 1999	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Work performed by Weather Modification, Inc. of Fargo, North Dakota.
Dec. 15, 1999-Apr. 5, 2000	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Work performed by Weather Modification, Inc. of Fargo, North Dakota.
Dec. 8, 2000-Mar. 31, 2001	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Work performed by Weather Modification, Inc. of Fargo, North Dakota.
Dec. 20, 2001 - Mar. 22, 2002	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Revised project design implemented, including airborne seeding and three automated high-output ground-based flare seeding (AHOGS) sites. Custom software utilized to combine NEXRAD and aircraft track data for use in operations.
Nov. 7, 2002 - May 2, 2003	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Airborne seeding and three automated high-output ground-based flare seeding (AHOGS) sites. Custom software utilized to combine NEXRAD and aircraft track data for use in operations.
Nov. 15, 2003 - Apr. 15, 2004	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Airborne seeding and three automated high-output ground-based flare seeding (AHOGS) sites. Custom software utilized to combine NEXRAD and aircraft track data for use in operations.

OPERATIONAL PERIOD	TARGET AREA	REMARKS
Nov. 15, 2004 - Apr. 15, 2005	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Airborne seeding and four automated high-output ground-based flare seeding (AHOGS) sites. Custom software utilized to combine NEXRAD and aircraft track data for use in operations. WxWorx display in aircraft cockpit of aircraft location, underlying terrain and current NEXRAD radar data.
Nov. 15, 2005 - Apr. 5, 2006	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Airborne seeding and five automated high-output ground-based flare seeding (AHOGS) sites. Custom software utilized to combine NEXRAD and aircraft track data for use in operations. WxWorx display in aircraft cockpit of aircraft location, underlying terrain and current NEXRAD radar data.
Nov. 15, 2006 - Mar. 31, 2007	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Airborne seeding and five automated high-output ground-based flare seeding (AHOGS) sites. WxWorx display in aircraft cockpit of aircraft location, underlying terrain and current NEXRAD radar data.
2007-2008 Winter Season	No Operations	Zaca Fire
Nov. 15, 2008 – Apr. 15, 2009	Twitchell watershed located in portions of northern Santa Barbara and southern San Luis Obispo Counties.	Revised project design partially implemented consisting of three high-output ground-based flare-seeding (AHOGS) sites. No aircraft seeding.
Nov. 15, 2009 – Apr. 15, 2010	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Revised project design partially implemented consisting of five high-output ground-based flare-seeding (AHOGS) sites. No aircraft seeding.

OPERATIONAL PERIOD	TARGET AREA	REMARKS
Nov. 15, 2010 – Mar. 31, 2011	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Revised project design implemented consisting of airborne seeding and six high-output ground-based flare-seeding (AHOGS) sites.
Dec. 1, 2011 – Apr. 22, 2012	Portions of northern Santa Barbara and southern San Luis Obispo Counties	Revised project design targeting only the northern (Huasna – Alamo) area, using three high-output ground-based flare seeding (AHOGS) sites.
Dec. 1, 2012 – Mar. 15, 2013	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Revised project design implemented consisting of six high-output ground-based flare-seeding (AHOGS) sites.
Nov. 15, 2013 – Apr. 15, 2014	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Revised project design implemented consisting of airborne seeding and six high-output ground-based flare-seeding (AHOGS) sites.
Nov. 15, 2014 – Apr. 15, 2015	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Revised project design implemented consisting of airborne seeding and six high-output ground-based flare-seeding (AHOGS) sites.
Nov. 1, 2015 – Apr. 30, 2016	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	For the first time in the history of the program, a six month long operational period occurred. This included six months of ground seeding and four months of aerial seeding.

OPERATIONAL PERIOD	TARGET AREA	REMARKS
Nov. 1, 2016 – Apr. 30, 2017	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Airborne seeding and six high-output ground-based flare-seeding (AHOGS) sites. Four of the Six AHOGS units were replaced with newly manufactured units that contained updated electronics and video cameras. Meteorological guidance for aircraft seeding operations conducted from Sandy, Utah. In all previous seasons the meteorologist was stationed in Santa Barbara or Santa Maria for the duration of the seeding programs. A new aircraft tracking system known as Spider Tracks was employed.
Nov. 15, 2017- Apr. 15, 2018	Portions of northern Santa Barbara and southern San Luis Obispo Counties	Revised project design targeting only the northern (Huasna – Alamo) area, using three high-output ground-based flare seeding (AHOGS) sites. No seeding in the Upper Santa Ynez Watershed due to Whitter Burn area. Introduction of the in-house HRRR model for cloud seeding guidance.
Nov. 15, 2018 – Apr. 15, 2019	Portions of northern Santa Barbara and southern San Luis Obispo Counties	Revised project design targeting only the northern (Huasna – Alamo) area, using two high-output ground-based flare seeding (AHOGS) sites. No seeding in the Upper Santa Ynez Watershed due to Whitter and Thomas Burn areas. Continued use of the in-house HRRR script model for cloud seeding guidance.
Dec. 1, 2019 – Apr. 15, 2020	Portions of northern Santa Barbara and southern San Luis Obispo Counties	Operational cloud seeding for only the northern (Huasna – Alamo) area using AHOGS sites. No seeding in the Upper Santa Ynez Watershed. Installation of a new site in southern San Luis Obispo County named Berros Peak.

APPENDIX B

2020-2021 CLOUD SEEDING PROGRAM SUSPENSION CRITERIA

A. General Criteria for the Entire Project Area in both Santa Barbara and San Luis Obispo Counties

Criteria in this category apply to the entire project area including all of Santa Barbara County and the Twitchell Reservoir Drainage of Southern San Luis Obispo County.

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.

B. Specific Criteria for Individual Areas/Watersheds

South Coastal Areas:

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

Santa Ynez River Watershed:

- As a result of the Whittier and Thomas Fires, the Santa Ynez River Watershed will not be seeded this year thus no special suspension criteria are needed.

Cuyama, Sisquoc and Santa Maria River Watersheds:

1. Cloud seeding operations shall be suspended in the Twitchell Watershed when District/Agency forecast that the conservation pool of Twitchell Reservoir will fill. The conservation pool is full at elevation 622.13’ (105,971 acre-feet (AF) of storage). This leaves 89,000 AF of Flood Control Capacity.

2. Seeding operations shall be suspended if the current or projected flow on the Cuyama River is 15,000 cubic feet per second (CFS) or greater at Buckhorn Canyon, as determined by the District/Agency using information supplied by the California-Nevada River Forecast Center.

