Annual Cloud Seeding Report

Santa Ana Watershed Project Authority
Cloud Seeding Pilot Program
2023-2024 Winter Season

Prepared For:

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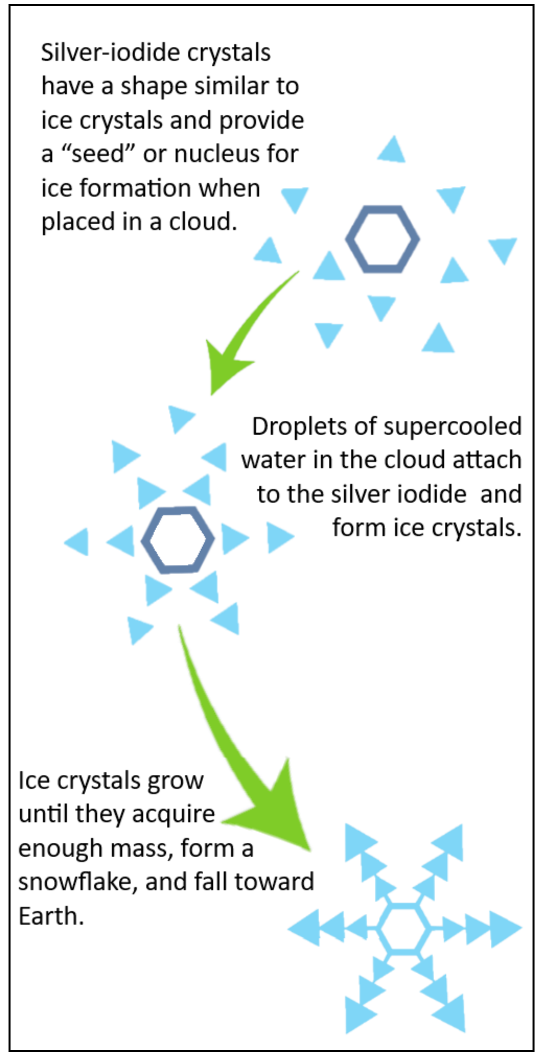
Table of Contents

The Science Behind Cloud Seeding

The Science

The cloud-seeding process aids precipitation formation by enhancing ice crystal production in clouds. When the ice crystals grow sufficiently, they become snowflakes and fall to the ground.

Silver iodide (AgI) has been selected for its environmental safety and superior efficiency in producing ice in clouds. Silver iodide adds microscopic particles with a structural similarity to natural ice crystals. Ground-based and aircraft-borne technologies can be used to add particles to the clouds.

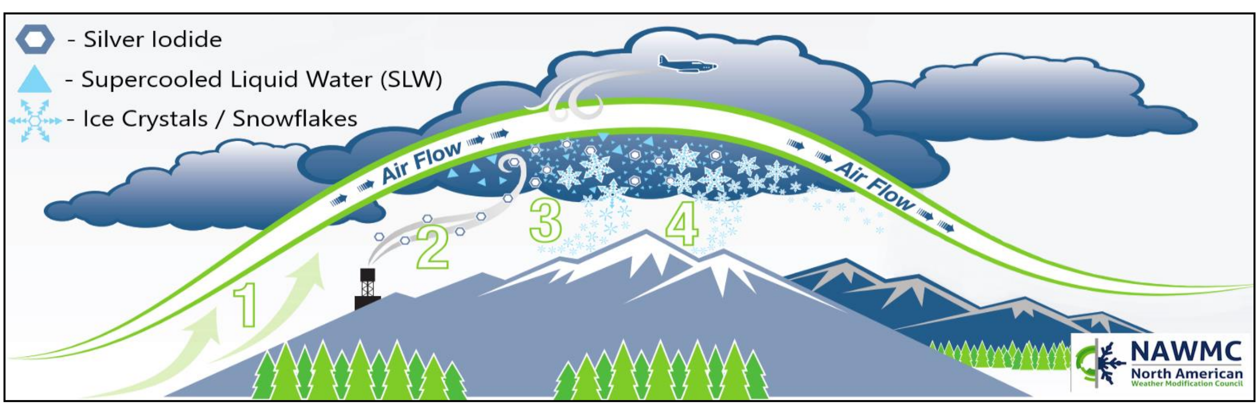


Safety

Research has documented that cloud seeding with silver iodide aerosols shows minimal impacts on the environment. Iodine is a trace element present in some foods and is added to some types of salt. Silver is both inert and naturally occurring. The amounts of silver released are far less than background silver already present in unseeded areas.

Effectiveness

Numerous studies performed by universities, professional research organizations, private utility companies, and weather modification providers have conclusively demonstrated the ability for silver iodide to augment precipitation under the proper atmospheric conditions.



EXECUTIVE SUMMARY

The first season of the Santa Ana Watershed Project Authority's (SAWPA) Cloud Seeding Pilot Program (Pilot Program) began on November 15, 2023, and continued through April 15, 2024. The program focused on precipitation enhancement efforts to increase snowpack and rainfall for runoff in four designated target areas in the mountains within the Santa Ana River Watershed (SARW); three of these areas (San Gabriel, San Bernardino, and San Jacinto Mountains) were designated for snowpack enhancement above 3000 feet mean sea level (MSL). The fourth area (Santa Ana Mountains) was intended for rainfall and runoff above 2000 feet MSL near the coast. Fifteen ground-based cloud seeding site units were deployed in the SARW: 12 Cloud Nuclei Generators (CNGs) and three Automatic High-Output Ground Seeding (AHOGS) units. A map of the program target areas and ground-based cloud seeding units are shown in Figure 1.

The 2023-2024 season was active, with 20 storm event periods. Of these, operations of cloud seeding occurred for 13 storm events. The storms were distributed relatively evenly across the season, with one "dry period" during the first three weeks of December 2023. A total of 13 seeded storm events occurred over a combined period of 22 days. A total of 2135.25 hours of seeding time from all CNG units was recorded, amounting to 17,082 g of silver iodide (AgI) used for seeding for the season. Additionally, a total of 32 AgI flares were used from the AHOGS units, totaling 640 g of AgI. One suspension period occurred during the season; from February 3-8, 2024, as a significant Atmospheric River event affected much of California bringing abundant mountain snow and heavy lower elevation rainfall resulting in significant flooding in some areas. There were also some severe weather events that included damaging winds, hail and tornadoes; none of these affected the SARW project area. A second period of active weather in mid-March 2024 also saw no seeding activity; this was not due to suspension criteria being enacted, but instead due to a wind flow pattern that the Pilot Program was not set up for as earlier studies showed the particular pattern to be a rare occurrence.

With the conclusion of the season, a review of all aspects of the Pilot Program was performed to assess the seeding operations, as well as identify areas where improvements can be made for future years. Recommendations for the Pilot Program going forward are presented at the end of the report.

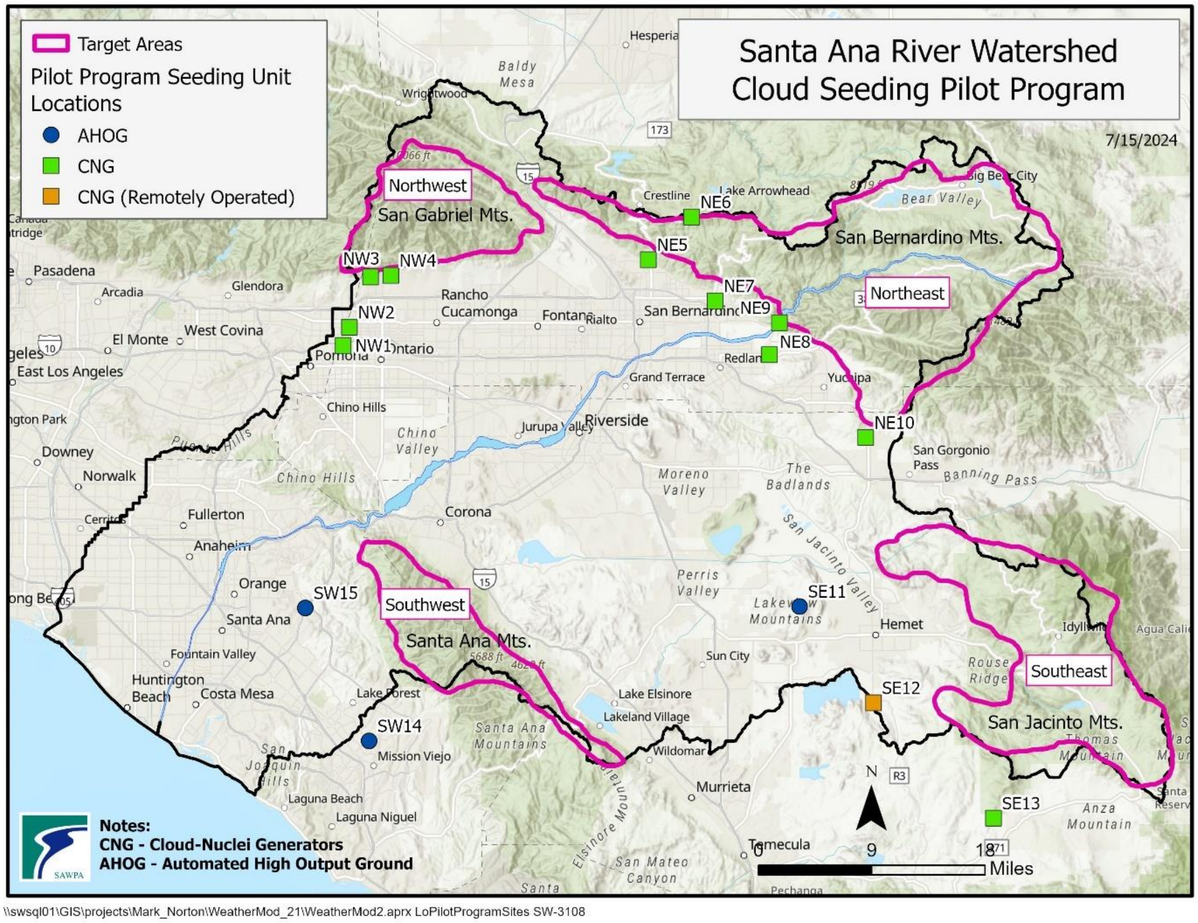


Figure 1. **SARW Cloud Seeding Pilot Program Project Area, consisting of 15 ground-based seeding units and four target areas (Northeast, Northwest, Southeast, and Southwest).**

1.0 INTRODUCTION

The Santa Ana Watershed Project Authority (SAWPA) is conducting a four-year Cloud Seeding Pilot Program (Pilot Program) in the Santa Ana River Watershed (SARW). The primary purpose of the Pilot Program is to validate the benefits of weather modification within the SARW, specifically within designated target areas, with the goal of producing additional precipitation – primarily snowfall in the higher elevations of the target areas and rainfall for some lower elevation target areas – resulting in additional runoff/streamflow for recharge as stormwater into groundwater basins. Using the results from the Santa Ana Watershed Weather Modification and Feasibility Study (SAWPA 2020) regarding the potential for a precipitation enhancement program in the watershed, a program was designed and implemented to conduct precipitation enhancement operations, with the 2023-2024 winter serving as the first season for the Pilot Program which ran from November 15, 2023, through April 15, 2024.

The duration of the first season was a five-month period with 15 ground-based cloud seeding units installed and utilized for cloud seeding operations. The target areas are located within four mountain ranges located within the Santa Ana Watershed and surrounding the Inland Empire, specifically at locations above 3000 feet MSL for three of the target areas (San Gabriel (northwest), San Bernardino (northeast), and San Jacinto Mountains (southeast)) where snowfall occurs each winter, and above 2000 feet MSL for the southwest target area (Santa Ana Mountains) which sees rain (snow on rare occasions).

This report covers the first season of cloud seeding activities for the Pilot Program during the 2023-2024 winter season. Section 2 discusses the program design used for the Pilot Program and subsequent equipment installation. Section 3 provides information on the meteorological data used to conduct operations of the Pilot Program. Section 4 reviews the storm events and seeding operations from the first operational season. A summary and recommendations for future seasons are provided in Section 5.

SAWPA has contracted with the Desert Research Institute (DRI) to conduct the validation of the additional precipitation and runoff of the Pilot Program, which will be provided in an independent report. The Pilot Program is operated consistent with the needs of the validation study.

2.0 PROJECT DESIGN

2.1 Background

In 2020, SAWPA completed a weather modification feasibility study for the Santa Ana River Watershed (SARW) located in southwest California (SAWPA, 2020). In the study, four potential target areas – mountainous regions within the SARW and surrounding the Inland Empire – were identified for cloud seeding operations that could contribute to seasonal runoff and streamflow. Storm events from five winter seasons were analyzed and detailed climatology was developed. Based on the climatological assessment, an array of seeding sites for the four target areas was created, established on their common upwind location from their intended target areas.

Two methods of ground-based cloud seeding were considered. The first method incorporates manually operated ground-based Cloud Nuclei Generators (CNGs), which burn a solution of silver iodide (AgI). The CNGs create a continuous plume of seeding material that provides broad coverage over primarily mountainous terrain through orographic lift. The second method of seeding from the ground incorporates proprietary units called Automatic High Output Ground Seeding (AHOGS) systems. These remotely operated units use burn-in-place flares that release a high concentration of AgI rapidly and are ideal for seeding convective bands with high concentrations of supercooled liquid water (SLW) and strong turbulence.

Additionally, aerial seeding was assessed, with two flight tracks developed for the two northern target areas. The use of a plane allows for the immediate release of seeding agents such as AgI at the most desirable location within a cloud. Though highly effective, aerial seeding can be cost prohibitive and requires special permits and approvals from the Federal Aviation Administration (FAA).

With both ground and aerial seeding design completed, advanced computer modeling was utilized for a subset of the previously analyzed storm events to model the movement of seeding plumes from both ground and air, with adaptations made to seeding unit location and flight tracks until results indicated successful dispersion of seeding agents over the target areas for a variety of storm conditions. Estimated increases in precipitation and streamflow were determined, and costs were estimated to calculate a benefit to cost ratio for the proposed program. It was determined that the program, as designed, would be technically feasible, with a ground-only program having a benefit to cost ratio of 10:1. The feasibility study concluded with a recommendation to implement a ground-only program and eventually expand into a ground and aerial program as needs for additional water supply increase.

Based on the results of the feasibility study, SAWPA approved a four-year pilot program to evaluate the potential benefits of cloud seeding in the watershed.

2.2 Seedability Criteria

Under the Pilot Program selective cloud seeding is conducted during winter storm events, which is the most efficient and cost-effective method. Selective seeding is conducted only during specific time periods and in specific locations where cloud seeding is likely to be effective. This decision is based on several criteria which determine the seedability of the storm. These criteria involve the characteristics of the atmosphere including temperature, stability, and wind flow, both in and below the clouds. The moisture content of the atmosphere, including cloud types and occurrence of supercooled liquid water (SLW) are crucial factors during seeding operations. Certain heavier storm periods may not be seeded due to factors which make the storm naturally efficient at producing precipitation. Other storm periods can be deemed unfavorable due to several factors including temperature, stability, or wind direction. The use of this focused seeding method has yielded consistently favorable results with very high cost/benefit ratios for projects conducted in the western United States.

The general criteria are as follows:

- Cloud bases are below the mountain barrier height.
- Low level wind speed and direction that would favor the transport of silver iodide seeding material, from its release locations into the target area.
- The absence of low-level inversions or stable layers that would restrict the vertical movement of silver iodide from the surface to the -5°C level (23°F) or colder.
- Temperatures at the 700 millibar (mb) level are warmer than -15°C (5°F)
- Presence of convective bands (for AHOGS usage) or distinct convective cells

The design of operational programs is also be based upon prior research programs that provided positive indications of increases in precipitation, to the extent that the research results are representative of the operational programs' conditions. This assumes research results from one location are transferable to the operational program's target area(s), a reasonable assumption if the topography and climate of the two areas are similar. This philosophy has worked well for additional programs in California, for example, Santa Barbara, Fresno (Kings River), Los Angeles (San Gabriel Mountains), and Upper American River Basin.

Building on the above criteria, a checklist of operational criteria to be considered on a storm-by-storm basis was developed, and it is presented as a tracking table in Table 2-1. This checklist was completed for each storm event and is provided in Appendix A.

Table 2-1
Operational Criteria Checklist/Tracking Table

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.		
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).		
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.		
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.		
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.		
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).		
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused		

2.3 Project Setup and Equipment

The design of the Pilot Program was based on the feasibility study (SAWPA, 2020). Locating the ground-based units entailed site visits and discussions with various public agencies, as well as private landowners. Program site sponsors entered into land lease/operator agreements wherein ground-based cloud seeding units would be installed on their property securely, and individuals within these agencies/sponsors would serve as operators.

Thirteen ground-based units were located on properties owned by watershed utilities and two of the units were installed and operated by private landowners, who also entered into land lease/operator agreements. Site review was performed at all locations to determine if site preparation work, such as concrete, grading or ground preparation work were needed to be done prior to unit installation and if additional site securing (e.g., fencing) was needed.

A biologist conducted preliminary and final biological surveys in July and October 2023, respectively, in response to the mitigation measures outlined in the Mitigation Monitoring and Reporting Plan based on the Initial Study and Mitigated Negative Declarations (IS/MND) prepared following a CEQA (California Environmental Quality Act) evaluation (SAWPA, 2022). No significant findings were identified by the biologist and mobilization/installation was scheduled for October 2023.

Sites were selected that were as close to locations from the feasibility study (SAWPA, 2020). In several instances, project sponsors located close to the feasibility study's proposed site locations were selected for installation of the ground-based cloud seeding units. Figure 2.1 shows the location of the seeding unit sites that were selected and the locations of the target areas of interest. Two changes that were made for the Pilot Program that were different than what was presented in the feasibility study (SAWPA, 2020) included the addition of another CNG unit for the Northwest (NW) Target Area, and the switch of one of the CNG sites for the Southeast (SE) Target Area to an AHOGS site, as it was determined that this area may benefit from convective lines pushing in from the coast. This increased the total number of seeding units from 14 to 15, with 12 CNG units and three AHOGS units. Table 2-2 provides information on site location and elevation above MSL.

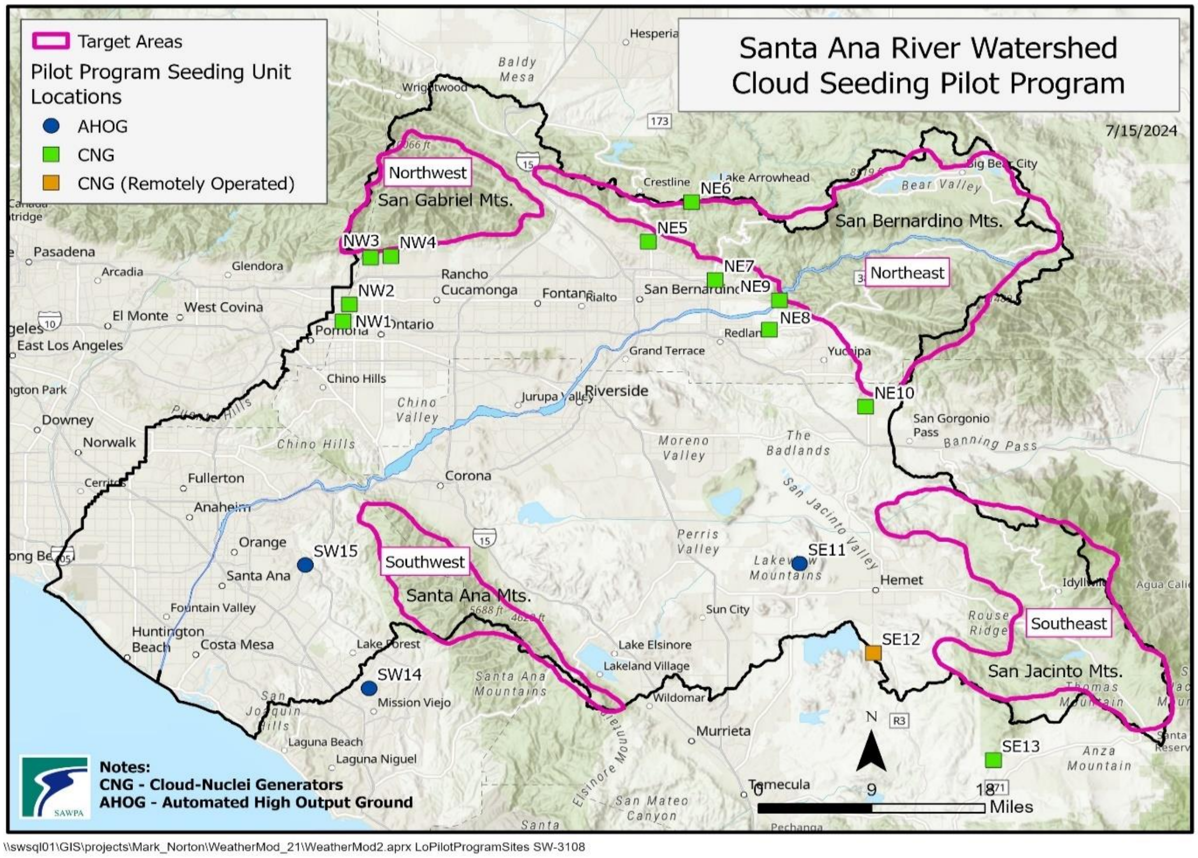


Figure 2.1. **Map of Target Areas and Ground-Based Seeding Site Locations. Legend denotes the type of cloud seeding unit.**

Table 2-2
Seeding Site Locations

Site	Name	Latitude (N)	Longitude (W)	Elevation (feet)
NW1	Chino Basin WCD Montclair #4	34° 04.75'	117° 42.31'	1030
NW2	Chino Basin WCD Upland/College Heights	34° 06.03'	117° 41.81'	1239
NW3	San Antonio Water Co. – East	34° 09.66'	117° 38.44'	2174
NW4	San Antonio Water Co. – West	34° 09.50'	117° 40.24	2250
NE5	San Bernardino – Sycamore WP	34° 10.81'	117° 16.96'	1599
NE6	Rimforest	34° 13.77'	117° 13.35'	5654
NE7	SBVMWD Highland/Summertrail Place	34° 07.96'	117° 11.39'	1435
NE8	SBVWCD Mentone/Mill Creek	34° 04.24'	117° 06.86'	1841
NE9	SBVWCD Santa Ana Dam	34° 06.45'	117° 06.04'	1963
NE10	San Gorgonio Pass WA – Cherry Valley	33° 58.52'	116° 58.89'	2830
SE11**	EMWD N – Balher Booster	33° 46.83'	117° 04.39'	2189
SE12*	EMWD S – Searle Tank II	33° 40.17'	116° 58.26'	1867
SE13	Lakeshore	33° 32.17'	116° 48.32'	3681
SW14**	El Toro WD – Reservoir	33° 37.35'	117° 40.15'	624
SW15**	EOCWD	33° 48.19'	117° 48.83'	288

* Remote CNG ** AHOGS unit

Two forms of ground-based seeding units were utilized for operations. The first and primary unit used in the Pilot Program were Cloud Nuclei Generators (CNGs), which use propane as a fuel source and contain a silver iodide (AgI) solution that burns when ignited and disperses AgI particles into the air. The solution is designed to be a fast-acting nucleation agent via the condensation-freezing mechanism versus the slower contact nucleation mechanism. This is important as some of the mountain barriers/portions of the Target Areas are relatively narrow. Figure 2.2 shows one of the manually operated CNG units.

Figure 2.2. Cloud Nuclei Generator (CNG) on the left side with propane tank at site NE10.

The second method of ground-based cloud seeding is designed to target convective cells that are developing and/or moving across the area, primarily as bands of convective cells. Quick, high-output amounts of AgI are desired for these elements to induce a positive seeding effect, as convective cells do contain supercooled liquid water (SLW), and in some cases at fairly high concentrations. Most convective bands observed will be associated with a cold front, but in some instances short convective lines develop in areas of convergence not associated with a front, and these can be targeted as well. For these situations, units that hold high-output silver iodide flares, called Automatic High Output Ground Seeding (AHOGS) systems are used.

AHOGS consist of flare trees that hold the high output flares, a camera and battery that allows for remote operation of the unit. Each flare on the tree is housed within a cylinder called a spark arrestor, which prevents any wayward sparks from the burning flares from dropping to the ground but allows the particles in the smoke to freely disperse. When convective bands or cells approach, the unit is activated and flares are burned depending on the size and intensity of the convection as indicated on radar, and convective currents or inflow/updrafts ahead of the convection carry the silver iodide particles upward into the cloud where they activate. Figure 2.3 shows one of the AHOGS units. AHOGS target convective cells, so their intended effect is to increase the rainfall and potentially help capture stormwater runoff that can be recharged into local groundwater basins, in the case of this specific unit, within or near the Southwest (SW) Target Area. Two other AHOGS units were utilized, one also in Orange County situated to target the SW area as well, and a third west of San Jacinto, which targets either the Southeast (SE) or Northeast (NE) areas.

Figure 2.3. Automatic High Output Ground Seeding (AHOGS) unit located at site SW14.

2.4 Personnel

Several individuals were tasked with running the program during the first season:

Todd Flanagan – Chief Meteorologist/Project Manager

Todd Flanagan served as the dedicated project meteorologist, managing the daily operations. Weekly forecasts for the program area were prepared by the meteorologist, with more focused and detailed daily forecasts ahead of and during storm events that also informed site operators of their need to be ready for activation. When seedable storm systems approached the project area, the meteorologist was tasked with contacting the operators to start/stop their respective units and field any additional necessary contact with them. Run times of all units were tracked and recorded, as well as meteorological conditions and operational notes pertaining to the storm event. Archiving of meteorological data and whether seeding occurred or not was completed. Seeding event reports as well as monthly reports on operations were completed and disseminated. As the project manager, ensuring that all components of the project were maintained in full operational readiness was the main task; this included making sure all ground-based cloud seeding units were properly serviced and kept in operational status, and any problems or malfunctions were communicated with the Technical Director and field technicians.

Jared Smith – Technical Director/Field Technician

Jared Smith served as the main contact on issues relating to contracts, site reconnaissance and site improvements, subcontractor coordination as well as a coordinator with all technicians. He sometimes served as the field technician when needed, but primarily advised the other field technicians from NAWC on issues related to servicing of the ground-based cloud seeding units when needed.

Carver Cammans/Parker Wall – Field Technicians

Carver Cammans and Parker Wall are both field technicians employed by NAWC and were dispatched from Utah to the SARW when needed during the season to trouble-shoot and address any problems with the cloud seeding units, refill CNGs with seeding solution and replace flares in the AHOGS.

Seeding Unit Operators

Operations of the cloud seeding units were directed by the meteorologist/project manager and any problems that were encountered during start-up or shutdown of the units were reported to the meteorologist/project manager by the site operators. A total of 11 manually operated CNGs were operated during the Pilot Program. Four manual CNGs were operated by three site sponsor staff that housed the units on their properties. Five manual CNGs were operated by a NAWC-contracted operator to operate units that were housed on site sponsor properties. Two manual CNGs were operated by two private landowners who housed the units on their respective properties. Three AHOGS units and one remotely operated CNG unit were operated by the meteorologist.

2.5 Suspension Criteria

Suspension criteria are used to ensure the safety of the public and property. Project-specific procedures for the suspension of cloud seeding operations are evaluated for all storms. Those criteria are provided in Appendix B. During the 2023-2024 seeding program, there was one period wherein a program suspension was deemed necessary; in early February 2024, a significant Atmospheric River event affected much of California, including the SAWPA program. Unusually heavy precipitation was expected and given the considerable risk for flooding, it was determined that seeding operations would not be beneficial to the area, particularly as the storms during this period were already producing precipitation (both rain and snow) at maximum efficiency. Further information about this storm period can be found in the Operations section (Section 4) of this report.

3.0 WEATHER DATA AND MODELS USED IN SEEDING OPERATIONS

Meteorological information is acquired from a wide variety of sources, including some subscriber services. This information includes radar data, satellite data (e.g., visible, infrared, water vapor) weather forecast model data, surface observations, rawinsonde (weather balloon) upper-air soundings, and weather cameras. NAWC's meteorologists have access to all meteorological products on a 24-hour basis, allowing for continued monitoring so that seeding operations can be performed at any time of the day or night. The wide variety of available meteorological data products and information provides the data necessary for meteorologists to determine when conditions are appropriate for cloud seeding.

Figures 3.1 – 3.7 show examples of a subset of the available weather information that was used in this decision-making process during the 2023-24 winter season. In Figure 3.1, radar imagery from Santa Ana, California (KSOX) is shown. Radar data provides the meteorologist with information about coverage and intensity of precipitation, measured by the amount of the radar's beam which reflects off hydrometeors (i.e., precipitation) and returns to the radar.

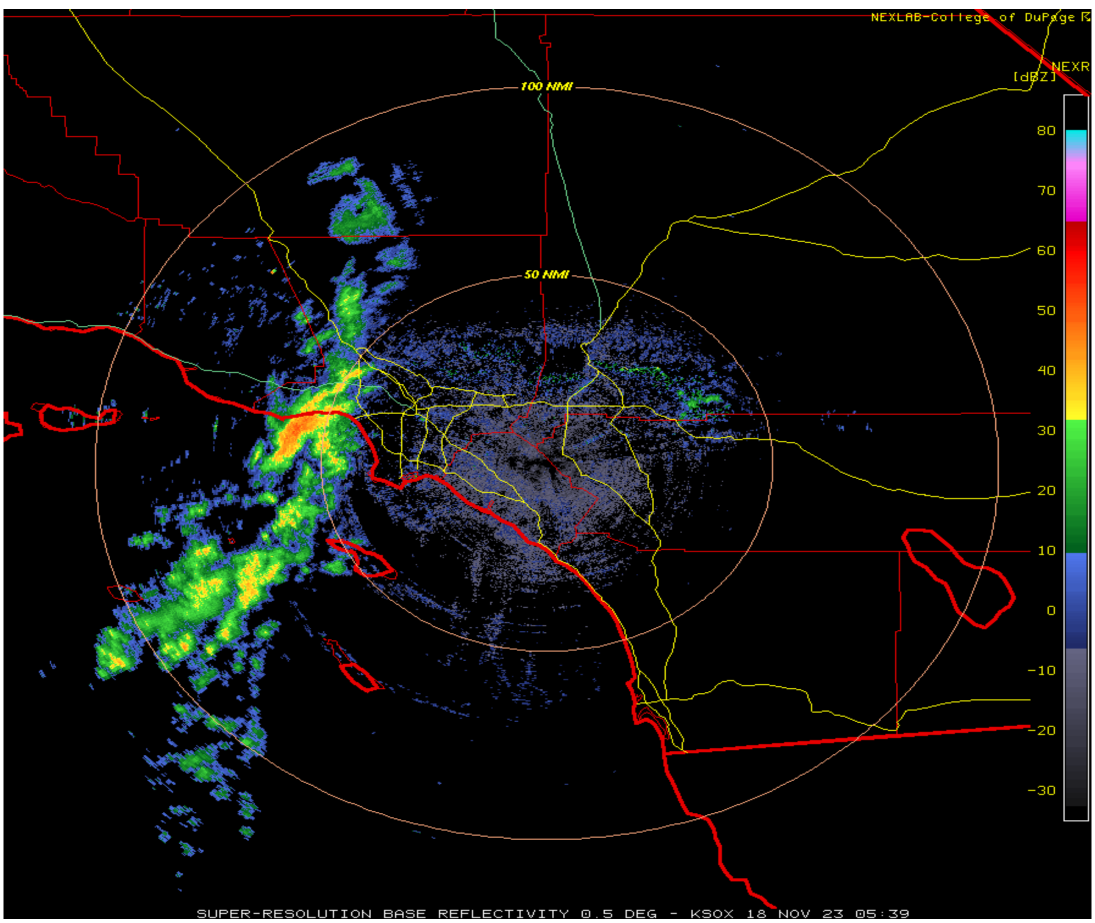


Figure 3.1. **Weather radar image from Santa Ana (KSOX) during a storm event on November 18, 2023, at 2139 PST (0539 UTC). The scale on the right shows reflectivity (power of returned echoes from reflecting off hydrometeors), which indicates precipitation intensity.**

Figure 3.2 shows a visible spectrum satellite image wherein clouds are visible because of the sunlight; visible imagery can show various cloud types (cumulus, stratus, etc.) embedded within storm systems, which may, for example, allow the meteorologist to determine if any convection is present which may benefit from using AHOGS flares for cloud seeding.

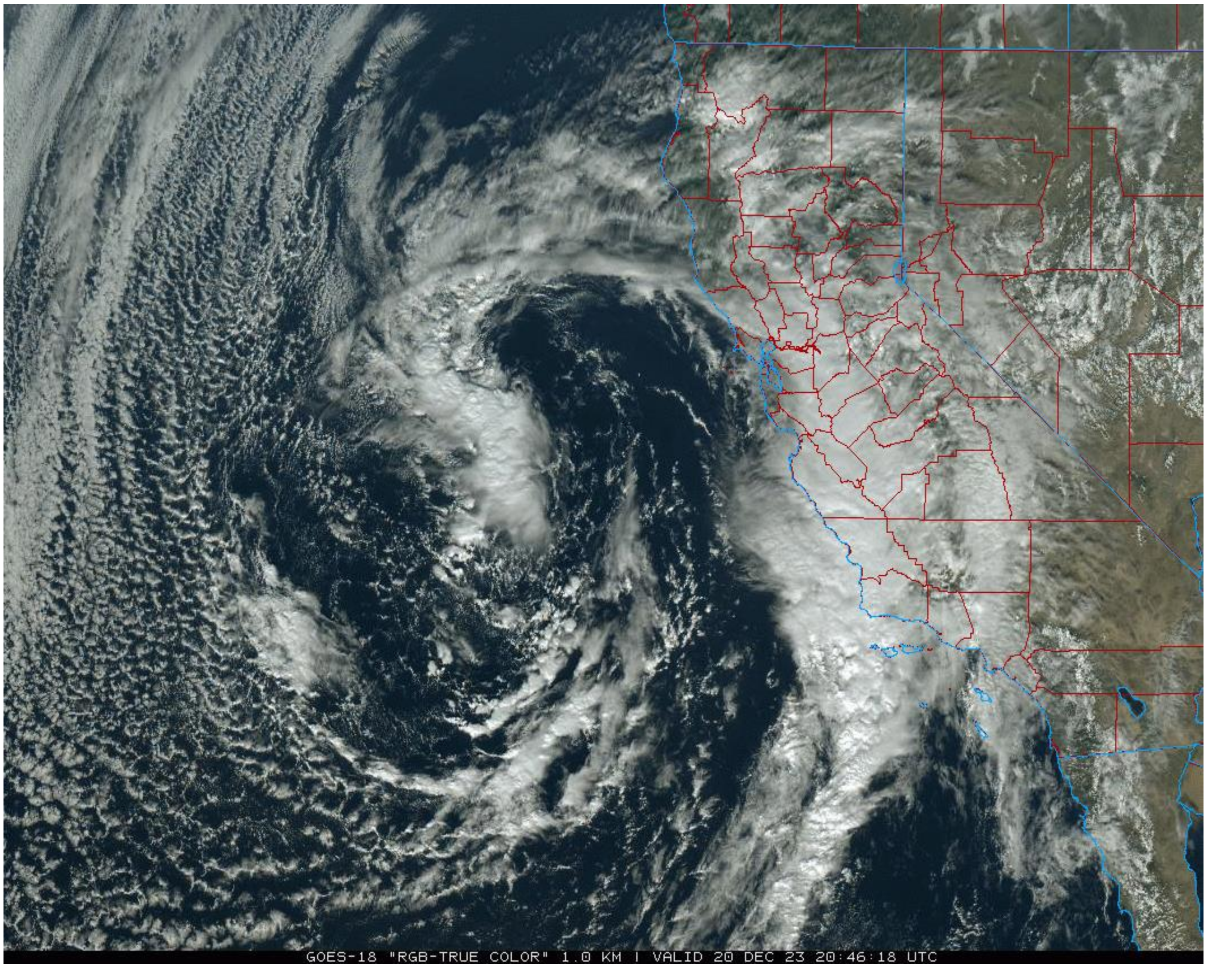


Figure 3.2. Visible spectrum satellite image on December 20, 2022, at 1246 PST (2046 UTC) showing an area of low pressure centered off the California coast with an area of enhanced cloudiness, the frontal boundary, pushing into southern California around Point Conception.

Another type of satellite imagery is shown in Figure 3.3: a water vapor satellite image. Water vapor imagery is important in showing areas of greater moisture content as well as regions of dry air. They can also reveal shortwave disturbances via swirls in the water vapor that may not appear in visible or infrared satellite imagery.