3. Seeding operations shall be suspended if the current or projected flow on the Sisquoc River near Sisquoc is 10,000 CFS or greater at Sisquoc River Garey, as determined by the District/Agency using information supplied by the California-Nevada River Forecast Center.

4. Cloud seeding operations shall be suspended in the Twitchell Watershed when District/Agency project the potential of adverse results following the Alamo Fire, now in the third year of recovery.

Special suspension criteria for the Twitchell Watershed due to the Alamo Fire:

- Selective seeding techniques will be used when high intensity precipitation events of 0.8 inches per hour or greater are predicted or observed in the target area. These predications are made by the National Weather Service and observed using a network of real-time precipitation gages monitored and operated by Santa Barbara County Flood Control personnel. Selective seeding will avoid the Alamo burn area and is accomplished by using computer models to predict the trajectory of the seeding material from the remotely operated flare sites.

Note: All suspension criteria are subject to revision should hydrologic conditions warrant it. All revisions must be documented in writing and be approved by District/Agency representatives with notification provided to the project meteorologist.

APPENDIX C

TARGET/CONTROL ANALYSES FOR SANTA BARBARA COUNTY'S OPERATIONAL WINTER CLOUD SEEDING PROGRAM

2015 WMA JOURNAL OF WEATHER MODIFICATION

TARGET/CONTROL ANALYSES FOR SANTA BARBARA COUNTY'S OPERATIONAL WINTER CLOUD SEEDING PROGRAM

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ABSTRACT: An operational winter cloud seeding program has been conducted most winter seasons in the Santa Barbara, California area since 1981. This program has been sponsored by the Santa Barbara County Water Agency (SBCWA). There have typically been two target areas: the Upper Santa Ynez drainage above Cachuma Dam located in the eastern part of Santa Barbara County, and the Twitchell Reservoir drainage (usually 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 following the completion of the Santa Barbara II research program which provided indications of positive seeding effects from seeding convection 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. This paper summarizes the work that was performed. 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). 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.

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).

1. INTRODUCTION AND BACKGROUND

An operational winter cloud seeding program has been conducted most winter seasons since 1981 sponsored by the Santa Barbara County Water Agency (SBCWA). There have typically been two target areas: the Upper Santa Ynez drainage above Cachuma Dam located in the eastern part of Santa Barbara County, and the Twitchell Reservoir drainage (usually 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 (Figure 1). For reference purposes, the distance between Lompoc and Santa Maria is 22 miles. The operational program has typically used both airborne and ground based seeding modes to target convection bands as they approach then pass over the two target areas. This operational program was implemented following the completion of the Santa Barbara II research program which provided indications of positive seeding effects from seeding convection bands some of which were statistically significant. Griffith, et al, 2005 provides an overview of the Santa Barbara II experiment and a discussion of the operational seeding program covering the 1981 – 2004 period. This operational program has continued to the present. Earlier references on the Santa Barbara II research program include: Elliott, et al, 1971 and Thompson, et al, 1975.

Figure 1: Map of the Two Cloud Seeing Target Areas and the Locations of Precipitation Control Sites (green) and Target Sites (red).

The task of determining the effects of cloud seeding has received considerable attention in recent years. Evaluating the results of a cloud seeding program for a single season is rather difficult, and such results should be viewed with appropriate caution. This difficulty stems from the large natural variability in the precipitation occurring in a given area from season to season, and between one area and another during a given season, and the relatively modest increases in precipitation that can be attributed to cloud seeding. Since cloud seeding is normally feasible only when existing clouds are near to (or already are) producing precipitation, it is not usually obvious if and how much the precipitation was actually increased by seeding due to this large natural variability. The ability to detect a seeding effect becomes a function of the magnitude of the seeding increase and the number of seeded events, compared with the natural variability in the precipitation pattern. Larger seeding effects can be detected more readily and with a smaller number of seeded cases than are required to detect smaller increases. Despite the difficulties involved, some techniques are available for evaluation of the effects of operational seeding programs. These techniques are not as rigorous or scientifically desirable as is the randomization technique used in research programs (e.g., the Santa Barbara II program), where typically about half the "seedable" storm events are randomly left unseeded. Most sponsors of operational cloud seeding programs do not wish to reduce the potential benefits of a cloud seeding program by half in order to better document the effects of the cloud seeding project. The less rigorous techniques do, however, offer helpful indications of the long-term effects of seeding on operational programs (Silverman, 2007, 2009 and 2010).

NAWC employs an historical target/control analysis to evaluate our operational cloud seeding programs (e.g., Griffith et al, 2009; Griffith et al, 2011). The target/control technique is one described by Dennis (1980). This technique is based on selection of a variable that would be affected by seeding (such as precipitation or snow water content). Records of the variable to be tested are acquired for an historical period of as many years duration as possible. Dennis (1980) suggests the need for a sufficient number of not seeded events (perhaps 30 or more) in order to assume the values are normally distributed. These records are partitioned into those located within the designated "target" area of the project and those in nearby "control" areas. Ideally, the control sites should be selected in areas meteorologically similar to the target area but unaffected by the seeding (or seeding from any other nearby projects). The historical data (e.g., precipitation and/or snow water content) in both the target and control areas are taken from past years that have not been subject to cloud seeding activities. These historical data are evaluated for the same seasonal period of time as when the seeding was later conducted. The target and control sets of data for the unseeded seasons are used to develop a linear or sometimes multiple-linear regression equation that can be used to predict the amount of target area precipitation, based on precipitation observed in the control area. This regression equation is then applied to the seeded period to estimate what the target area precipitation should have been without seeding, based on the control area precipitation. This allows a comparison to be made between the predicted seasonal target area precipitation and the actual observed precipitation that occurred during the seeded period to look for any differences potentially caused by the seeding activities. Typically the observed precipitation amounts are divided by the predicted amounts. If this ratio is greater than 1.0, there is an indication of more precipitation in the target area than that predicted from the control area precipitation. This technique had not been previously attempted by NAWC for the Santa Barbara operational program for the following reasons:

- Most storms that impact Santa Barbara County during the winter typically move from west to east so upwind control areas would preferably be over the Pacific Ocean.
- The seeding during the operational program might occasionally impact areas in Santa Barbara County outside the target areas, which could impact potential control sites.

These conditions would suggest that the best control areas (those not impacted by seeding) would be west or southwest of Santa Barbara County. Obviously this is not possible since these areas are over the Pacific Ocean (see Figure 1). If control sites were used that might be impacted by the cloud seeding and the seeding was effective, this would potentially raise the control area precipitation amounts during seeded periods. If these control amounts were entered into the regression equation or equations for the seeded periods, they would over-predict the amount of the estimated target precipitation. This would in turn lower the ratio of observed over predicted precipitation. In other words, this would cause an underestimate of any seeding effects.