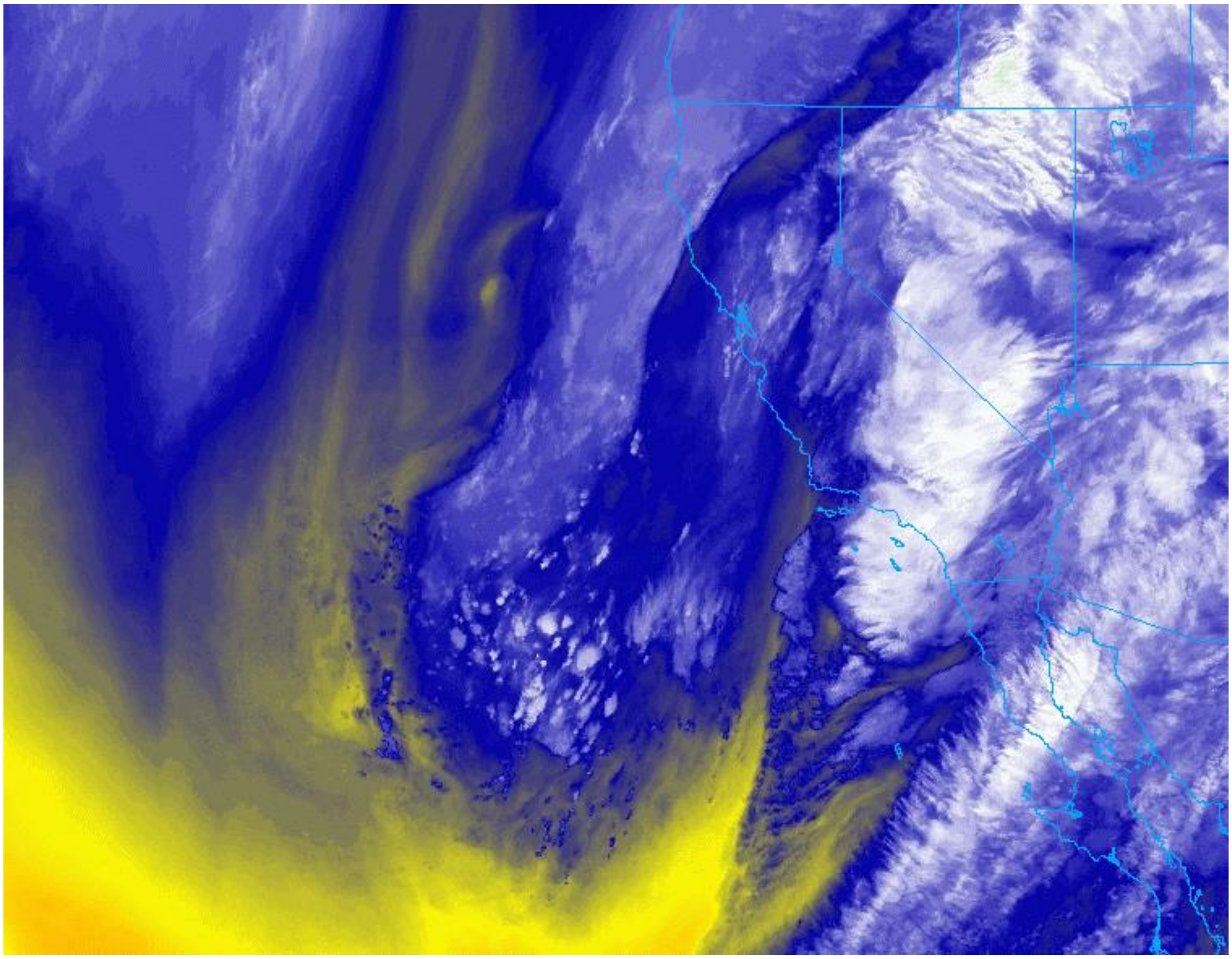


Figure 3.3. Water vapor satellite image on February 5, 2024, at 2201 PST (0601 UTC) showing concentration of atmospheric water vapor across the western United States and adjacent eastern Pacific. In the above picture, dry air is indicated by the yellow and orange colors, while moisture is shown in blue and white (white indicating the greatest amount of water vapor).

Figure 3.4 shows a surface observation map via MesoWest over the Inland Empire and adjacent mountain areas. Surface observations, which include temperature, dewpoint, wind speed and direction, cloud cover and precipitation and barometric pressure are very important as they can help the meteorologist identify features such as areas of convergence (looking at winds), moisture pooling (e.g., higher dewpoints in one area vs. another), mixing and location of fronts (changes in temperature and wind).

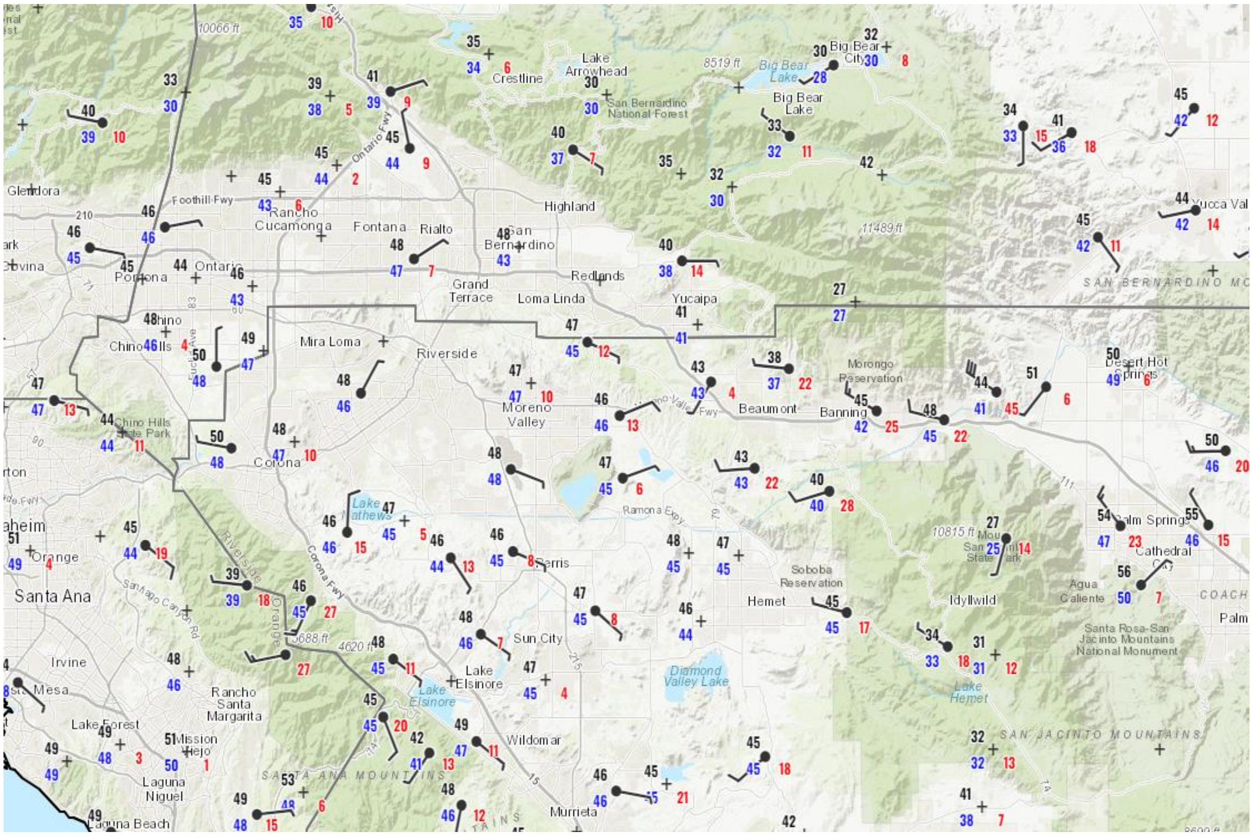


Figure 3.4. **MesoWest surface observation data map centered on the Inland Empire on February 6, 2024, at 1330 PST. In the above picture, black numbers represent temperature, blue are dewpoint, red are wind gusts, and the stick/barbs indicate wind speed and direction from which the wind is blowing. Courtesy of NWS/NOAA, https://www.wrh.noaa.gov/map/?obs=true&wfo=sgx .**

Figure 3.5 shows an example of an upper air weather balloon sounding or rawinsonde from San Diego (NKX). Soundings are important for the meteorologist as they can show the thermal profile of the airmass over the location sampled, which is important in cloud seeding as the presence of stable layers (i.e., temperature constant or increasing with height) can determine whether or not seeding plumes would be able to rise to cloud base, and how these plumes might travel as they rise and flow with the given winds at a particular altitude.

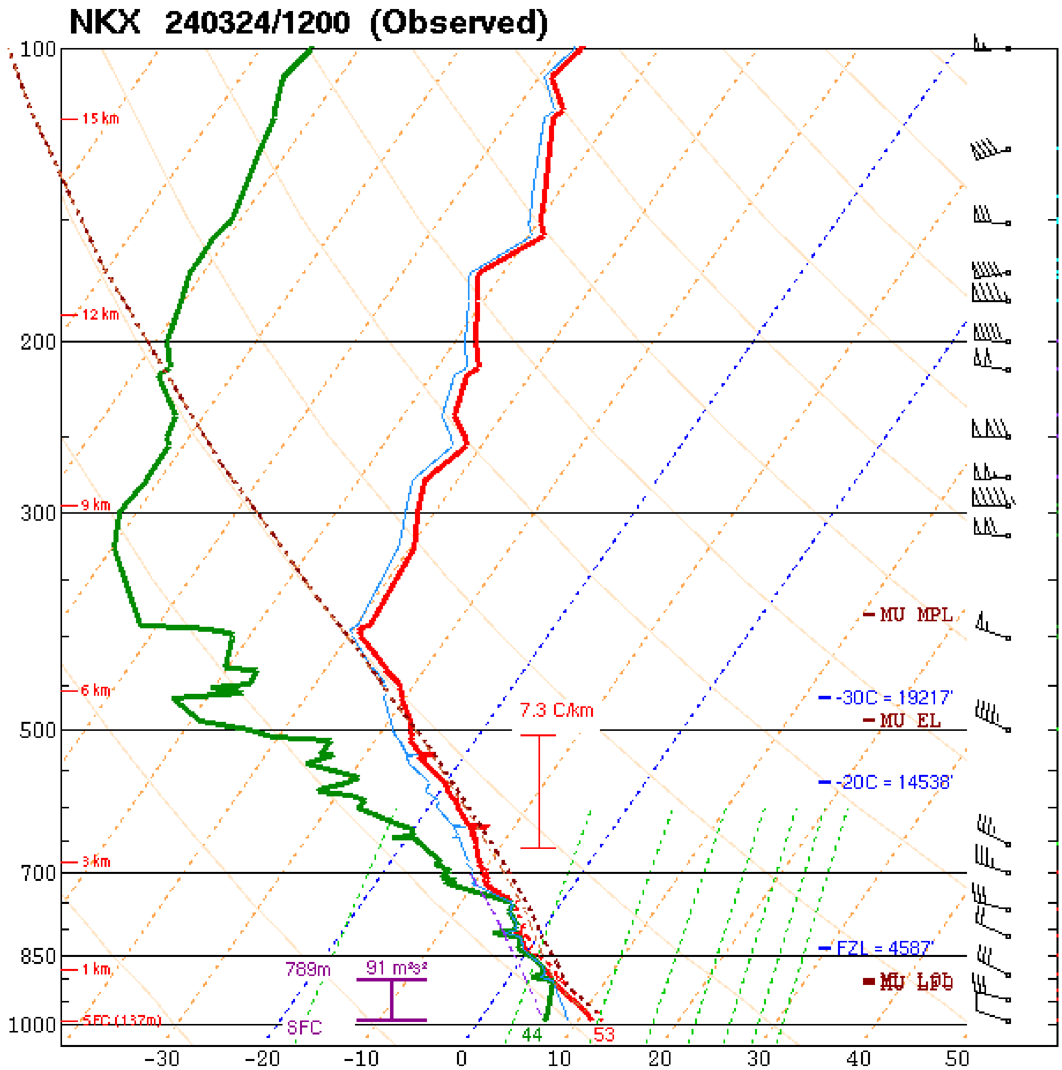


Figure 3.5. Weather balloon/rawinsonde sounding from San Diego (NKX), valid at 12Z/1700 PDT on March 24, 2024, showing temperature (red line), dewpoint (green line) and wind speed/direction (right side barbs) from the surface to 100 mb (approximately 52,000 feet MSL). Courtesy of Storm Prediction Center website, https://www.spc.noaa.gov.

Global and regional forecast models are a cornerstone of modern weather forecasting, and a crucial tool for operational meteorologists. These models forecast a variety of parameters at various levels of the atmosphere, including winds, temperatures, moisture, and surface parameters such as accumulated precipitation. Figure 3.6 is an example of a display from the Global Forecast System **(GFS)** model. Other models used on a daily basis during the Pilot Program include **but are not limited to** the European Center for Medium-Range Weather Forecast **(ECMWF)** model, High-Resolution Rapid Refresh **(HRRR)** model, North American Model **(NAM)**, and National Blend of Models **(NBM),** the last being a blend of both National Weather Service (NWS) and non-NWS numerical weather prediction model data. Figure 3.7 shows a forecast from the HRRR model for supercooled liquid water (SLW), the primary target of seeding operations.

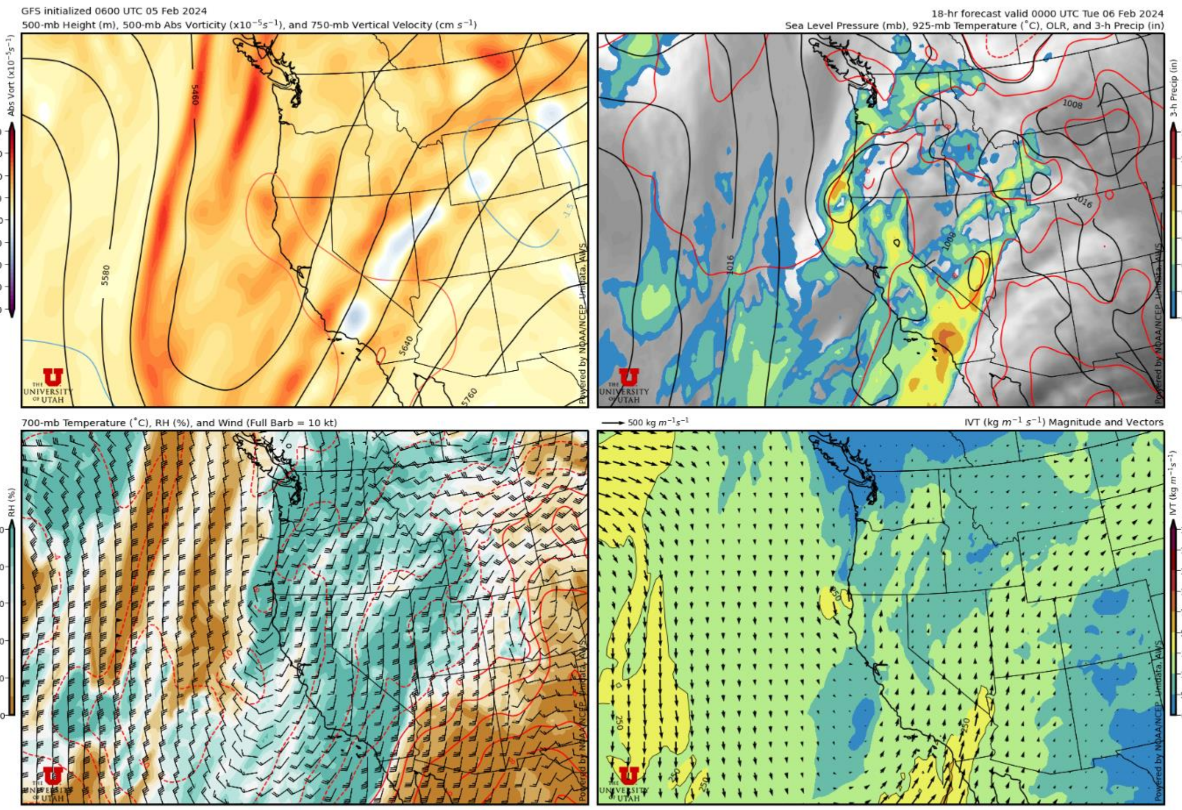


Figure 3.6. **GFS (Global Forecast Systems) model forecast (4-panel plot) valid 1600 PST (0000 UTC) on February 5, 2024. Courtesy of University of Utah weather website, https://weather.utah.edu .**

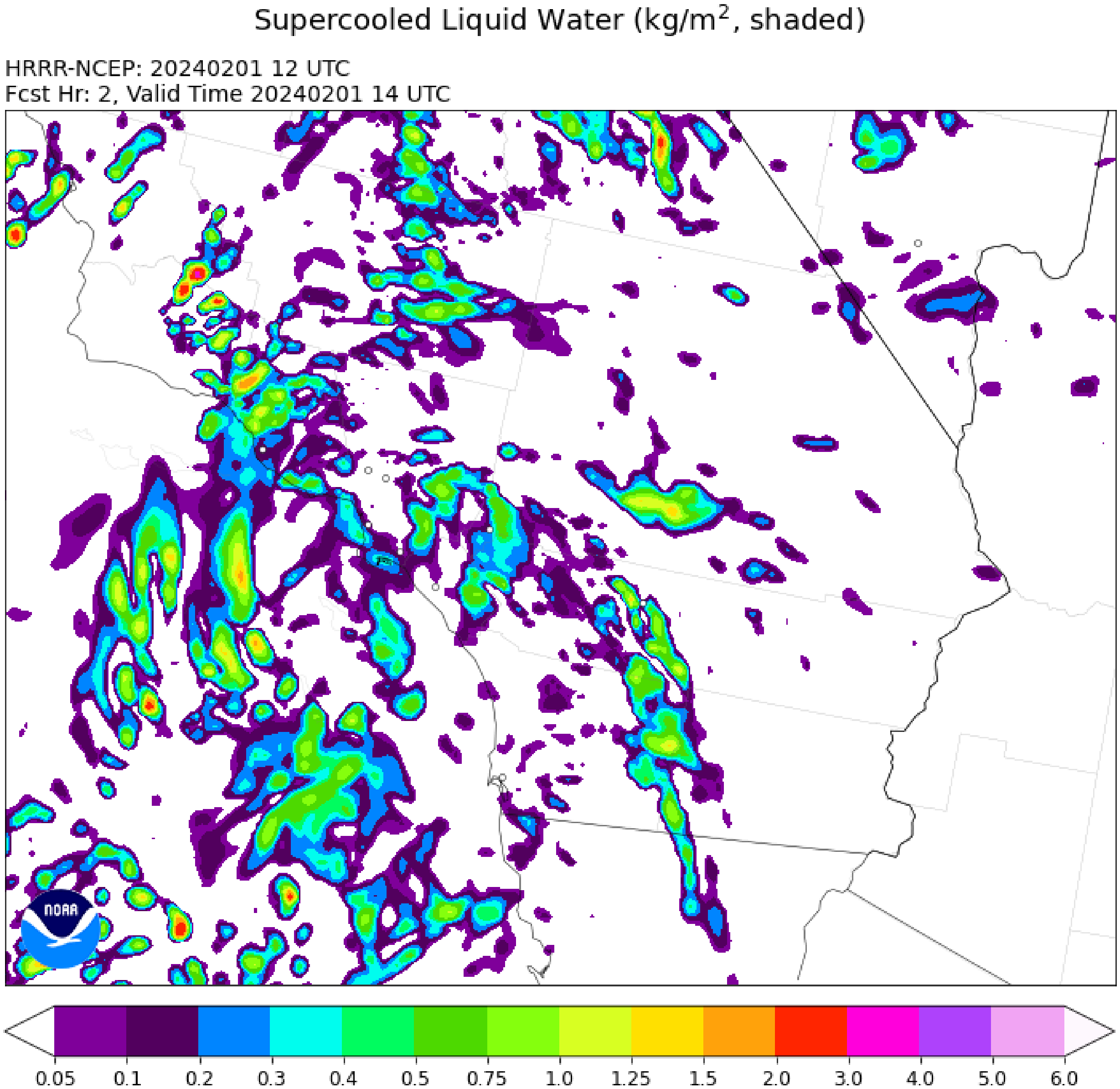


Figure 3.7. Two-hour forecast of Supercooled Liquid Water (SLW) over southern California, valid at 0600 PST (1400 UTC) on February 1, 2024. Shading indicates concentration of SLW (kg SLW per m^2 of air). Data courtesy of NOAA GSL's HRRR website, https://rapidrefresh.noaa.gov/hrrr .

Figures 3.8 and 3.9 illustrate the predictions of ground-based seeding plume dispersion for the SAWPA program using the National Oceanic and Atmospheric Administration's (NOAA) HYSPLIT (**HY**brid **S**ingle-**P**article **L**agrangian **I**ntegrated **T**rajectory) model. This model provides forecasts of the horizontal and vertical spread of a plume from potential ground-based seeding sites in real-time, based on wind and temperature fields contained in the weather forecast models.

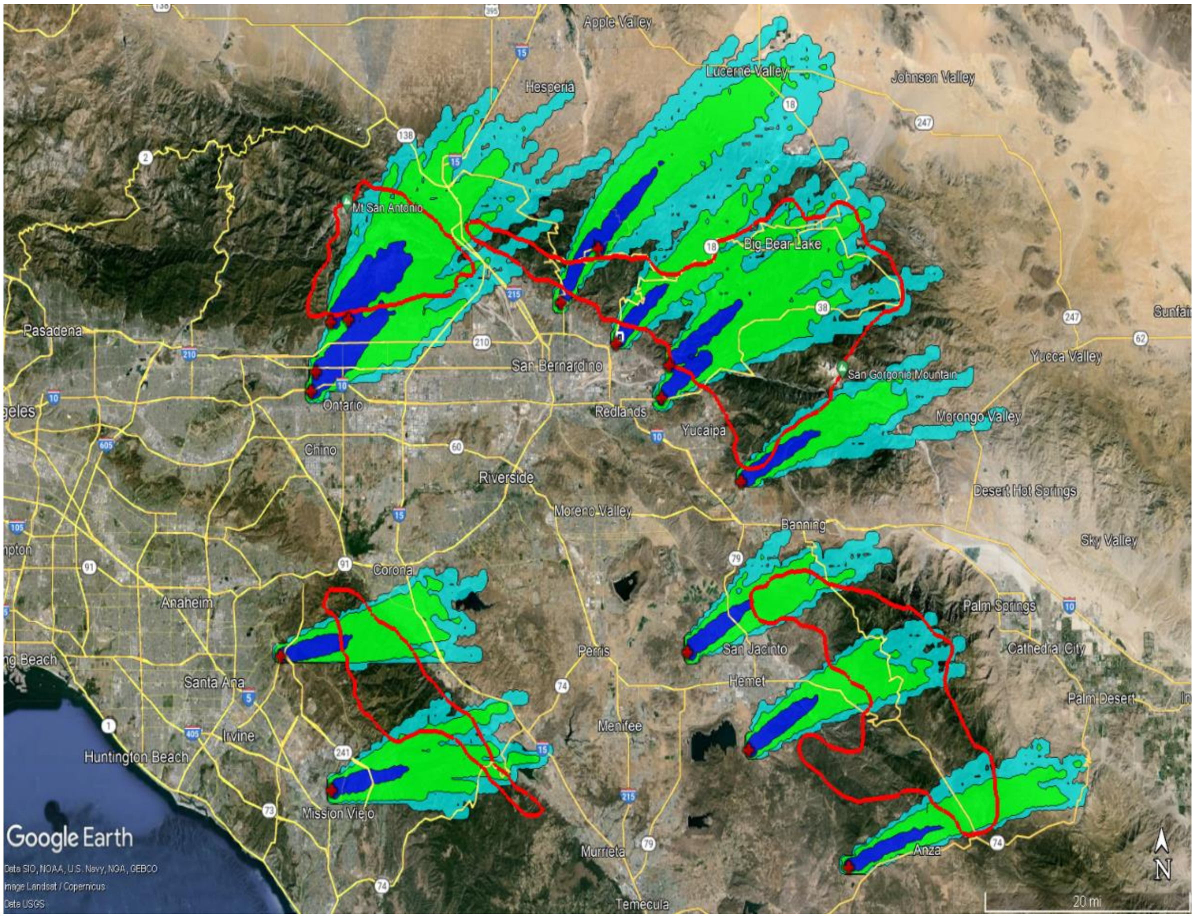


Figure 3.8. **HYSPLIT 1-hour horizontal plume dispersion forecast from SAWPA's seeding units for a storm event, valid on April 5, 2024, at 1300 PDT. Colors indicate the concentration of particles, blue being the greatest concentration followed by green and cyan.**

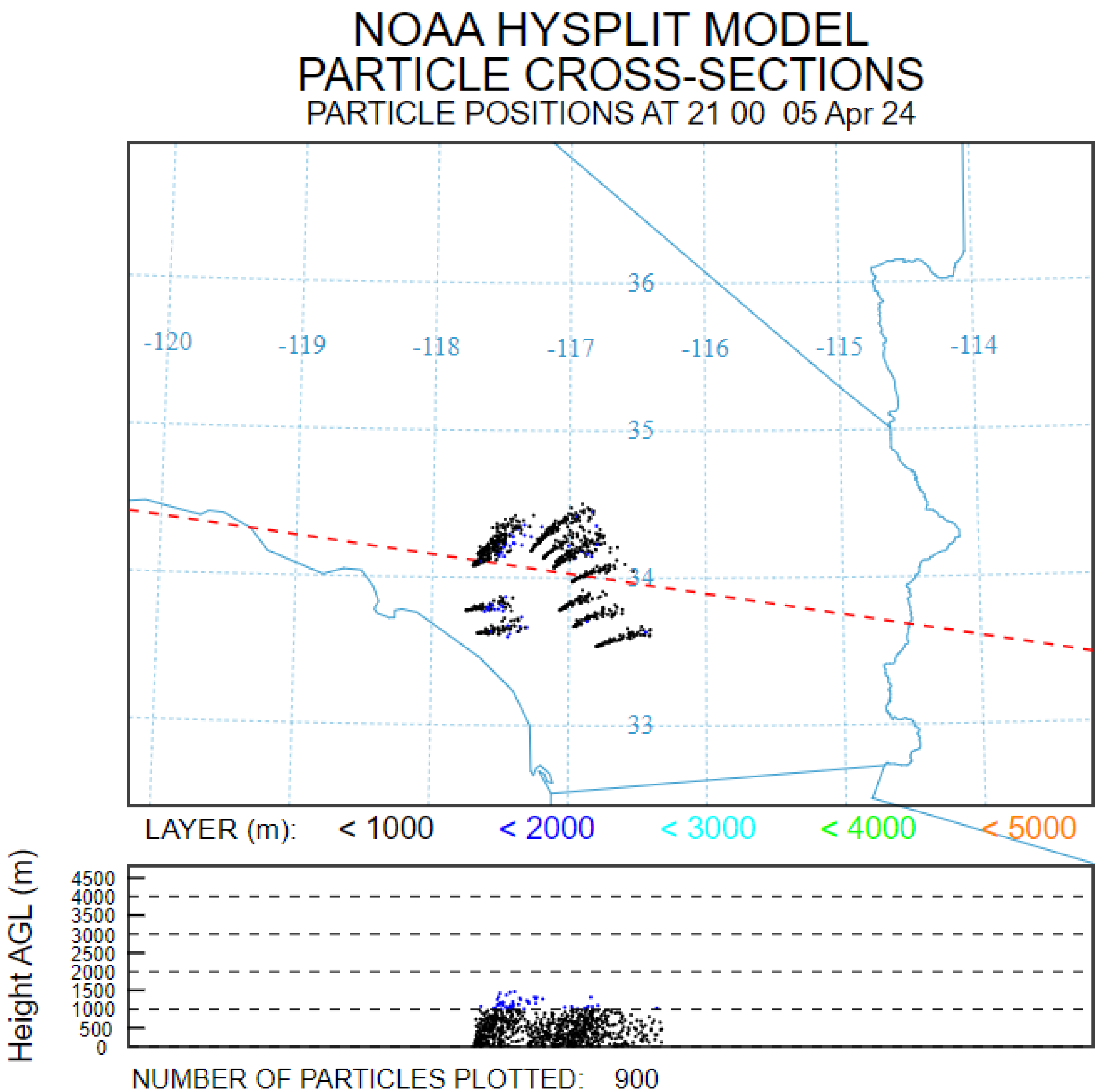


Figure 3.9. **HYSPLIT 1-hour horizontal (top) and vertical (bottom) plume dispersion from SAWPA's seeding units for same storm event and time as in Figure 3.8.**

4.0 OPERATIONS

The 2023-2024 cloud seeding Pilot Program began on November 15, 2023, and ended on April 15, 2024. During the season, there were 13 seeded storm events over a total of 22 days, broken down as follows:

Date	Number of Seeded Storms	Duration of Storms	Total Duration (days)
November 2023	1	Two consecutive days	2
December 2023	2	Two two-day storm events	4
January 2024	3	One one-day storm event; and Two two-day storm events, overlapping	4
February 2024	2	One one-day storm event; and One two-day storm event	3
March 2024	3	Three two-day storm events	6
April 2024	2	One one-day storm event; and One two-day storm event	3

A cumulative 2135.25 hours of seeding time from 12 CNG units occurred, along with a combined 32 AgI flares from the three AHOGS units. Table 4-1a and 4-1b show the dates and hours of CNG usage and flare burn during the season.

Table 4-1a
CNG hours and AHOGS flare usage November 2023 through February 1, 2024

	Nov 17-18	Dec 21-22	Dec 29-30	Jan 3	Jan 20-21	Jan 21-22	Feb 1
NW1			23.00	6.50		*	10.00
NW2			23.00	7.00		*	9.00
NW3	11.25	22.00	21.00	5.75	*	*	23.50
NW4	13.25	20.75	22.00		*	*	23.00
NE5		26.50	21.25	8.75	17.25	24.50	*
NE6		21.50	9.00	12.25	17.00	14.25	11.75
NE7		22.75	21.00	9.00	17.00	*	*
NE8		22.25	18.75	9.75	18.50	23.25	7.75
NE9		23.00	18.75	9.50	18.25	23.25	8.00
NE10		24.25	21.25	9.25	17.75	24.75	11.50
SE12		8.75	5.50	9.75	*	*	14.00
SE13		19.00	6.50	8.00	15.25	24.50	12.25
SE11		5 flares		2 flares		4 flares	1 flare
SW14		1 flare	3 flares		1 flare	3 flares	
SW15						*	

*** Units were not operated or operated at a reduced level due to operational issues.**

Table 4-1b
CNG hours and AHOGS flare usage February 20, 2024 through April 2024

	Feb 20-21	Mar 6-7	Mar 23-24	Mar 30-31	April 5	April 13-14
NW1	16.75	16.00	22.00	30.00	12.75	7.00*
NW2	16.25	*	20.25	*	9.25	7.00*
NW3	19.50	14.00	22.50	26.75	8.50	24.75
NW4	19.75	14.00	22.50	27.75	8.50	25.00
NE5	*	17.00	22.75	31.25	12.25	25.50
NE6	18.25	14.00	18.00	31.25	14.00	20.25
NE7	23.00	17.75	22.75	31.25	12.50	25.50
NE8	*	15.00	20.50	*	13.00	25.00
NE9	20.50	*	20.25	32.25	12.75	25.50
NE10	24.25	18.75	22.50	31.25	12.25	25.25
SE12		17.00	4.75*	33.00	9.00	
SE13		12.75	18.25	32.75	12.75	
SE11				1 flare	1 flare	
SW14		1 flare		2 flares	2 flares	
SW15		2 flares			1 flare	2 flares

*** Units were not operated or operated at a reduced level due to operational issues.**

Precipitation during the season was above normal. A strong El Niño signal was present in the Equatorial Pacific, and this may have affected the intensity of storms impacting southern California particularly during the middle portion of the season. Table 4-2 shows precipitation for selected sites within the four-target-area program, and Figure 4.1 shows a map of the locations of the precipitation sites.

Table 4-2
Seasonal Precipitation for the SAWPA Program Area

Site	Name	Nov 2023	Dec 2023	Jan 2024	Feb 2024	Mar 2024	Apr 2024	Season Total
1	Upper Day Canyon	0.95	0.90	2.28	7.92	2.33	1.02	15.40
2	Deer Creek Dam	1.26	1.89	2.76	19.77	9.80	3.23	38.71
3	Cable Canyon	1.38	2.96	2.40	12.29	8.08	2.20	29.31
4	Oak Creek Canyon	1.41	1.70	2.24	13.07	6.14	2.44	27.00
5	Big Bear City Airport	0.66	0.53	1.38	7.44	1.78	2.14	13.93
6	Camp Angelus	0.99	1.57	2.91	12.32	4.65	1.50	23.94
7	Oak Glen Watershed	2.01	1.58	3.07	12.72	6.06	1.89	27.33
8	Idyllwild NWS	1.48	1.35	4.45	9.41	5.43	1.74	23.86
9	Hurkey Creek	0.98	0.54	2.65	5.49	3.16	1.14	13.96
10	Upper Silverado Canyon	0.24	1.94	1.02	4.96	7.25	1.34	16.75
11	Riverside Muni Airport	0.17	0.86	1.68	6.94	2.38	0.14	12.17
12	Hemet	0.87	0.80	1.94	4.33	1.69	0.67	10.30

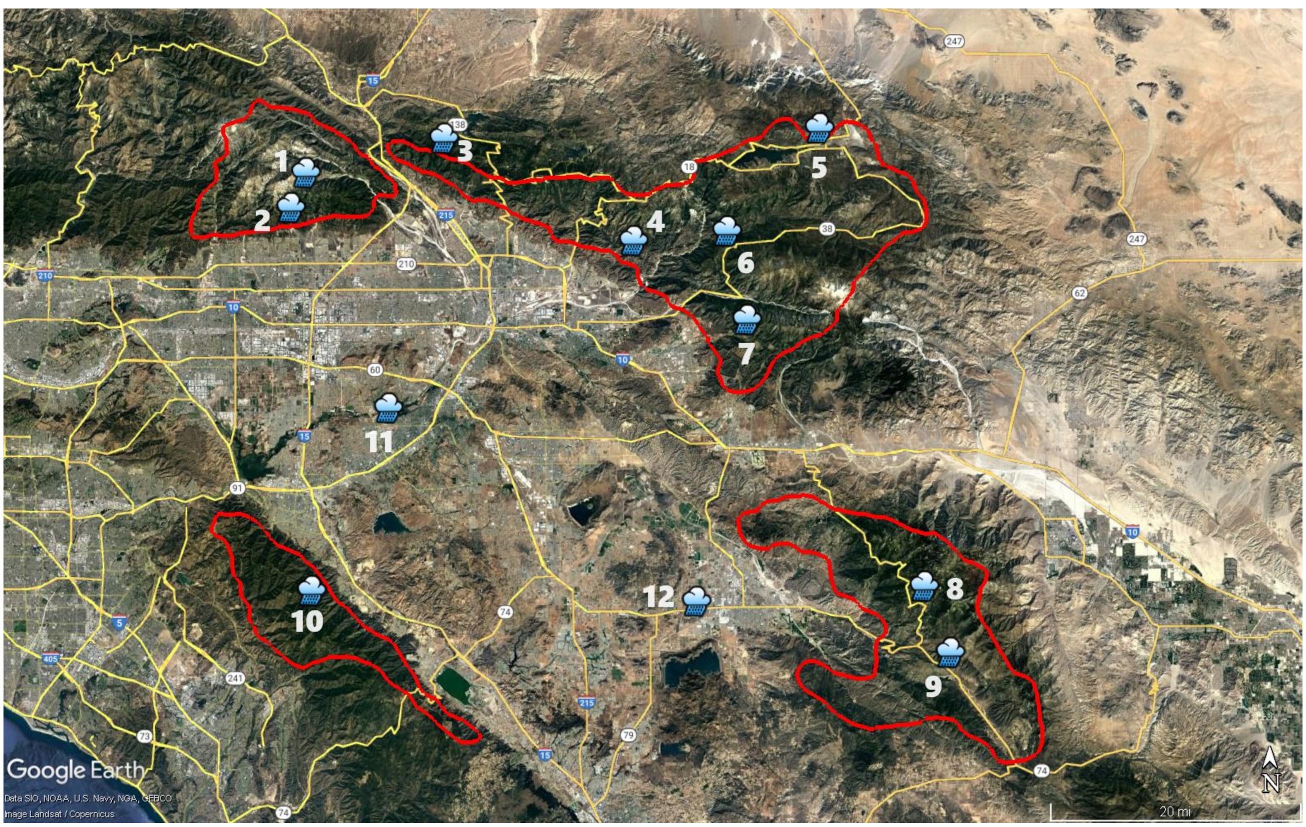


Figure 4.1. **Location of precipitation sites from Table 4-2. Red outlines are the four target areas.**

4.1 Storm Summaries

NOVEMBER 2023

<u>November 15 (no seeding)</u>

An upper low was sitting off the coast of central California, and a subtropical jet with associated moisture was feeding into the underside of the low. A shortwave disturbance emanating from the low ejected out across southern California during the afternoon and evening bringing periodic heavy showers and isolated thunderstorms. Given the subtropical nature of the airmass over southern California, temperatures aloft were quite warm, with 700 mb (approximately 10,000 feet MSL) temperatures of +4°C/+5°C (39-41°F) measured on the morning and afternoon balloon soundings from San Diego. Because of the warm air, seeding operations were not able to take place. Figure 4.2 shows a radar image during the early part of the event, centered on the Inland Empire (KF70 is Murrieta/Temecula airport; KHMT is Hemet Ryan Airport).

Seedability: POOR. Although wind flow was ideal for targeting and moisture availability was good, the airmass accompanying the storm system was warm, with temperatures above freezing at 700 mb / 10,000 feet MSL. For this reason, seeding operations would have had no effect and were not conducted.

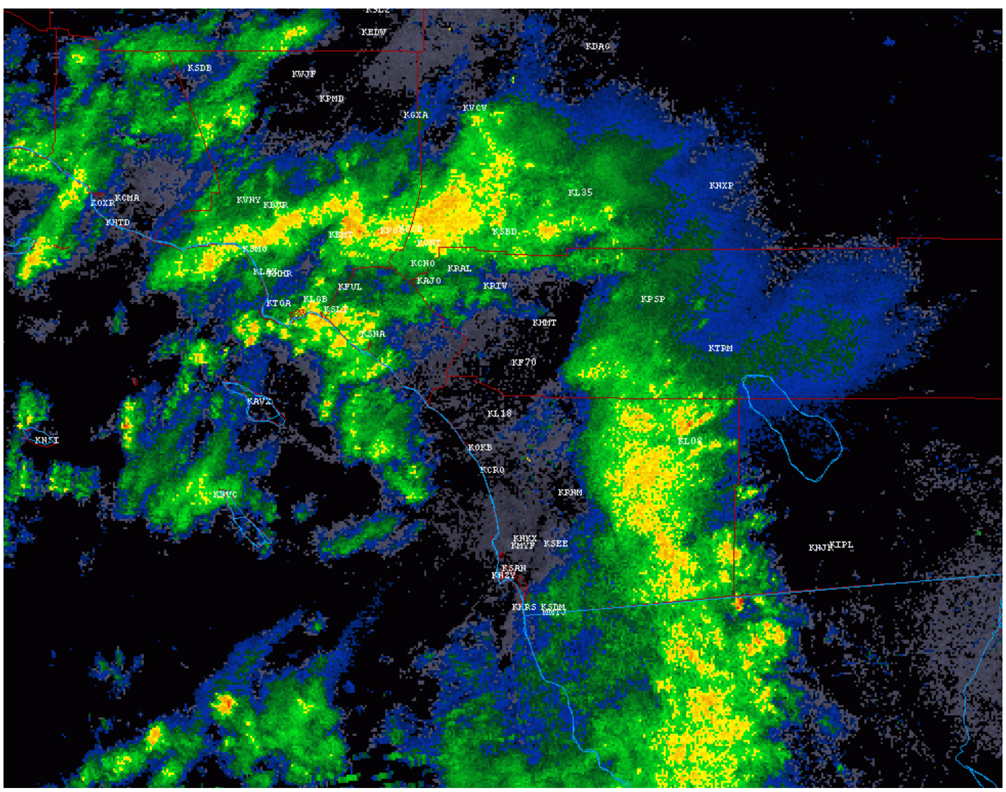


Figure 4.2. **Radar image from 1945Z (1145 PST) on November 15 showing numerous showers across the SAWPA WM PP area. Image courtesy of College of DuPage webpage, https://weather.cod.edu**

<u>**November 17-18**</u>

An upper low located several hundred miles west of the California coast was in the process of evolving into an open trough of low pressure and starting to shift northeast toward the central and northern California coast. The southern extent of the trough was forecast to swing across the project area from late evening of November 17 into the afternoon of November 18 bringing cooler mid-level temperatures and moisture that would be marginally sufficient for potential seeding operations. Two CNG sites, NW3 and NW4 were activated late evening of November 17/early morning of November 18 in anticipation of more favorable conditions arriving for seeding operations. The map of the location of the active sites is shown in Figure 4.3, and Figure 4.4 shows the presence of modeled supercooled water adjacent to the NW Target area. Two other nearby sites were not activated as HYSPLIT modeling indicated the plumes from these other sites (NW1/NW2) would remain south of the NW Target area. As it turned out, temperatures aloft did not cool sufficiently and moisture availability was less than forecast, so although both sites ran for 11-13 hours, it is unlikely any effects from seeding occurred. Infrared satellite imagery showing some of the shower activity during the event is shown in Figure 4.5.