2. SELECTION OF CONTROL AND UPPER SANTA YNEZ TARGET SITES

Given the above as background, NAWC in conjunction with SBCWA, conducted a search for possible long-term precipitation measurement sites which could be used to estimate potential seeding results from the SBCWA long-term cloud seeding program. Control sites were sought that would have minimal or no impact from the seeding program. Due to the long history of seeding operations in Santa Barbara County, with research and operational programs conducted during most years since 1950, sites with long and reliable records were identified for this analysis. This would provide a significant amount of historical data which would exclude the seeded periods from which historical regression equations could be developed. Dennis (1980) suggests the need for a sufficient number of not seeded events (perhaps 30 or more) in order to assume the values are normally distributed. NAWC's experience has been that longer historical records (preferably greater than 20 historical seasons without any seeding activity) lead to more representative regression equations for the evaluation of seasonal programs.

For the Santa Ynez target in eastern Santa Barbara County, monthly rainfall records (expressed in inches of precipitation) from Gibraltar Dam and Jameson Reservoir were available dating back to 1926 making these sites potentially suitable target sites. A search for potential control sites in Santa Barbara County identified the following possibilities: 1) Santa Barbara, 2) Rancho San Julian in southwestern Santa Barbara County, 3) Santa Cruz Island, 4) Betteravia, 5) Los Alamos, 6) Santa Maria and 7) Guadalupe. A site in San Luis Obispo County (Paso Robles) was also identified as a possible control site. All these sites had monthly precipitation data dating back to 1920 or before, although the Paso Robles site only had consistent data back to the 1926 water year. Of potential interest, the average annual water year rainfall for the 95 year period of record at Gibraltar Dam is 26.59″ with a maximum value of 73.12″. This site is in a favored location for orographic enhancement of rainfall due to the west-east oriented Santa Ynez Mountains ridgeline located a few miles south of this site and frequent strong low-level southerly winds being present in winter storms that impact the area.

After several quality control checks of the data available from these sites plus consideration of which possible control sites might be impacted by seeding, three control sites were selected: Rancho San Julian, Paso Robles, and Santa Cruz Island. In a similar fashion two target sites were selected: Gibraltar Dam and Jameson Reservoir. Figure 1 depicts the locations of these control and target sites. It can be seen from Figure 1 that the three control sites bracket the target area, a feature that has been found to provide better correlations between control and target areas.

These sites are maintained by public agencies (e.g., the SBCWA) with their own quality control procedures. For purposes of quality control of the precipitation data for this analysis, NAWC utilized an engineering tool known as a double-mass plot. These plots compare the historical trend between two given sets of data and help to identify any break points (i.e. change in slope of the line) that may indicate a long-term change in the relationship between the two data sets. NAWC has previously used this technique in selecting target and control sites for evaluations of a number of operational cloud seeding programs (e.g., Griffith, et al, 2009). In this application, if there is a break in the plots, it could be due to a site move, change in equipment used at the site, effects of cloud seeding programs, change in vegetation around the site over time, or other unknown reasons. Double mass plots are scatterplots of cumulative (in this case, precipitation) data for two sites over some time period. This technique was applied to sites tentatively identified as potential control or target sites. Figure 2 is an example of a double-mass plot showing a distinct change in the relationship between the control site average and a potential target site (West Big Pine) for the December-March period, but without any correspondence to the timing of a cloud seeding program. This break occurred in Water Year 1994 for unknown reasons. Figure 3 is an example of a plot where the relationship is not perfect, but there does not appear to be any significant change in the relationship between the two sites over time.

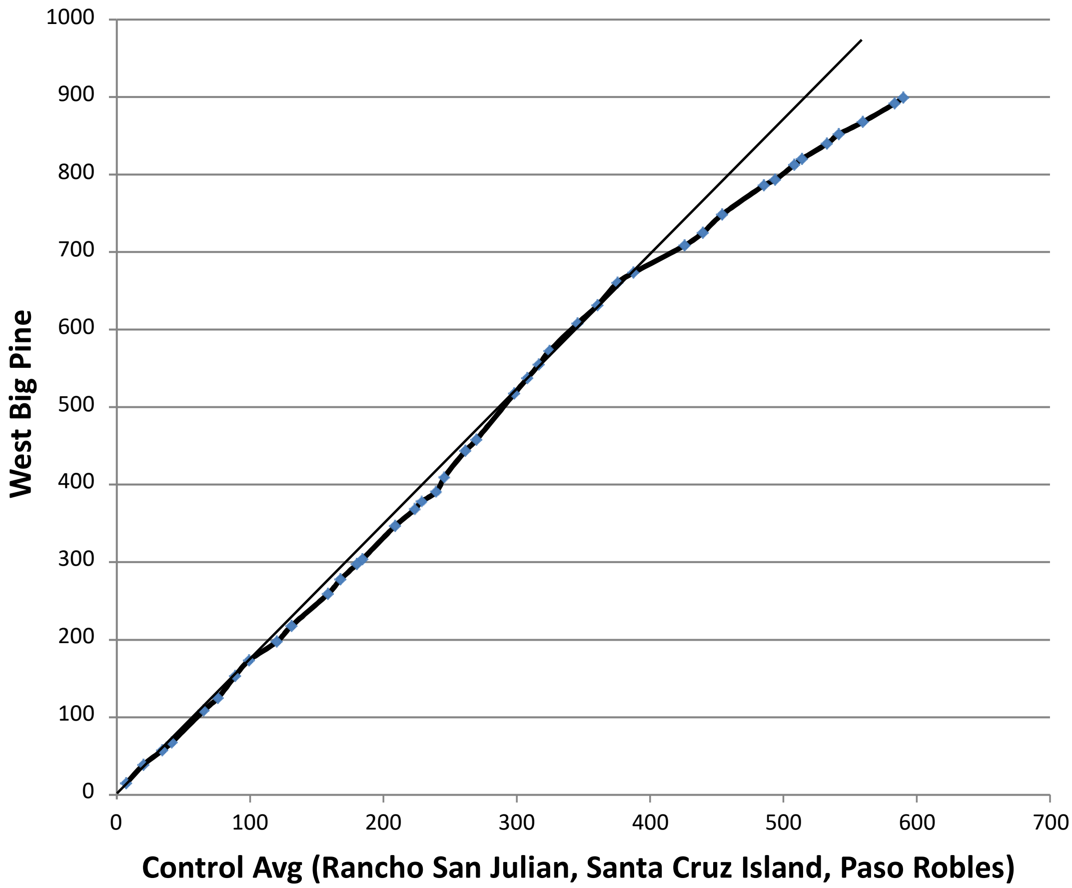

Figure 2: Double Mass Plot of West Big Pine December to March Precipitation versus the Average December to March Precipitation from Three Control Sites. A trend line has been added to illustrate the break in the plot.