Seedability: POOR. Moisture was confined primarily to the western parts of the area. Two of four sites in the northwest portion of the area were activated with the expectation – based on forecast models – that temperatures aloft, which were too warm at the start of the storm would cool sufficiently such that seeding operations would become more ideal. Temperatures did eventually cool, but not enough for seeding efforts to be effective.

Problems/issues: None.

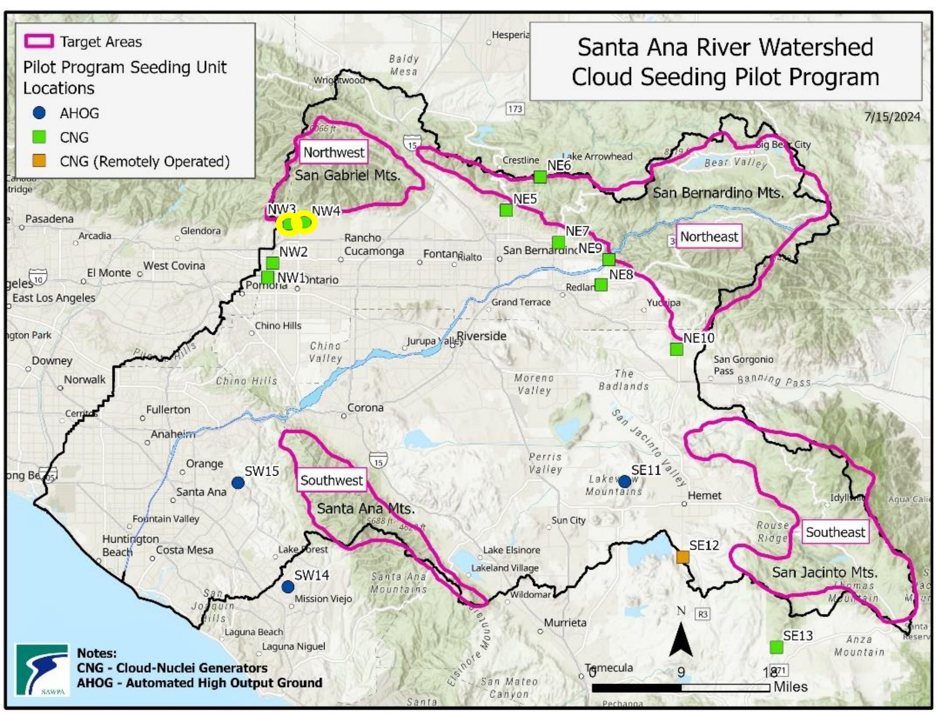


Figure 4.3. **Map showing active seeding sites on November 17-18, 2023, indicated by yellow circles.**

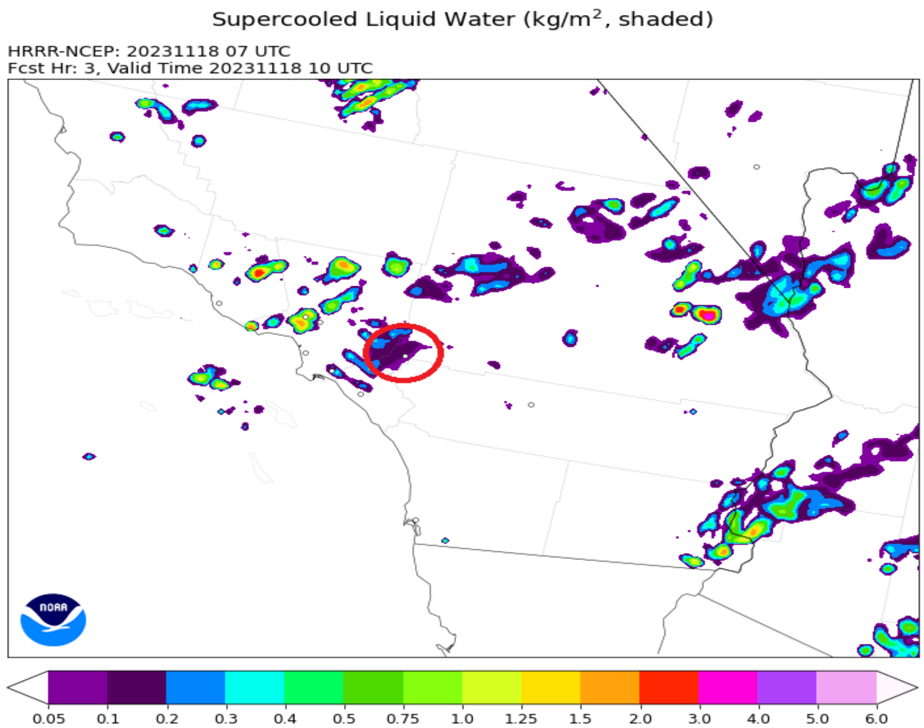


Figure 4.4. **HRRR model run from 07Z/Nov 18 (2300 PST Nov 17) showing marginal amounts of SLW (Supercooled Liquid Water) across southwestern San Bernardino County (in red circle), valid at 0200 PST on Nov 18. Image courtesy of NOAA's HRRR model page, https://rapidrefresh.noaa.gov/hrrr .**

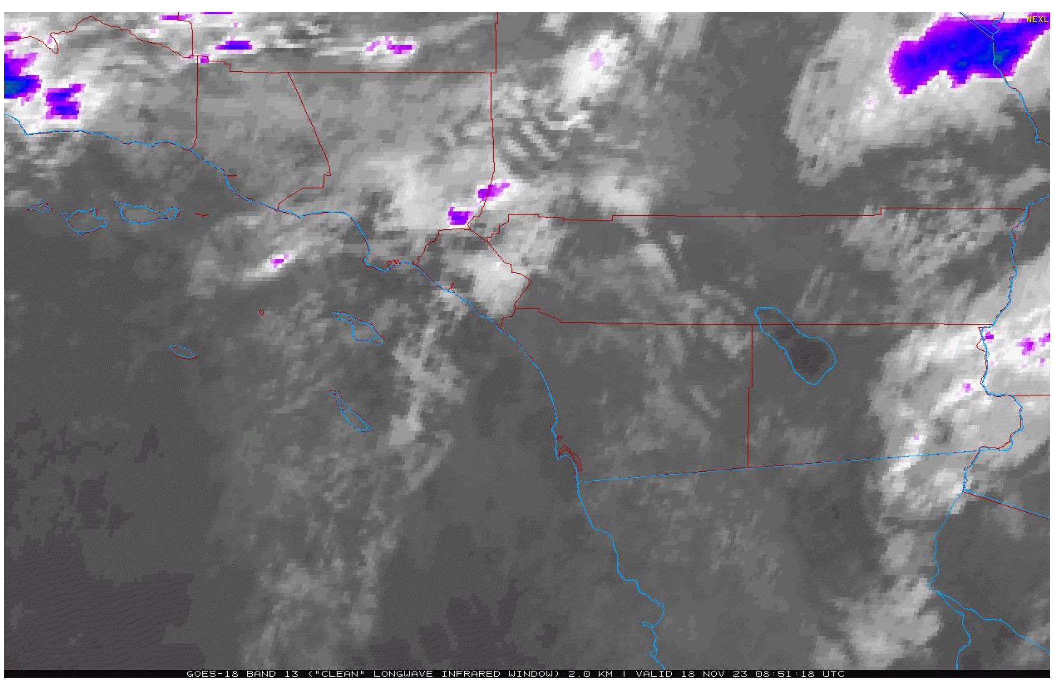


Figure 4.5. **Infrared satellite imagery from 0051 PST on November 18 centered on Inland Empire. Image courtesy of College of DuPage website.**

<u>November 30 (no seeding)</u>

A weak upper-level disturbance moved across central and southern California during the afternoon and evening hours. Although moisture was limited, the storm had some decent upper-level dynamical forcing thanks to the presence of an upper-level jet stream oriented in a northwest-southeast fashion across central and southern California. Because of the jet stream dynamics, scattered showers and thunderstorms were able to develop along the southern edge of the San Bernardino mountains and move southeast across the Inland Empire. Later in the evening a few short-lived showers and thunderstorms managed to develop southwest of Big Bear Lake and, again, move southeast out over the Inland Empire. Mid-level temperatures were just a bit below freezing which was marginally sufficient for seeding operations, however a small stable layer of air around 800 mb (approximately 6500-7000 feet MSL) as sampled on the late afternoon San Diego sounding was in place, which would prevent seeding plumes from rising above it. As such, no seeding operations took place. Figure 4.6 shows a lightning strike map from the evening of the event.

Seedability: POOR. Although mid-level temperatures were marginally ideal for seeding operations, wind flow suggested only eastern areas would see ideal targeting of any seeding plumes, and the presence of a low-level stable layer indicated that rising seeding plumes would not be able to reach high enough for any seeding effects to occur.

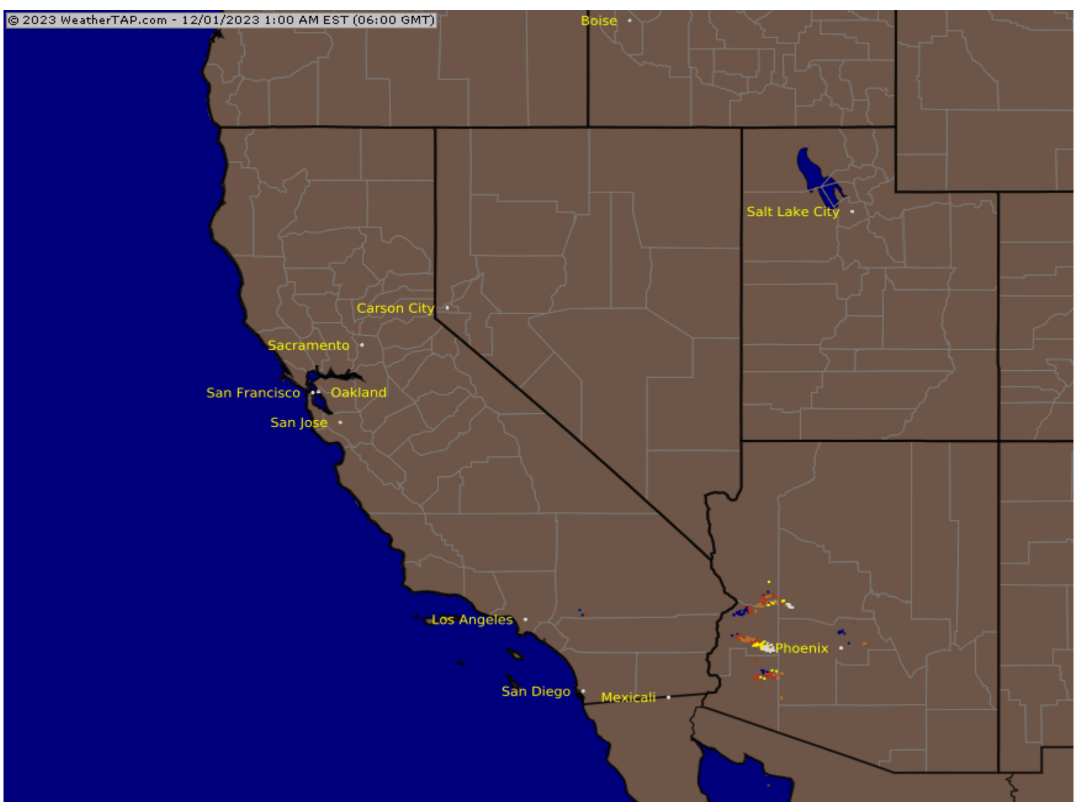


Figure 4.6. Lightning strikes, valid at 2200 PST on November 30. Note isolated strikes in SW San Bernardino County. Color coding indicates strikes were 90-120 minutes old.

DECEMBER 2023

December 19-22

Moist onshore flow set up on December 19 in response to a trough of low pressure and developing upper-level low off the Pacific Northwest coast. Mild temperatures and scattered showers moved across the area, but conditions were too warm and stable for seeding operations at this time. Over the course of the next couple of days, the upper low continued to develop, dropping southward several hundred miles west of the California coast while maintaining moist, stable onshore flow across the project area along with periodic rounds of showers. Figure 4.7 shows a visible satellite image taken at 1421 PST on December 20. As the low reached waters west/southwest of the project area on the afternoon of December 21, more substantial precipitation was poised to push into southern California, along with cooler temperatures aloft. Seeding sites were activated during the late afternoon/evening of December 21, with 9 of 11 manual CNGs activated for the storm; the two Chino Basin sites (NW1/NW2) were not used as HYSPLIT modeling indicated plumes missing the target areas. The remote CNG (SE12) was activated shortly after midnight. As the wave of rain and embedded convection pushed onshore into Orange County, one flare was fired from the AHOGS (SW14). SW15 was not utilized due to improper targeting based on wind direction. Figure 4.8 shows a radar image from 0145 PST on December 22 as the main wave of precipitation was pushing into the area. Seeding continued through the overnight hours as rain and higher elevation snow. As the low moved closer to the coast on the morning and early afternoon of December 22, daytime heating of the now unstable airmass allowed for scattered convective cells to develop and move northwestward. Some of this activity neared the AHOGS site near Hemet, and five flares were burned. A PIREP (PIlot REPort) over Banning/descending into Palm Springs during this time confirmed the presence of supercooled water (reported as moderate rime icing) over the area. Location of all active sites during the event is shown in Figure 4.9.

Seedability: FAIR. Mid-level temperatures were warm to start but as the system neared, temperatures cooled to marginally ideal levels. Moisture availability was good during the seeded portion of the storm. Wind flow was poor to start, then as the main portion of the low arrived the flow pattern improved for better targeting.

Problems/issues: None.

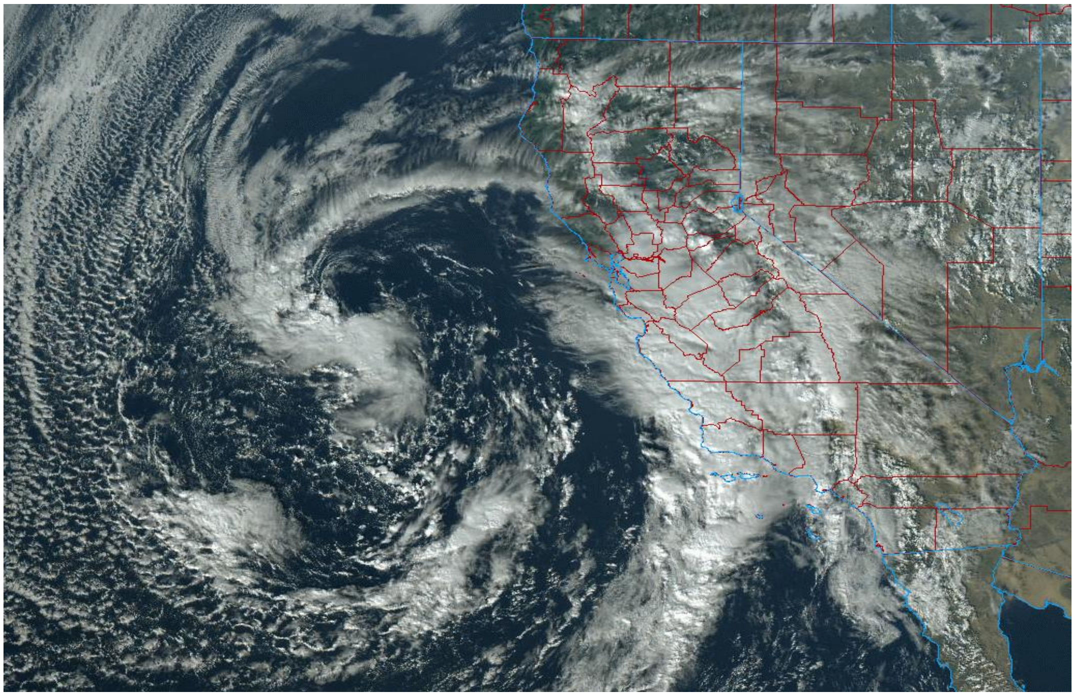


Figure 4.7. Visible satellite image from 1421 PST on December 20 shows the location of the upper low west of the central California coast. Image from College of DuPage Weather.