Double-mass plots were used to eliminate some sites from consideration, due to long-term changes which did not correspond with the timing (beginning or end) of any cloud seeding programs. The remainder of the control sites (which would be largely unaffected by seeding) showed very similar patterns in terms of their long-term history, suggesting the data from those sites are of good quality for this analysis. Similar comparisons between target sites (which would have been affected by seeding after a certain point in time) also showed good agreement for the sites that were utilized. This gives confidence that the sites which exhibited different long-term trends in the double-mass plots (such as West Big Pine) were indeed outliers from the bulk of the data set and likely not reliable enough for use in the target/control analysis.

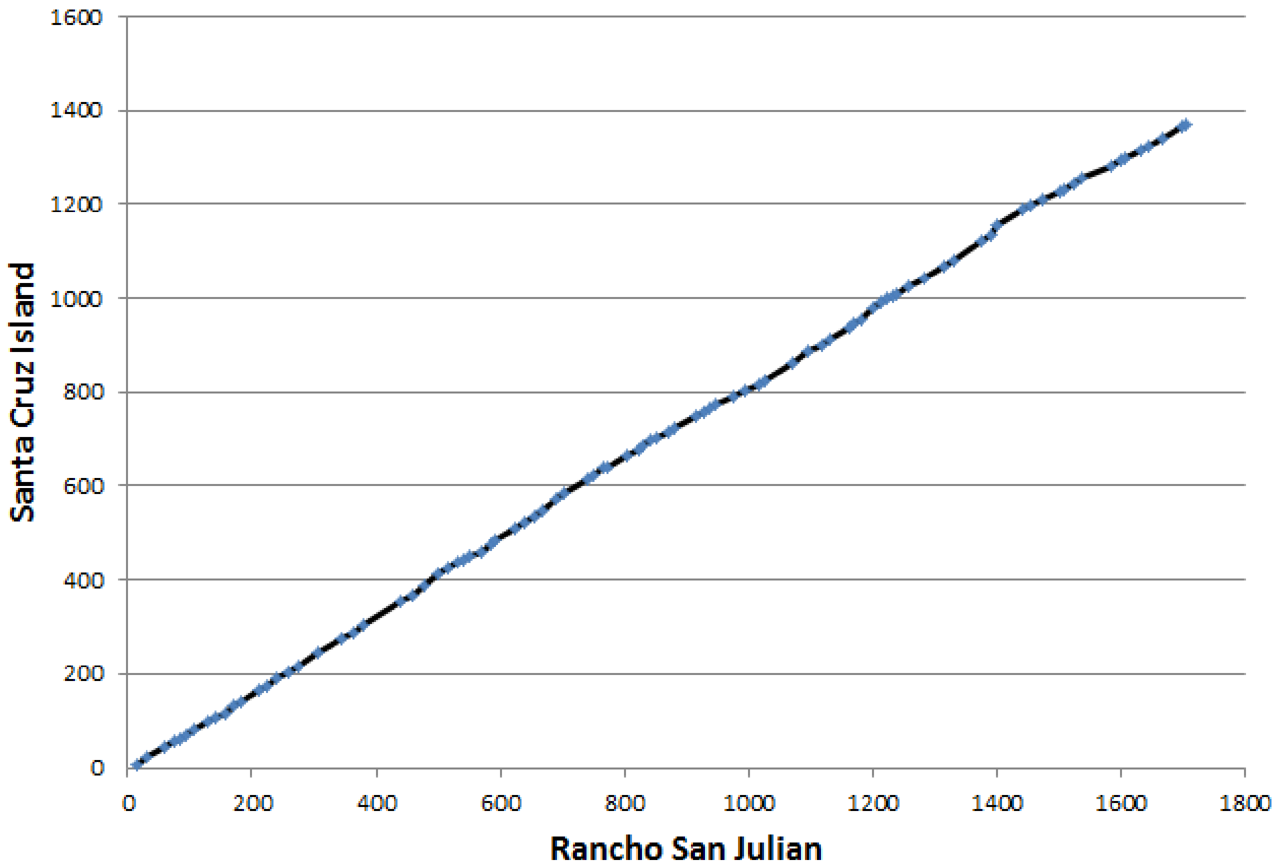

Figure 3: Double Mass plot of December to March Precipitation at Santa Cruz Island versus December to March Precipitation at Rancho San Julian.

3. SELECTION OF CONTROL AND HUASNA-ALAMO YNEZ TARGET SITES

It was decided that the same three control sites identified for use in the Upper Santa Ynez target evaluation would be used in the Huasna-Alamo target evaluation e.g., Rancho San Julian, Paso Robles, and Santa Cruz Island based principally on the relatively high r^2 values obtained in the regression equations, plus a consideration of the sparcity of potential control gauges with long historical records. There were two sites in the target area that had publically available data: Shell Peak, which only had records dating back to the 1992 water year and was therefore rejected, and Twitchell Dam. Checks on the data quality from the Twitchell Dam site indicated that the data were of good quality for use in the analysis. Unfortunately, historical data from this site only dates back to water year 1963 which is a much shorter record than that of the two target sites used in the Upper Santa Ynez target area evaluation. Lacking suitable alternatives, the Twitchell Dam site was selected as a target site. Of potential interest, the average annual water year rainfall for the 52 year period of record at Twitchell Dam is 18.01″ with a maximum value of 47.11″. This site is further removed from the Santa Ynez ridgeline and consequently is subject to less orogaraphic influence during storm periods.

SBCWA personnel suggested another possible target site. This site was located on the Porter Ranch in southern San Luis Obispo County within the intended target area (refer to Figure 1). It was found that there were some long-term precipitation observations available from this site that dated back to the 1952 water year. These observations had been made by members of the Porter family. It was discovered that there were only hand-written records available from this site. Due to the very desirable location of this site, it was arranged to borrow these hand written records. Monthly totals from this site were then digitized. It should be understood that data from this site were not collected and quality checked as would be the case of such public records as those from the Twitchell Dam site. Quality control checks (double mass plots) with other nearby sites indicated that these records appeared to be stable. It was decided to include data from this site in the evaluation which provided the evaluation with two target sites (the same number as the Upper Santa Ynez evaluation).