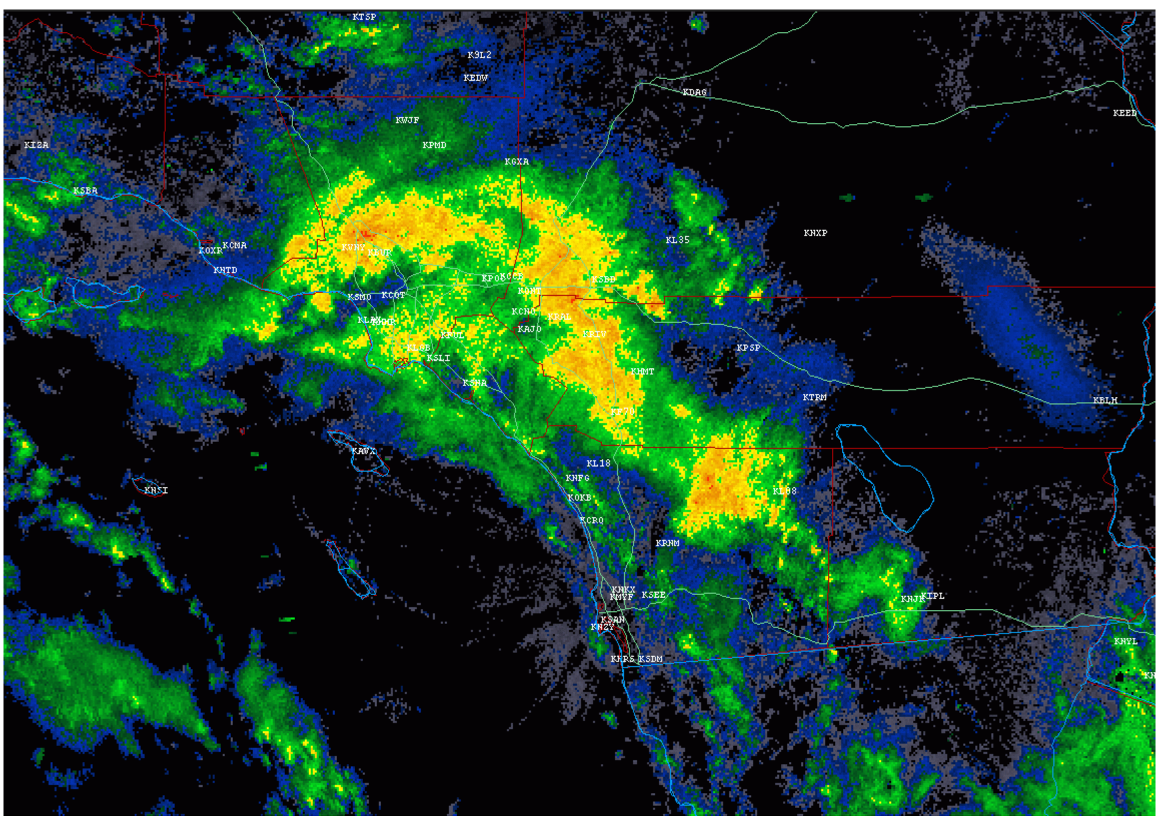


Figure 4.8. Radar image from 0145 PST on December 22 showing precipitation over the area Image courtesy of College of DuPage Weather.

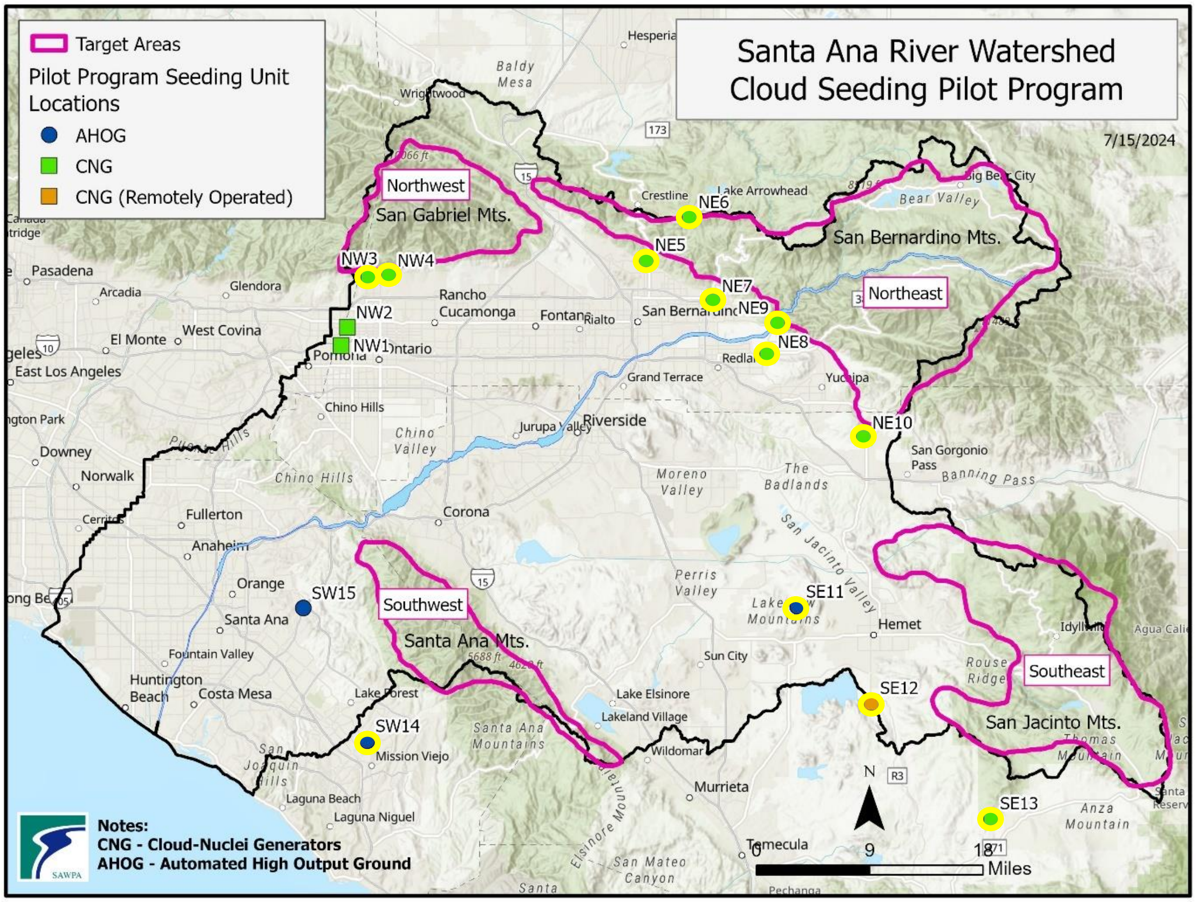


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Figure 4.9. **Map showing active seeding sites on December 21-22, 2023, indicated by yellow circles.**

December 29-30

An extensive trough of low pressure was positioned from west of British Columbia southward to west of southern California on December 29. The trough approached the coast during the evening hours, with rain spreading in from the west overnight. All CNG sites were activated during the evening of December 29/morning of December 30. The frontal band reached the western edge of the project area between 0500 and 0600 PST on December 30 and pushed across the area during the morning. HRRR modeling indicated the presence of supercooled liquid water (SLW), an image of which is shown in Figure 4.10. As the band pushed into Orange County, two flares were fired from the El Toro AHOGS site. Precipitation continued through the morning, with most activity out of the area by early afternoon. A few convective cells developed in Orange County just before 1400 PST and one additional flare was burned at El Toro as the cells passed by. With no other activity expected, all operations were halted. Figure 4.11 shows the location of all active sites during the event.

Seedability: GOOD. Just ahead of the frontal band that moved across the area, a stout inversion was in place at 850 mb / 5000 feet MSL that would have prevented seeding plumes from rising above that level, in addition to mid-level temperatures being too warm. The inversion mixed out with the arrival of the frontal band and mid-level temperatures cooled, resulting in improving seeding conditions. Afternoon convection also provided for a few seeding opportunities with an AHOGS unit in Orange County.

Problems/issues: Operators at sites NW2 and NE7 indicated smelling propane when turning off sites at end of storm event. Notified respective propane companies who investigated and fixed leaks near valves.

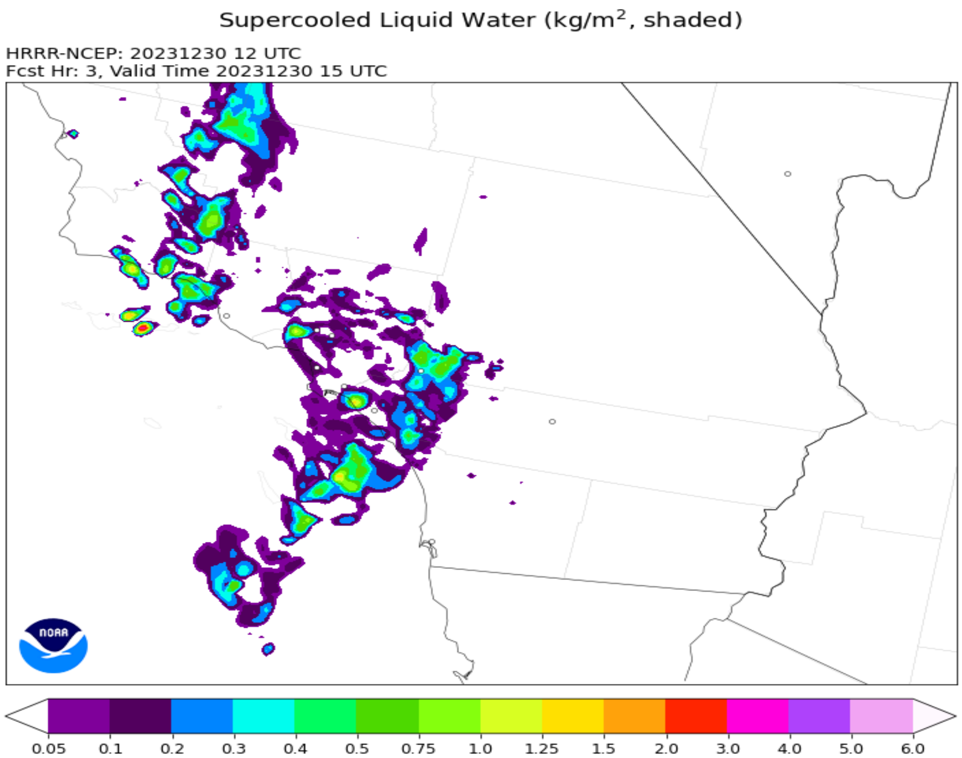

Figure 4.10. **HRRR model showing supercooled liquid water (SLW) over western SAWPA area at 0700 PST on December 30.**

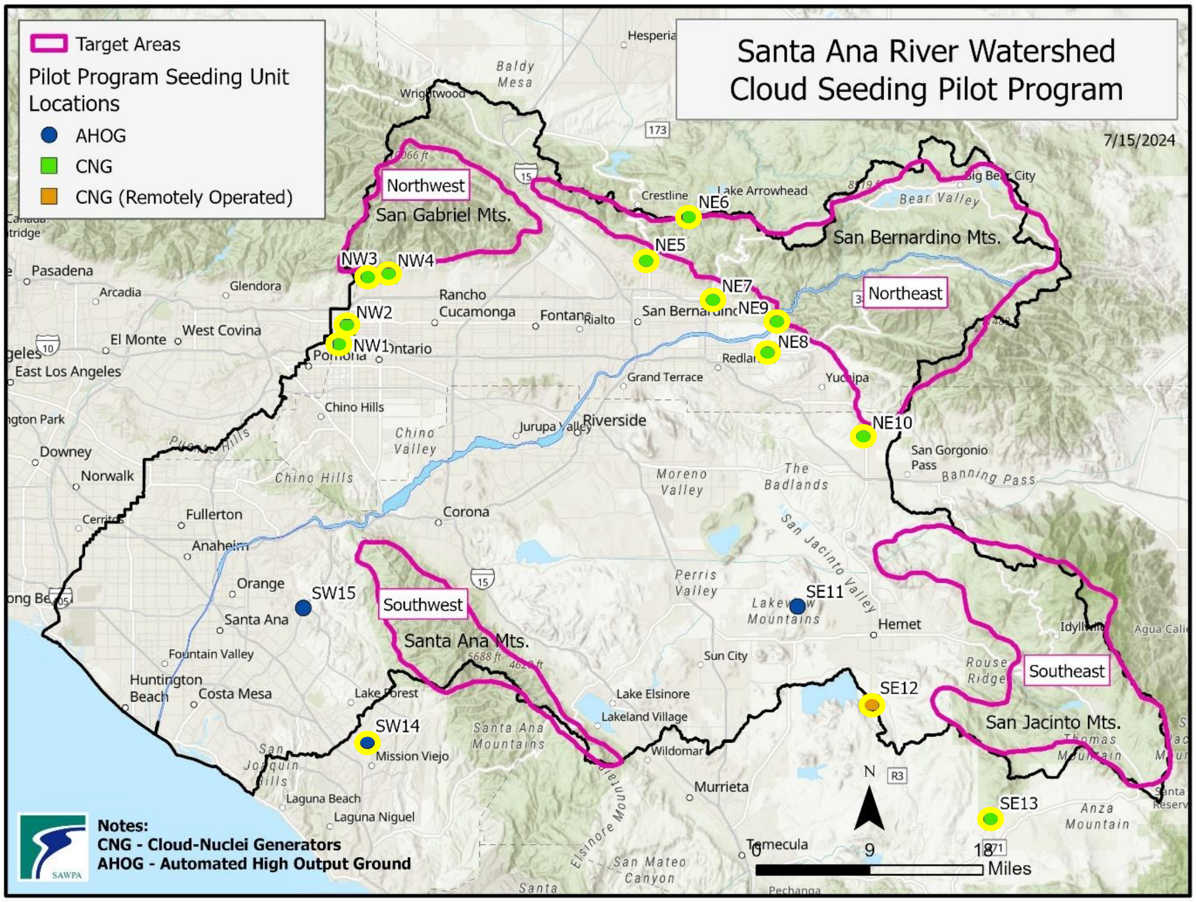

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Figure 4.11. Map showing active seeding sites on December 29-30, 2023, indicated by yellow circles.

JANUARY 2024

January 3

Late in the evening of January 2, a trough of low pressure extended from west of British Columbia southward into the eastern Pacific with the base of the trough several hundred miles west of Point Conception. Very cold air aloft accompanied the trough, with 500 mb (approx. 18,000 feet MSL) temperatures around -30°C near the core, and 700 mb (approx. 10,000 feet MSL) temperatures were -7°C to -8°C. Figure 4.12 shows an infrared satellite image depicting the trough west of California. Moisture was lacking with this system, however upper-level diffluent flow (the spreading of winds laterally) in the southeast quadrant of the trough, which would move across southern California, was increasing lift across this region and compensating for the lower moisture content. At midnight on January 3, a cold front accompanied by a band of precipitation, was located from northeastern California to near Bakersfield to Santa Barbara, with motion east and southeast toward the project area. Before dawn, the frontal band reached the western parts of the project area, by which time all but one CNG site was active. The front and its associated precipitation moved across all target areas during the morning hours, with the back edge of the band exiting the eastern areas by 1100 PST. Figure 4.13 shows radar imagery from 0745 PST while the band was lying across the entire area. With a combination of daytime heating and the cold core of the trough moving overhead during the afternoon hours, the airmass across the area became slightly unstable, and scattered convective cells began to develop across the San Bernardino Mountains (NW/NE target areas) with a motion to the east-southeast. Scattered rain showers/higher elevation snow showers and even thunderstorms moved across the eastern parts of the project area through late afternoon before tapering off. Two flares from the SE11 AHOGS site were used for seeding during this period as convection approached this site. Figure 4.14 shows all active sites during the storm period.

Seedability: GOOD. Mid-level temperatures cooled to ideal levels (i.e., below -5°C) with the frontal band that moved across the area. Wind flow was ideal for proper targeting until the tail end of the storm event. Moisture availability was marginal, with precipitable water (PWAT) values between 0.55-0.60".

Problems/issues: Operator at NE9 noted solution leak when turning off CNG. Passed info on to field technician in Utah who visited shortly after and repaired leak. Operator unable to get access to NW4 due to condition of the access road.

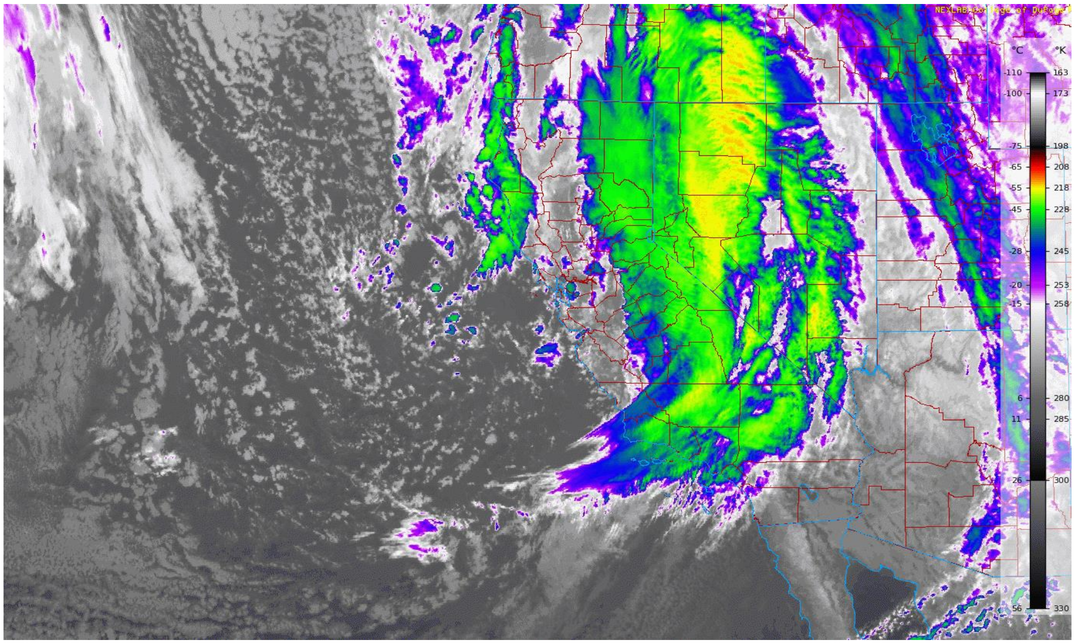

Figure 4.12. **Infrared satellite image from 0121 PST on January 3 shows the location of trough west of the California coast with the frontal band on the east side of the trough. Image from College of DuPage Weather.**

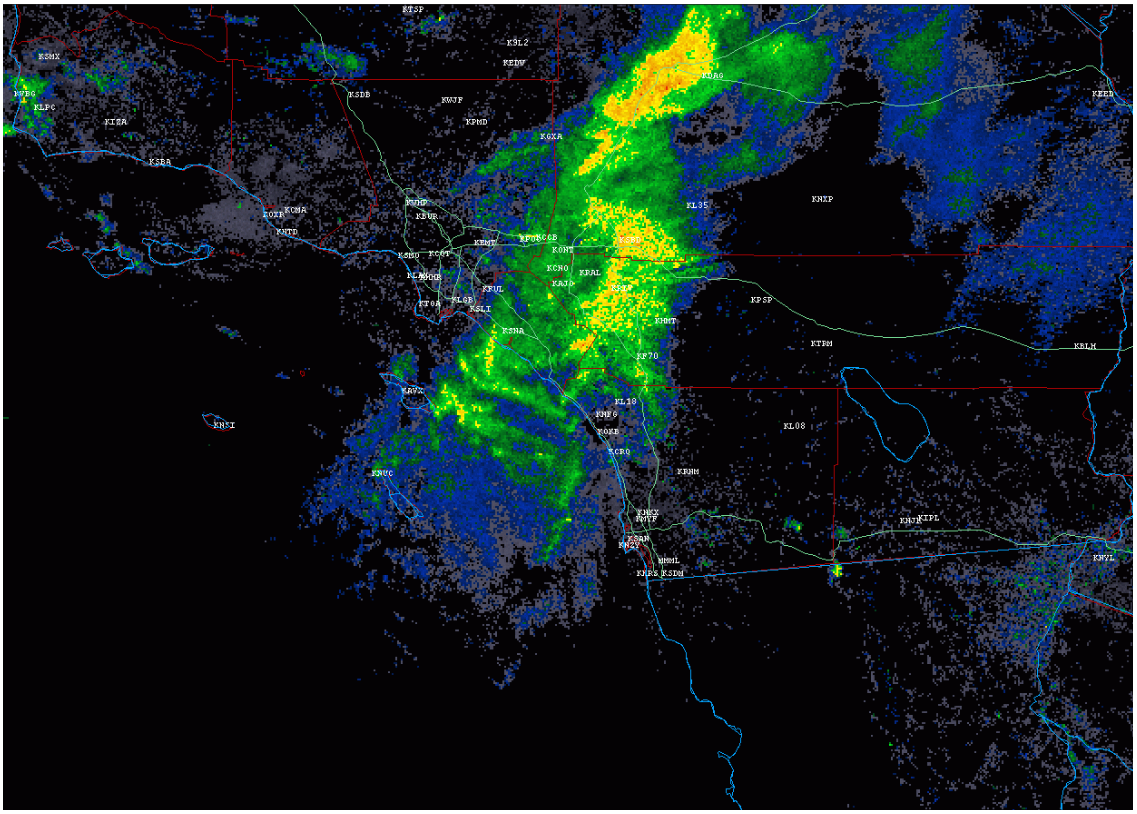

Figure 4.13. **Radar image from 0745 PST on January 3 showing frontal band over the area. Image courtesy of College of DuPage Weather.**