4. DEVELOPMENT OF THE REGRESSION EQUATIONS FOR THE UPPER SANTA YNEZ TARGET AREA

Development of target/control regression equations involves comparisons of the control site data to target site data (either a single target site or an average of target area data). In this case, all three control sites were used to develop regression equations for the historical (either pre-1951 or other not-seeded) seasons for the target area. For this evaluation, a sum of December-March precipitation was used for each not-seeded season. The December-March period was chosen because it was judged to be most representative of when seeding normally occurred during the operational seasons.

There were two basic types of regression equations that were developed: Linear regression, which averages the data from the three control sites to compare to that of the average of the two target sites; and multiple-linear regression, which considers each control site separately versus the average of the two target sites. The linear regression equation contains only a slope and offset term (of the form y= ax + b), while the multiple-linear regression contains a coefficient (or multiplier) term for each control site, plus an offset term. Both of these equations were based on the same set of historical seasons (water years 1926-1950; 1956-57; 1961-67; 1974-75; 1977; 1980-81; 1984; 1986; 2008-2009; 2012), a total of 44 seasons during which no seeding was conducted to impact the Upper Santa Ynez target area. Water years 1920-25, 1976, and 1979 had some missing data at one or more control sites and were not used. Other intervening seasons had either research or operational seeding programs conducted in the County.

The linear regression equation that was developed was:

(1) $y = 1.27x + 0.82$

where y is the predicted average Gibraltar/Jameson December – March precipitation and x is the average value of the three control site's December - March precipitation. The r^2 value was 0.84, which is a measure of the accuracy of the predictions (the variance). A perfect prediction would have an r^2 value of 1.0. The 0.84 value would be considered to represent a reasonably high correlation between the target and control sites. This equation had a standard error of 4.2″.

The multiple-linear regression equation was:

(2) $y = + 0.71(\text{Rancho San Julian}) + 0.62 (\text{Paso Robles}) - 0.03 (\text{Santa Cruz}) + 0.19$

The r^2 value was 0.86, which is nearly the same as that obtained with the linear regression equation. This equation had a standard error of 4.1″.

5. DEVELOPMENT OF THE REGRESSION EQUATIONS FOR THE HUASNA-ALAMO TARGET AREA

As in the Upper Santa Ynez evaluation, linear and multiple-linear regression equations were developed. Both of these equations were based on the same set of 12 historical seasons (water years 1963-67, 74-75, 77, 80-81, 86, and 2008) during which no seeding was conducted to impact the Huasna-Alamo target area. The limited number of not-seeded seasons was determined by the shorter period of record that was available from the Twitchell Dam site. Water years 1976 and 1979 had some missing data at one or more control sites and were not used. Other intervening seasons either had research or operational seeding programs conducted in the County. A longer historical period than 12 seasons would have been highly desirable. The same December-March period was used in the development of these equations.

The linear regression equation that was developed was:

(3) $y = 0.87x + 0.36$

where y is the predicted average Twitchell Dam/ Porter Ranch average December - March precipitation and x is the average value of the three control site's December - March precipitation. The r^2 value of 0.87 indicates a reasonably high correlation exists between the target and control sites. This equation had a standard error of 2.0″.

The multiple-linear regression equation that was developed was:

(4) $y = 0.62$ (Rancho San Julian) + 0.15 (Paso Robles) + 0.15 (Santa Cruz) + .20

The r^2 value was 0.91, which is nearly the same as that obtained with the linear regression equation. This equation had a standard error of 1.8″.

Due to the uncertainty about the quality of the data from the Porter Ranch site, NAWC also developed linear and multiple-linear equations based solely on the Twitchell Dam data. The linear regression equation was:

(5) $y = 0.79x + 0.16$

with an r^2 value of 0.77 and a standard error of 2.4″.

The multiple-linear regression equation was:

(6) $y = 0.63$ (Rancho San Julian) + .18 (Paso Robles) – 0.10 (Santa Cruz) – 0.50

with an r^2 value of 0.87 and a standard error of 2.0″.

6. APPLICATION OF THE REGRESSION EQUATIONS TO EXAMINE POSSIBLE SEEDING EFFECTS IN THE UPPER SANTA YNEZ TARGET AREA

Once the regression equations were established, they were applied to seasons with operational seeding activities that targeted the Upper Santa Ynez target area (water years 1985; 1987-2007; 2010-11), a total of 24 seasons. No 2013 data had been obtained for Santa Cruz Island and therefore water year 2013 was not included.

The predicted value for each December – March season was compared to the observed value. This was done by dividing the observed values by the predicted values. If the resulting ratio was greater than 1.0, this would indicate more precipitation was observed than predicted at the target sites. Ratios less than 1.0 would indicate less precipitation than predicted.

In this evaluation, both the linear and multiple-linear regression evaluations yielded similar results. Table 1 provides the individual seeded season results from the linear regression equation. The resultant average observed/predicted ratios for the combination of the 24 seeded seasons was 1.21 for the linear equation and 1.19 for the multiple-linear equation. These ratios suggest an average 21% or 19% precipitation increase for the December – March period at Gibraltar Dam and Jameson Reservoir in the seeded seasons. These results are equivalent to an average of 4.3 or 4.0 inches of additional December – March rainfall based on the linear and multiple-linear equations, respectively. Possibly of interest is the observation that there were 13 ratios greater than 1.0 and 9 ratios that were less than 1.0.

Figure 4 was prepared to provide a graphic display of the indicated results from the linear regression equation. This figure indicates the variability of the results.

Table 1: Linear Regression Seeded Seasons Results, December-March Precipitation, Gibraltar Dam and Jameson Reservoir, Upper Santa Ynez Target Area.

Water Year	Control Average (inches)	Target Average (inches)	Target Predicted (inches)	Ratio Obs. / Pred.	Difference (inches)
1985	8.79	11.87	11.98	0.99	-0.11
1987	10.52	9.80	14.17	0.69	-4.37
1988	9.04	16.48	12.30	1.34	4.18
1989	6.90	12.45	9.57	1.30	2.88
1990	5.26	10.56	7.50	1.41	3.06
1991	15.54	30.46	20.55	1.48	9.91
1992	19.05	40.35	25.01	1.61	15.34
1993	26.42	54.59	34.36	1.59	20.23
1994	12.02	17.88	16.07	1.11	1.80
1995	38.37	60.37	49.52	1.22	10.85
1996	13.65	18.75	18.15	1.03	0.60
1997	14.48	15.77	19.20	0.82	-3.44
1998	31.26	58.63	40.50	1.45	18.13
1999	8.56	11.59	11.68	0.99	-0.10
2000	13.38	23.22	17.80	1.30	5.42
2001	20.41	30.81	26.73	1.15	4.07
2002	5.06	4.97	7.24	0.69	-2.27
2003	13.21	14.89	17.58	0.85	-2.69
2004	10.49	12.84	14.14	0.91	-1.30
2005	30.03	57.65	38.94	1.48	18.70
2006	14.31	20.83	18.98	1.10	1.84
2007	5.83	7.68	8.22	0.93	-0.54
2010	17.99	22.68	23.65	0.96	-0.98
2011	23.78	33.16	31.01	1.07	2.15
Seeded Mean	**15.60**	**24.93**	**20.62**	**1.21**	**4.31**

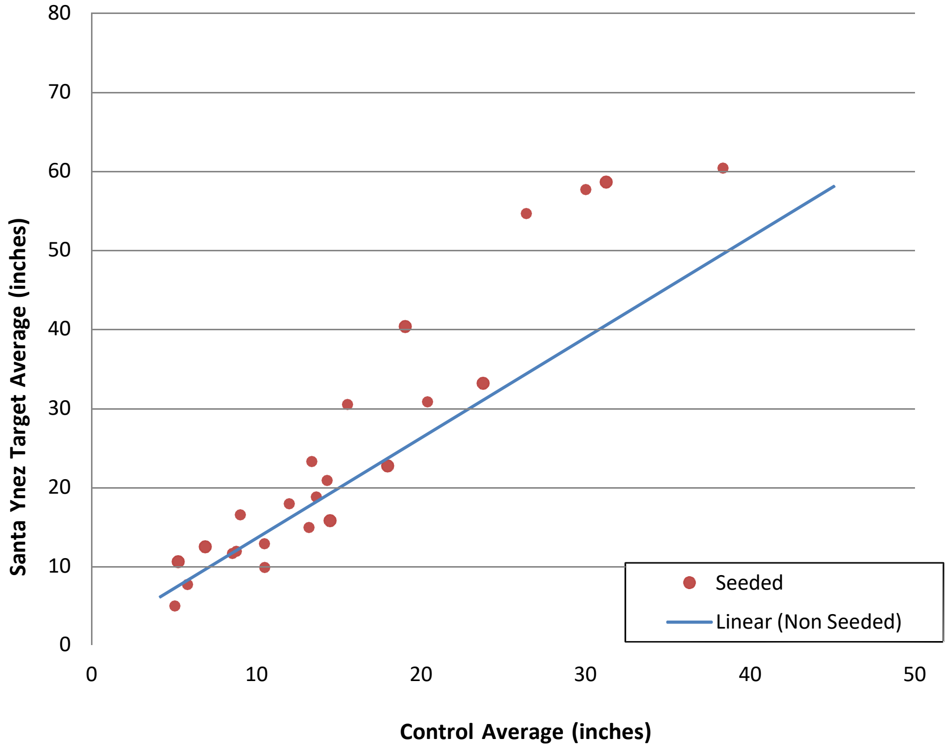

Figure 4: Plot of the Average Upper Santa Ynez Target Area Precipitation versus the Average Control Area Precipitation for the December-March Seeded Seasons. The diagonal blue line is the best fit linear regression line for the not-seeded seasons.

7. APPLICATION OF THE REGRESSION EQUATIONS TO EXAMINE POSSIBLE SEEDING EFFECTS IN THE HUASNA-ALAMO TARGET AREA

Once the regression equations were established, they were applied to seasons with operational seeding activities that targeted the Huasna-Alamo. A total of 27 years with operational seeding were evaluated for the Huasna-Alamo target (water years 1984-85, 1987-2007, and 2009-2012), similar to the Santa Ynez target except with the addition of water years 1984, 2009, and 2012 in which years only the Huasna-Alamo target was seeded. No 2013 data had been obtained for Santa Cruz Island and therefore water year 2013 was not included.

In this evaluation, both the linear and multiple-linear regression evaluations yielded the same average result for the combined Twitchell Dam and Porter Ranch average precipitation; a ratio of 1.09 for the 27 seeded seasons. Table 2 provides the individual seeded season results. These ratios suggest an average 9% precipitation increase for the December – March period when the Twitchell Reservoir and Porter Ranch data were averaged together. These results are equivalent to approximately an average of 1.1 inches of additional December – March rainfall based on the linear and multiple-linear equations. The individual season results are again rather variable even with relatively high r^2 values. Figure 5 was prepared to provide a graphic display of the indicated results from the linear regression equation. This figure indicates the variability of the results. Possibly of interest is the observation that there were 21 ratios greater than 1.0 and 6 ratios less than 1.0.

Due to uncertainties about the quality of the Porter Ranch precipitation data, calculations were made of the apparent impacts on just the Twitchell Dam precipitation gauge site. The indicated average results for that site are the same for both the linear and multiple-linear equations (a positive 17%). Table 3 provides the individual seeded season results. This 17% value is closer to the average ratios that were obtained in the Upper Santa Ynez evaluation (19 – 21%). The estimated average increase was 1.9 inches of water.

Table 2: Linear Regression Seeded Seasons Results, December-March Precipitation, Twitchell Dam and Porter Ranch Sites, Huasna-Alamo Target Area.

Water Year	**Control Average (inches)**	**Target Average (inches)**	**Target Predicted (Inches)**	**Ratio Obs. / Pred.**	**Difference (inches)**
1984	6.09	5.81	5.63	1.03	0.18
1985	8.79	10.12	7.97	1.27	2.15
1987	10.52	11.33	9.47	1.20	1.86
1988	9.04	9.09	8.19	1.11	0.90
1989	6.90	10.48	6.33	1.65	4.14
1990	5.26	6.37	4.91	1.30	1.45
1991	15.54	15.34	13.82	1.11	1.52
1992	19.05	14.97	16.86	0.89	-1.89
1993	26.42	23.16	23.24	1.00	-0.08
1994	12.02	10.46	10.76	0.97	-0.30
1995	38.37	26.83	33.59	0.80	-6.76
1996	13.65	19.19	12.18	1.58	7.01
1997	14.48	16.60	12.90	1.29	3.70
1998	31.26	30.72	27.43	1.12	3.29
1999	8.56	11.98	7.77	1.54	4.21
2000	13.38	17.18	11.94	1.44	5.24
2001	20.41	17.65	18.04	0.98	-0.39
2002	5.06	6.65	4.74	1.40	1.91
2003	13.21	10.56	11.79	0.89	-1.24
2004	10.49	10.30	9.45	1.09	0.85
2005	30.03	18.98	26.37	0.72	-7.39
2006	14.31	16.21	12.75	1.27	3.45
2007	5.83	6.95	5.40	1.29	1.55
2009	8.88	9.08	8.05	1.13	1.03
2010	17.99	16.15	15.93	1.01	0.22
2011	23.78	24.85	20.95	1.19	3.89
2012	6.54	6.43	6.02	1.07	0.40
Seeded Mean	**14.66**	**14.20**	**13.05**	**1.09**	**1.14**