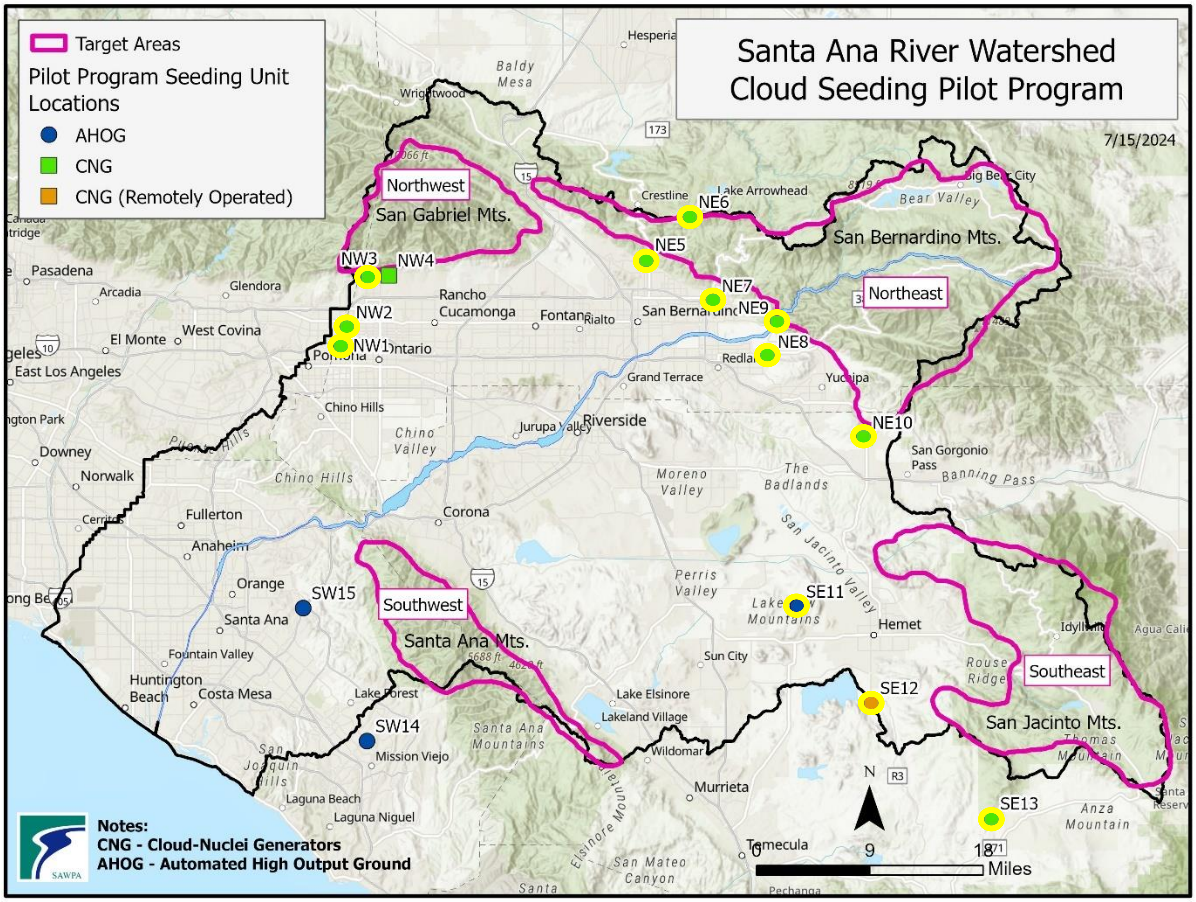

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Figure 4.14. **Map showing active seeding sites on January 3, 2024, indicated by yellow circles.**

January 7 (no seeding)

An inside slider was moving southeast through the interior of California accompanied by a tight pressure gradient and some moisture, with rain and mountain snow showers being observed in some areas of the project area. Winds associated with the system were strong, with High Wind Warnings in place for the San Bernardino and Riverside County mountains where wind gusts exceeded 60 mph, peaking at 92 miles per hour (mph) at Burns Canyon. Winds in the Inland Empire and other lower elevation sites were frequently exceeding 40 mph. Because of the stronger winds in place, seeding operations were not conducted as targeting would not be appropriate. Figure 4.15 is a radar image from the overnight hours of January 7 as some precipitation moved across portions of the project area.

Seedability: POOR. Strong winds were in place, and any seeding units that would have been activated would have produced very long and narrow seeding plumes that would likely not nucleate before passing the target areas.

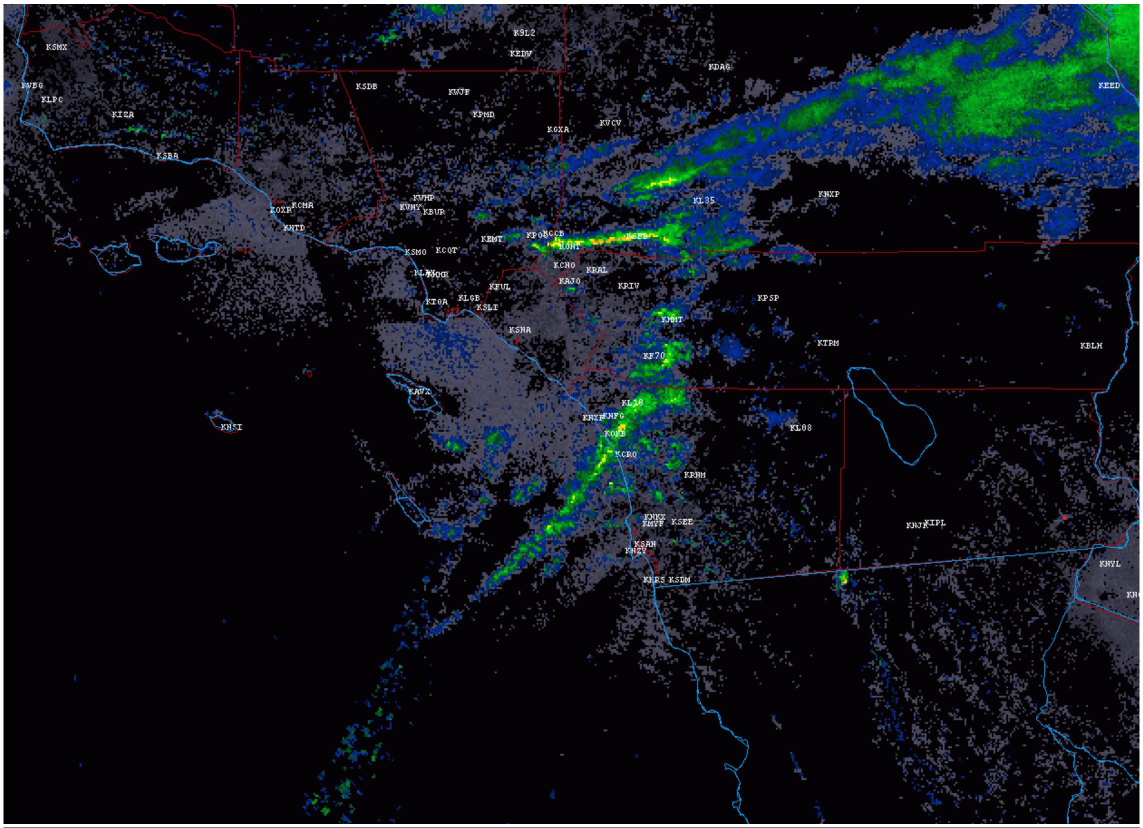

Figure 4.15. **Radar image from 0230 PST on January 7 showing scattered showers moving across portions of the SAWPA area.**

<u>January 20-22</u>

A trough of low pressure was located across the West Coast. Several shortwave disturbances embedded within the flow of the trough were poised to move across southern California, with the first one arriving during the late morning hours of January 20. No seeding operations with the CNGs were conducted with this first wave as the morning sounding from San Diego indicated a stable airmass below 6000 feet and 700 mb temperatures were warm, at +1°C. However, weak convective cells began developing just offshore from Orange County during the noon hour and approached the coast; one flare was fired from the AHOGS unit (SW14) at 1251 assuming any convective currents near this activity would be sufficient to draw the AgI plume up into the cloud. Figure 4.16 shows a visible satellite image just prior to the moment of seeding from SW14 AHOGS unit. The first wave of precipitation exited to the east by evening. The late afternoon (January 20) sounding from San Diego indicated that 700 mb temperatures had cooled to -3°C and weak stability remained, though less than earlier in the day, along with an increase in precipitable water. Snow levels were around 7000-7500 feet. The next shortwave disturbance within the trough was pushing into Los Angeles County at mid evening. Ahead of this, with better conditions in place for seeding, several sites were activated for the NE and SE target areas; the remote generator SE11 was not able to start because earlier rainfall had soaked the ignitor, preventing it from sparking a flame. Figure 4.17 shows the sites active for this part of the storm period. Precipitation entered the western parts of the project area prior to midnight and continued to move east across the area into the overnight period, with activity exiting to the east with the shortwave after 21/0300 PST. Radar imagery during this time is shown in Figure 4.18. Sites were turned off during the morning of January 21, and for the remainder of the afternoon and evening, a few showers moved across the area with little accumulation.

The next, and final shortwave disturbance within the trough began to move into southern California around Santa Barbara County during the evening hours of January 21. Prior to this system's arrival, several CNGs were re-activated. Steady precipitation arrived in the western portions of the project area at 0400 early on January 22, spreading across the entire area by daybreak. Rain and higher elevation snow continued through the morning, with snow levels remaining around 7000-7500 feet. After the steady precipitation ended over western areas, isolated convective development occurred just offshore, moving into Orange County between 1030 and 1100 for which two flares were burned from the SW14 AHOGS unit. Later in the afternoon, additional convective development occurred over the eastern areas and four flares were burned from the SE11 AHOGS site between 1520 and 1550 PST as a short line of moderate to heavy convection moved across the eastern areas. Figure 4.19 shows a camera snapshot of a flare burning from the SE11 AHOGS site during this time period. One more flare was burned at the SW14 site shortly after 1600 as additional showers moved across parts of Orange County. All activity ended early in the evening. Figure 4.20 shows the sites that were active for this disturbance.

Seedability: FAIR to GOOD. Temperatures at 700 mb were generally between 0°C and -3°C; while cooler temperatures aloft would be more ideal, convective currents were likely able to loft seeding plumes to cooler temperatures. Wind flow was good for proper targeting except for the Chino Basin sites where plumes were shown to be missing the target areas. Moisture availability was good with PWAT values between 0.75" and 1.10".

Problems/issues: Sponsors for sites NW3/NW4 changed the locks without informing the operator. As a result, the operator did not have the key for the gate during the weekend and was unable to access the sites to activate the units. These sites did not run for either wave of precipitation. Site NE7 ran low on propane and only ran for the first wave of precipitation. Remote site SE12 had a wet ignitor and could not light the CNG, so it did not run for storm event. Sites NW1/NW2, which were not run for first wave of precipitation as HYSPLIT modeling indicated plumes not targeting target area, were more ideal for second wave but, as copper line sleeving was still not completed, did not run for this portion of storm as well. Finally, connection to the AHOGS unit SW15 could not be established due to an inadequate power supply, as multiple cloudy days had kept the battery on the low side.

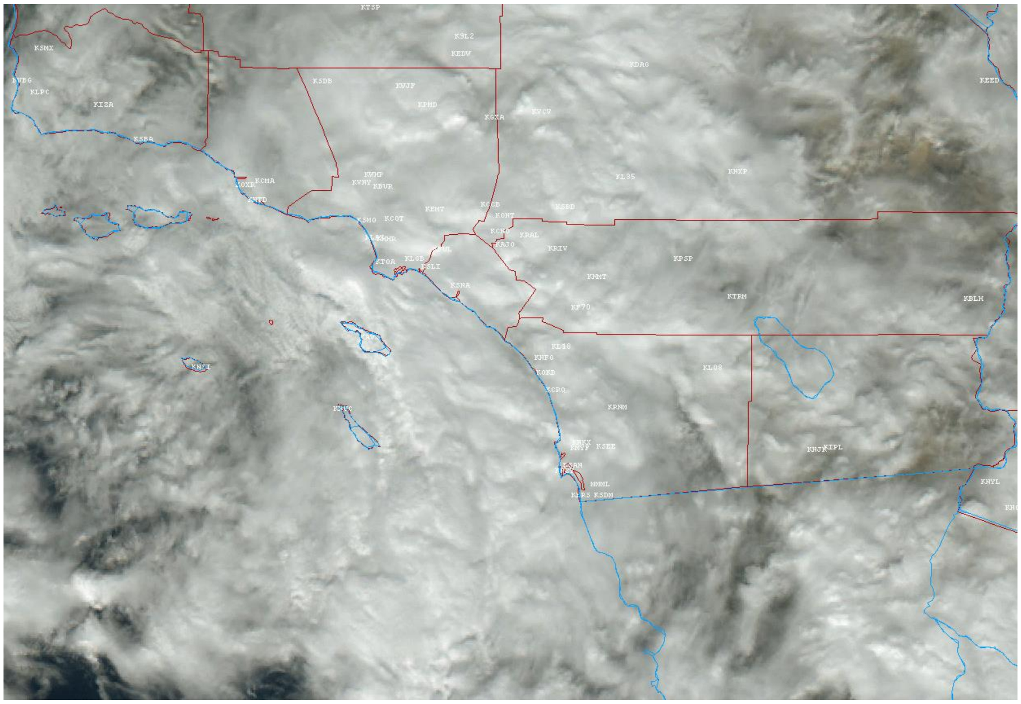

Figure 4.16. **Visible satellite image from 1241 PST on January 20, prior to the firing of a flare from the El Toro AHOGS unit in Orange County.**

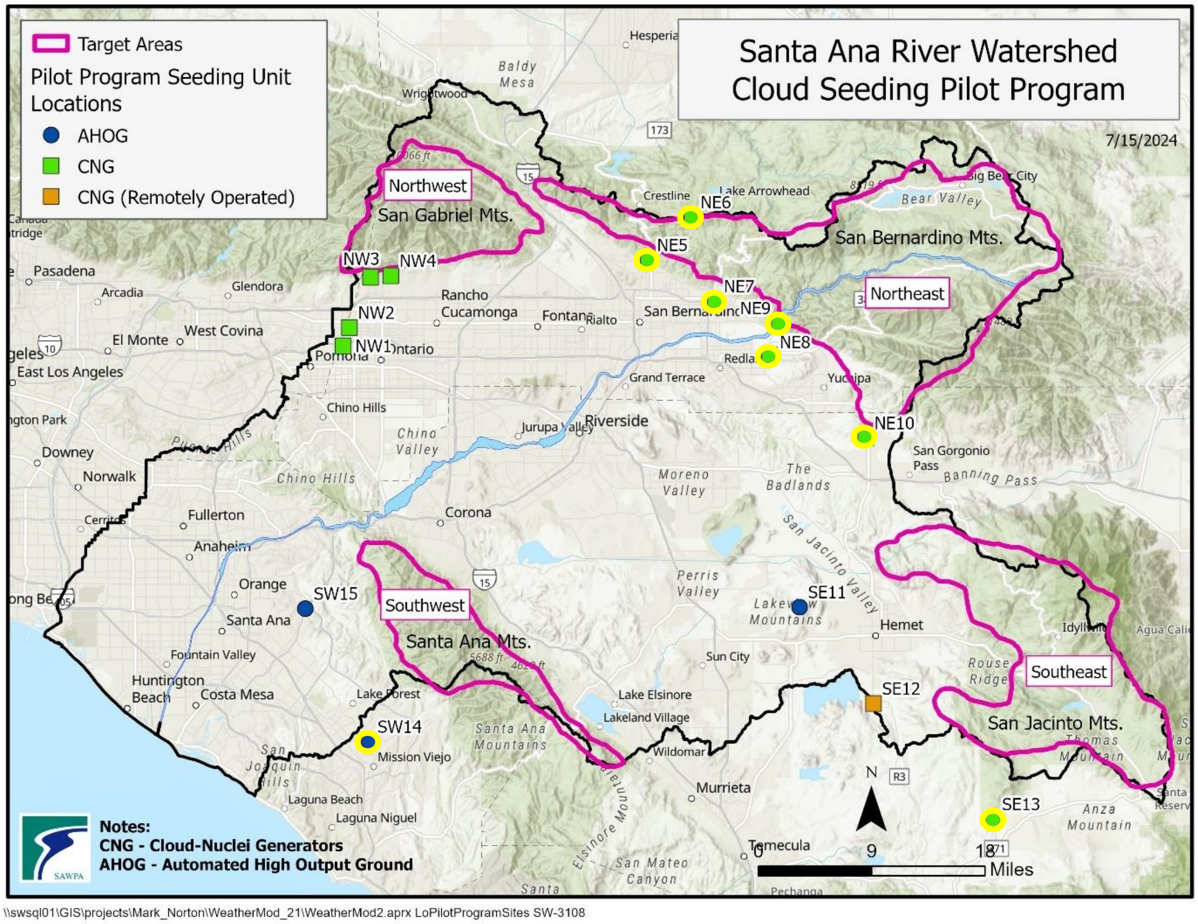

Figure 4.17. Map showing active seeding sites on January 20-21, 2024, indicated by yellow circles.