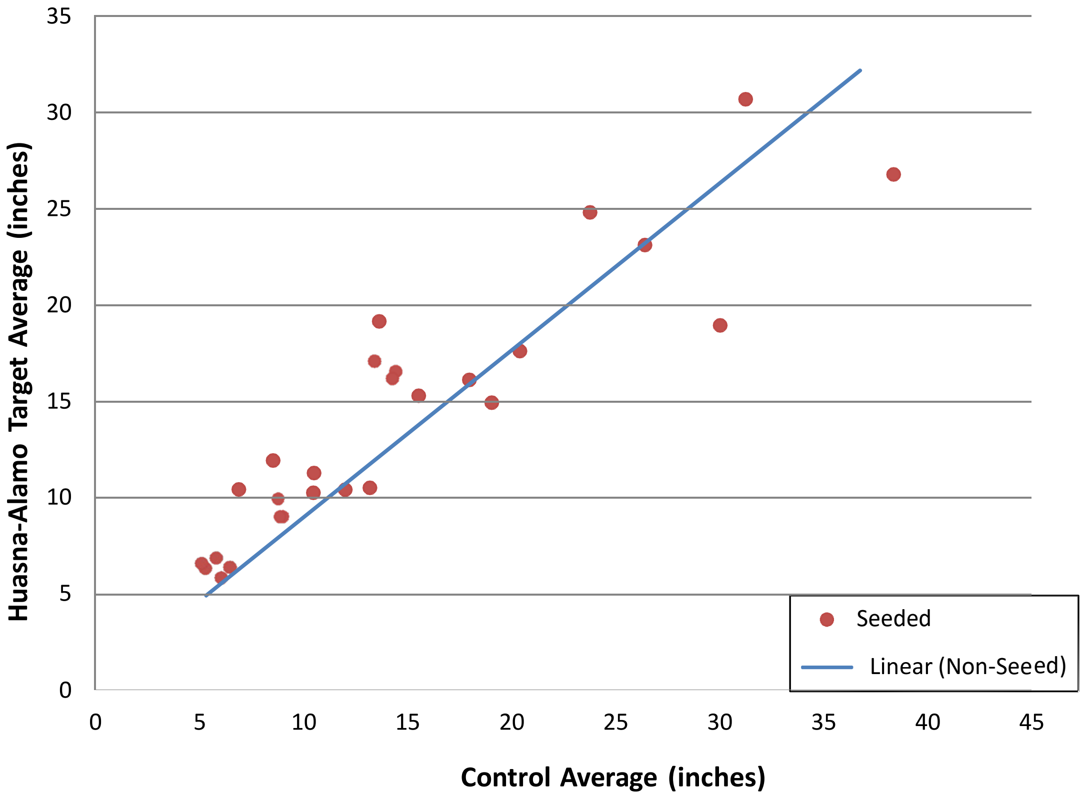

Figure 5: Plot of the Average Huasna-AlamoTarget Area Precipitation versus the Average Control Area Precipitation for the December-March Seeded Seasons. The diagonal blue line is the best fit linear regression line for the not-seeded seasons.

Table 3: Linear Regression Seeded Seasons Results, December-March Precipitation, Twitchell Dam, Huasna-Alamo Target Area.

Water Year	Control Average (inches)	Target Average (inches)	Target Predicted (inches)	Ratio Obs. / Pred.	Difference (inches)
1984	6.09	5.26	4.94	1.06	0.32
1985	8.79	10.16	7.07	1.44	3.09
1987	10.52	10.66	8.43	1.26	2.23
1988	9.04	8.03	7.27	1.11	0.76
1989	6.90	10.06	5.58	1.80	4.48
1990	5.26	6.98	4.29	1.63	2.69
1991	15.54	13.74	12.38	1.11	1.36
1992	19.05	14.61	15.14	0.96	-0.53
1993	26.42	22.85	20.94	1.09	1.91
1994	12.02	9.95	9.61	1.04	0.34
1995	38.37	26.42	30.33	0.87	-3.91
1996	13.65	18.48	10.89	1.70	7.59
1997	14.48	15.38	11.55	1.33	3.83
1998	31.26	30.44	24.74	1.23	5.70
1999	8.56	12.53	6.89	1.82	5.64
2000	13.38	18.23	10.68	1.71	7.55
2001	20.41	17.03	16.21	1.05	0.82
2002	5.06	6.36	4.14	1.54	2.22
2003	13.21	9.30	10.54	0.88	-1.24
2004	10.49	9.52	8.41	1.13	1.11
2005	30.03	17.75	23.78	0.75	-6.03
2006	14.31	13.79	11.41	1.21	2.38
2007	5.83	6.65	4.74	1.40	1.91
2009	8.88	8.81	7.14	1.23	1.67
2010	17.99	14.99	14.30	1.05	0.69
Seeded Mean	**14.66**	**13.62**	**11.69**	**1.17**	**1.94**

8. SUMMARY AND DISCUSSION OF INDICATED RESULTS

8.1 Indications for the Upper Santa Ynez Target Area

Three control sites (Rancho San Julian, Paso Robles and Santa Cruz Island) and two target sites (Gibraltar Dam and Jameson Reservoir) with long-term records dating back to 1926 were identified that were used to develop both regression equations. Control sites were selected from areas that were expected to have minimal seeding impacts during the seeding seasons. More control and target sites would have been desirable but choices were limited due to the need for long term records and for the control site locations to be in areas not expected to be affected by the cloud seeding activities. Long-term records were desired since there have been a number of seeding projects conducted in Santa Barbara County that date back to the 1950's. These years had to be excluded due to the unknown impacts of these programs on precipitation in the operational program's target areas. Linear and multiple-linear regression equations were developed from these data sets based upon average December through March seasonal precipitation values.

The resultant observed/predicted ratios for the combination of the 24 seeded seasons were 1.21 for the linear and 1.19 for the multiple-linear equations. These ratios suggest approximately an average 21% or 19% precipitation average increase for the December – March period at Gibraltar Dam and Jameson Reservoir in the seeded seasons. These results are equivalent to approximately an average of 4.3 and 4.0 inches of additional December – March rainfall based on the linear and multiple-linear equations, respectively. Application of the one-tailed Student's t test suggests that there is only a 16-18% probability that these differences are due to chance. The inference is that the indicated differences are likely due to the cloud seeding program. The individual season results were rather variable even with reasonably high r^2 values. Although there were several seasonal ratio values less than 1.0, it is considered unlikely that there is any potential of reducing precipitation through cloud seeding. Such ratios for individual seasons are to be expected occasionally because of the imperfections built into the regression equation prediction technique. Similar fluctuations have been observed in target/control analyses of other winter cloud seeding programs conducted by NAWC as documented in annual reports on these programs.

Often there is a significant amount of season-to-season variability in the indicated results of seeding using the historical target/control evaluation technique, even when the regression equation correlation coefficients are high. Different predominate storm tracks in different seasons can impact the indicated results. Some winter seasons may contain more "seedable" storm periods than others. For these and other reasons, the focus should be on the accumulated results derived from a number of seeded seasons rather than focusing on individual season results. In other words, the average estimated increases of 19% to 21% are more representative of the likely impacts of the seeding program than any individual seasons observed over predicted ratio. The 19-21% values are surprisingly similar to estimates of seeding potential in the Upper Santa Ynez target area contained in a NAWC report to the Santa Barbara County Flood Control and Water Conservation District and Water Agency that estimated approximately an 18% average seasonal increase at Juncal Dam (Jameson Reservoir) and Gibraltar Dam, the same precipitation gauges used in this analysis (Solak, et al, 1996).

The estimated 19% to 21% increases are on the high side when compared with a range of potential effects of 5% to 15% contained in the Weather Modification's Capability Statement on Weather Modification (WMA 2011) and the 0% to 15% range of indicated increases from eleven long-term programs conducted in the Sierra Nevada (Silverman, 2010).

8.2 Indications for the Huasna-Alamo Target Area

Twitchell Dam was determined to be in a location that would make it a representative target site. Another site, Porter Ranch, had unpublished daily records dating back to the 1952 water year. These records were digitized then used in combination with the Twitchell Dam site to represent the Huasna-Alamo target area. It should be understood that data from the Porter Ranch site were not collected and quality checked as would be the case of such public records as those from the Twitchell Dam site. For example, it is unknown if the same type of precipitation gauge was used throughout the long history of this site. It is unknown if the location of this gauge may have stayed the same or if it was moved from time to time. These factors could impact the data quality from this site.

As in the Upper Santa Ynez evaluation, linear and multiple-linear equations were developed based upon the same three control sites, with the Porter Ranch and Twitchell Dam sites as target sites. The linear and multiple-linear equations were then used to predict the expected average of the Porter Ranch and Twitchell Dam December-March precipitation for 27 previous seasons in which seeding was conducted to impact the Huasna-Alamo target area.

The resultant observed/predicted ratios for the combination of the 27 seeded seasons were both 1.09 for the linear and the multiple-linear equations. This ratio suggests an average 9% precipitation increase for the December – March period at the Porter Ranch and Twitchell Dam sites in the seeded seasons. These results are equivalent to approximately an average of 1.1 inches of additional December – March rainfall based on the linear and multiple-linear equations. Application of the one-tailed Student's t test suggests that there is a 28-29% probability that these differences are due to chance.

Due to some potential concerns with the Porter Ranch data, calculations were made of the apparent effects of cloud seeding by only using Twitchell Dam to represent the Huasna-Alamo target area. The resulting observed over predicted ratios were both 1.17 for the linear and multiple-linear regression equations, suggesting a 17% increase with an average of 2.0 inches of additional rainfall per season. Application of the one-tailed Student's t test suggests that there is only a 14% probability that this difference was due to chance. NAWC interprets this to mean that the difference is likely due to the cloud seeding program.

8.3 Discussion of the Indicated Results

The historical target/control regression technique offers one means to estimate the effects of cloud seeding from operational cloud seeding programs. As applied to the Santa Barbara program a few considerations should be kept in mind:

- More than two precipitation gauges in the two target areas and more than three control gauges would have been highly desirable. More gauges would provide better information on the distribution of rainfall in the target and control areas. For example, how representative are two sites considering the size and differences in topography of the two target areas? Due to the requirement for sites with long periods of record and the complications of earlier cloud seeding programs being conducted over Santa Barbara County before the operational seeding began, a number of potential precipitation gauges in the target and control areas were eliminated from consideration.
- The length of record for the selected target and control gauges is important. NAWC's experience has been that longer periods (preferably more than 20 seasons) of record from the historical not-seeded period lead to the development of more accurate regression equations. There were only 12 historical seasons available for analysis in the Huasna-Alamo analysis. Equations with high r^2 values and low standard errors provide more accurate estimates of any potential seeding effects. This would indicate that the evaluations of the Upper Santa Ynez program may be somewhat more accurate that those conducted for the Huasna-Alamo target area.
- It is encouraging that the results from the linear and multiple-linear regression equations were quite similar for both target areas. Such similarity using different mathematical techniques increases the level of confidence in the results.
- The potential average amounts of increases in seasonal rainfall are likely underestimated since these estimates were made for a four-month, December through March period but the programs in Santa Barbara County are frequently conducted for the five-month period of November 15th though April 15th each seeded season.

- Any positive seeding impacts on any of the control sites during the seeded seasons would raise the predicted "natural" precipitation thus lowering any estimated increases due to the seeding.

The individual season's results are rather variable even with relatively high r^2 values as demonstrated in Figures 4 and 5. These figures indicate high season-to-season variability in the indicated results of seeding using the historical target/control evaluation technique. Even when the regression equation correlation coefficients are relatively high, there can still be significant variability in the predictions. Whether some of this variability is due to different seeding effectiveness from season to season is unknown. Different predominate storm tracks in different seasons can impact the results. Some winter seasons may contain more "seedable" storm periods than others. For these and other reasons, NAWC focuses on the accumulated results (e.g. average or mean values) derived from a number of seeded seasons rather than focusing on individual season's results such as those provided in Table 1. It may take 15-20 or more seeded seasons to reach the point where the indicated results seem to stabilize (Silverman, 2007).

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