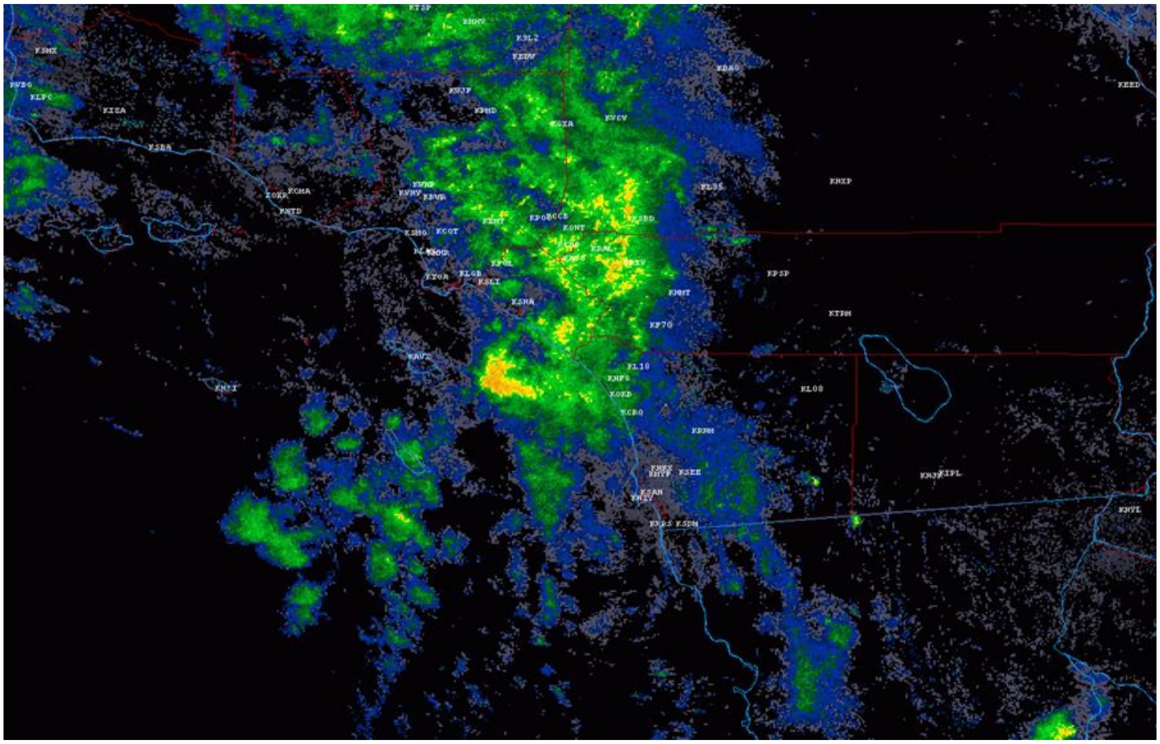

Figure 4.18. Radar image from 0015 PST on January 21.

Figure 4.19. Camera snapshot of flare burning from SE11 AHOGS site at 1548 PST on January 22, 2024.

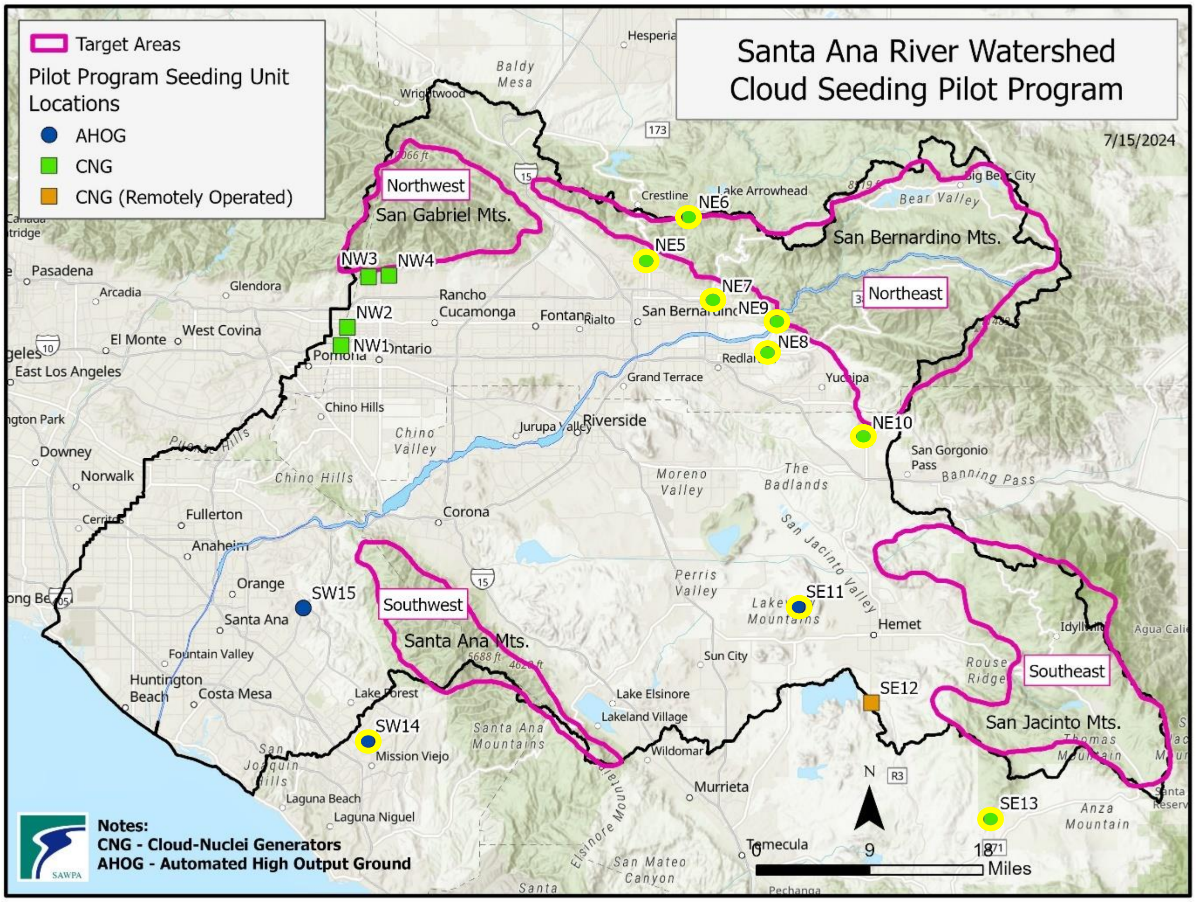

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Figure 4.20. Map showing active seeding sites on January 21-22, 2024, indicated by stars.

FEBRUARY 2024

<u>February 1</u>

A powerful low pressure center was located off the Pacific Northwest coast, with its attendant trough and cold front extending southward to west of southern California. Strong south and southwesterly flow was in place ahead of the front, which arrived in the western parts of the project area around 0400. Snow levels started out around 6500 feet ahead of the frontal band, with heavy snow above 7000 feet. CNGs were activated beginning the evening prior for NW3/4 sites and for the remainder of the sites during the early part of the event. As the morning progressed, the band moved across the entire area bringing moderate to heavy rainfall and higher elevation snow. Figure 4.21 shows a visible satellite image depicting the frontal band over the area during the latter part of the morning, and Figure 4.22 is a radar image from the same time. Precipitation continued into the afternoon hours, tapering off to showers by mid-afternoon, and mostly ending by early evening. CNG sites were shut off by early evening. However, later in the evening, an area of scattered showers and thunderstorms developed across the northwest part of the SAWPA area and moved southeast. One flare was burned from SE11 AHOGS site. Figure 4.23 shows the sites active during the storm.

Seedability: VERY GOOD. Ahead of and immediately at the beginning of the precipitation, temperatures were above freezing with a substantial stable layer below cloud base. This quickly evolved to more ideal conditions as temperatures quickly cooled behind the leading edge of the precipitation and mixing eroded the stable layer. Additionally, wind flow was ideal, with seeding plume dispersion from the sites properly targeting the target areas, and diffluent flow aloft was aiding in lift of these plumes.

Problems/issues: Propane company had not been able to get to sites NE5/NE7 as driver called in sick, and these sites did not run for this storm event due to inadequate propane supply. Leak found at SE13, which was fixed by operator. When the operator went to shut off site NE10, they noticed a weak flame and low flow, but the CNG was still running. The operator notified the field technician.

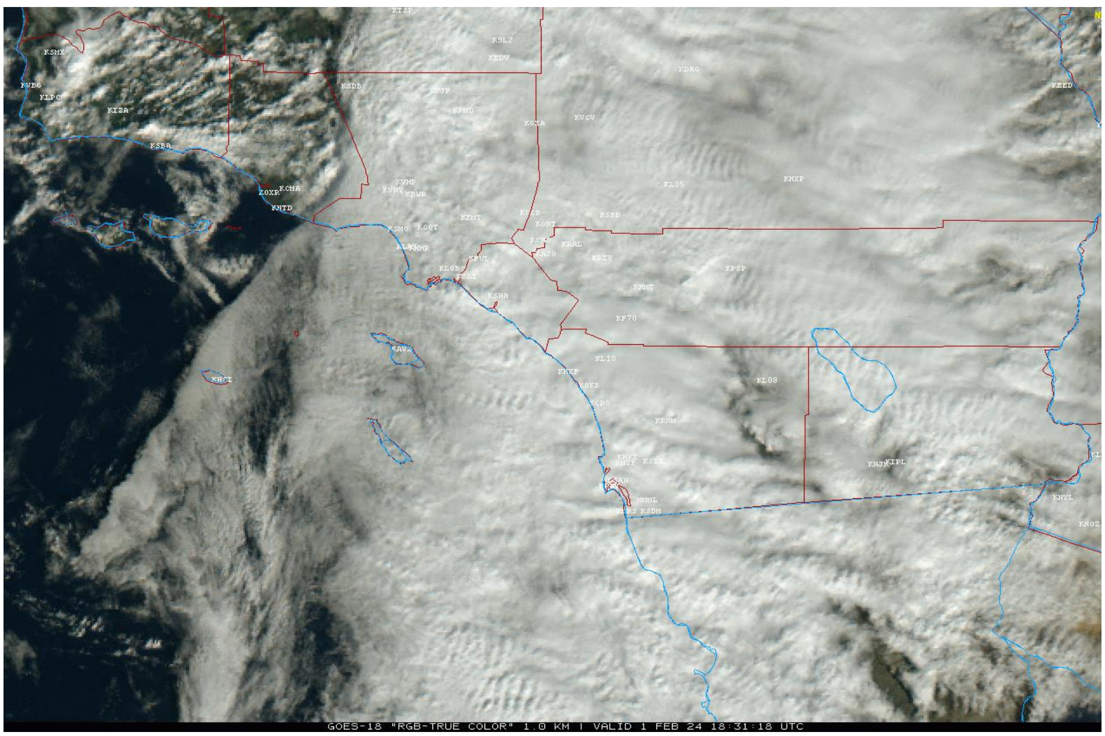

Figure 4.21. **Visible satellite image from 1031 PST on February 1 showing the frontal band and accompanying precipitation moving across southern California. Image from College of DuPage Weather, https://weather.cod.edu/satrad/ .**

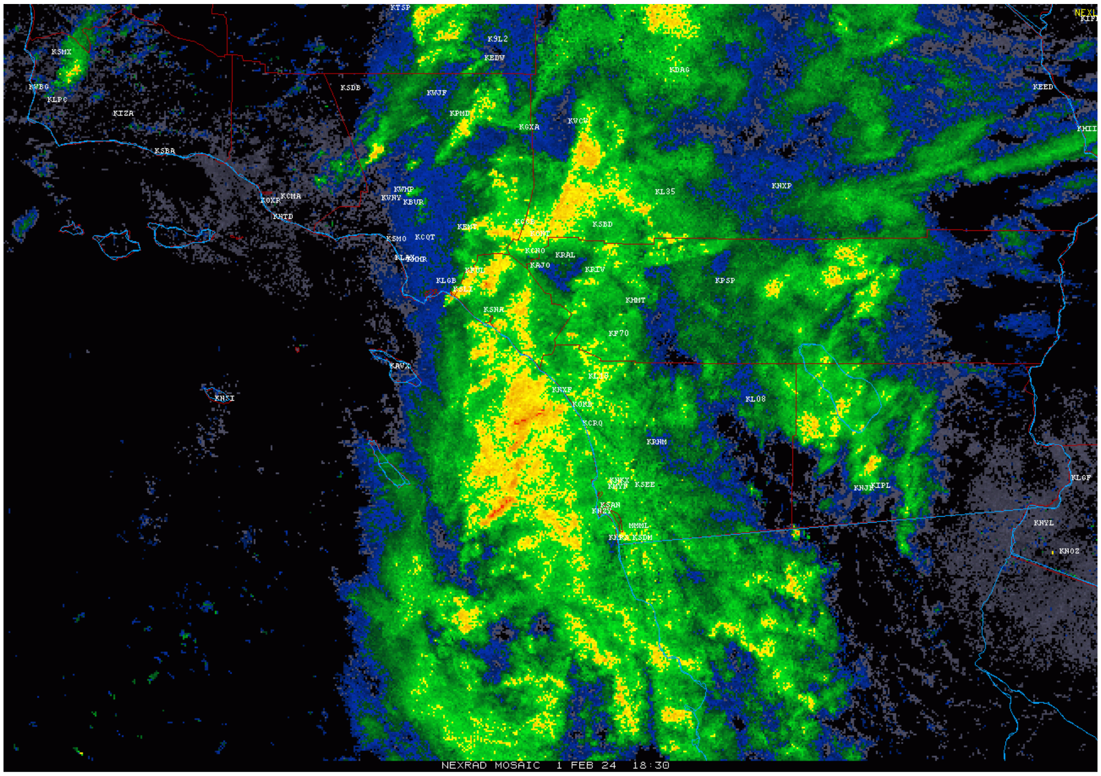

Figure 4.22. Radar image from 1030 PST on February 1 showing frontal band over the area. Image courtesy of College of DuPage Weather.

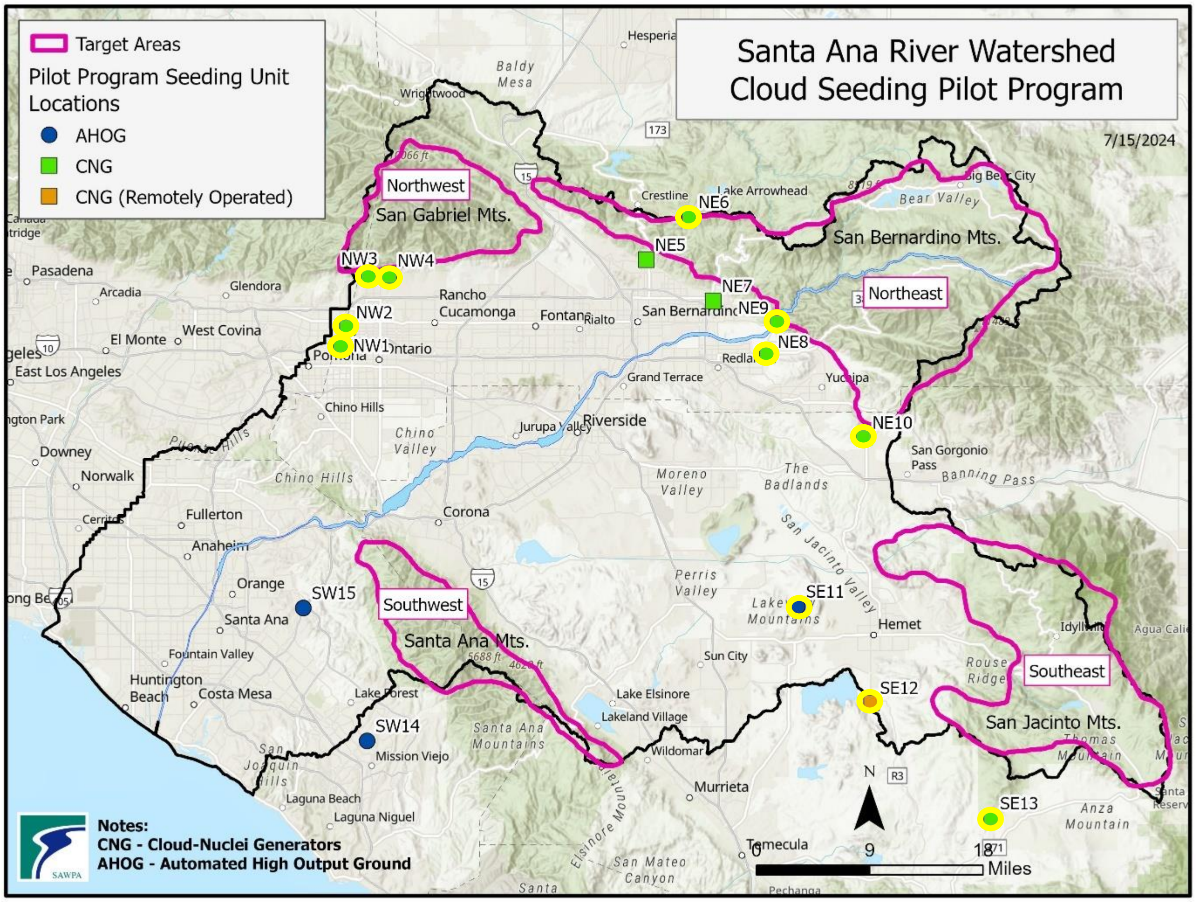

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Figure 4.23. Map showing active seeding sites on February 1, 2024, indicated by yellow circles.

<u>February 3-8 (no seeding)</u>

A well-advertised Atmospheric River event began to unfold on February 3 as a large upper trough was located in the northeastern Pacific. The trough began to pull copious amounts of subtropical moisture into itself and then direct the moisture into California, accompanied by several shortwave disturbances that enhanced lift as they moved across southern California. Once the stream of moisture and associated moderate to heavy rain (and higher elevation snow) arrived late in the afternoon of the 4th, it continued almost unabated for nearly 48 hours, first as a southwest-to-northeast band of precipitation, gradually re-orienting to a nearly north-south band as the trough moved closer to the coast. Figure 4.24 is a water vapor satellite imagery from the early afternoon of February 5, clearing showing subtropical moisture flowing into southern California ahead of a sharp trough of low pressure. Figure 4.25 shows an infrared satellite image taken at 2200 PST on February 5 showing moisture band solidly over the project area. Figure 4.26 shows the corresponding radar image. By late afternoon/early evening of February 6, the main band of precipitation had shifted east of the area with westerly flow and scattered rain/higher elevation snow showers moving across the area. The showery regime pattern continued into the morning hours of February 7 before a brief break in the precipitation occurred as the main trough of low pressure was finally shifting east of the area. Figure 4.27 shows three-day precipitation totals for California as compiled by Weather Prediction Center. A strong shortwave disturbance on the backside of the trough moved southeast along the central coast during the afternoon hours, arriving in southern California in the evening with an attendant cold front sweeping across the area. The front brought a line of heavy showers and thunderstorms along with strong wind gusts and lowering snow levels to 4000 feet. Figure 4.28 shows a radar image from 2200 PST on February 7, just as the cold front arrived at the western edge of the SAWPA area. Flood advisories and a Severe Thunderstorm Warning were issued during the frontal passage. Scattered mainly light to moderate showers continued mainly in the mountains in the post-frontal airmass, gradually tapering off by the evening of February 8. Precipitation during the event was significant and very heavy, with **the highest total of 15.48 inches of rain** falling at Middle Fork Lytle Creek in the NW Target area, and **several locations in the NE and NW Target areas seeing upwards of 10 inches of rain.** In terms of snow, the multi-day event produced **80-97 inches of snow** at Snow Valley near Running Springs in the NE Target area, with **60 inches** at Bear Mountain Snow Summit and **56 inches** at Mt Baldy in the NW Target area.

Because of the threat of excessive precipitation and subsequent effects of such (flooding, mudslides, etc.), seeding operations were suspended for this storm event.

<u>Seedability</u>: POOR initially, becoming GOOD. Most of the storm event was warm as the source region for the moisture/air was subtropical, although high elevations were cold enough for snow, where copious amounts fell. The latter part of the event – from about February 6-8 – saw improved conditions for seeding with colder temperatures aloft, although the suspension remained in place due to the excessive amount of rain occurring at lower elevations.

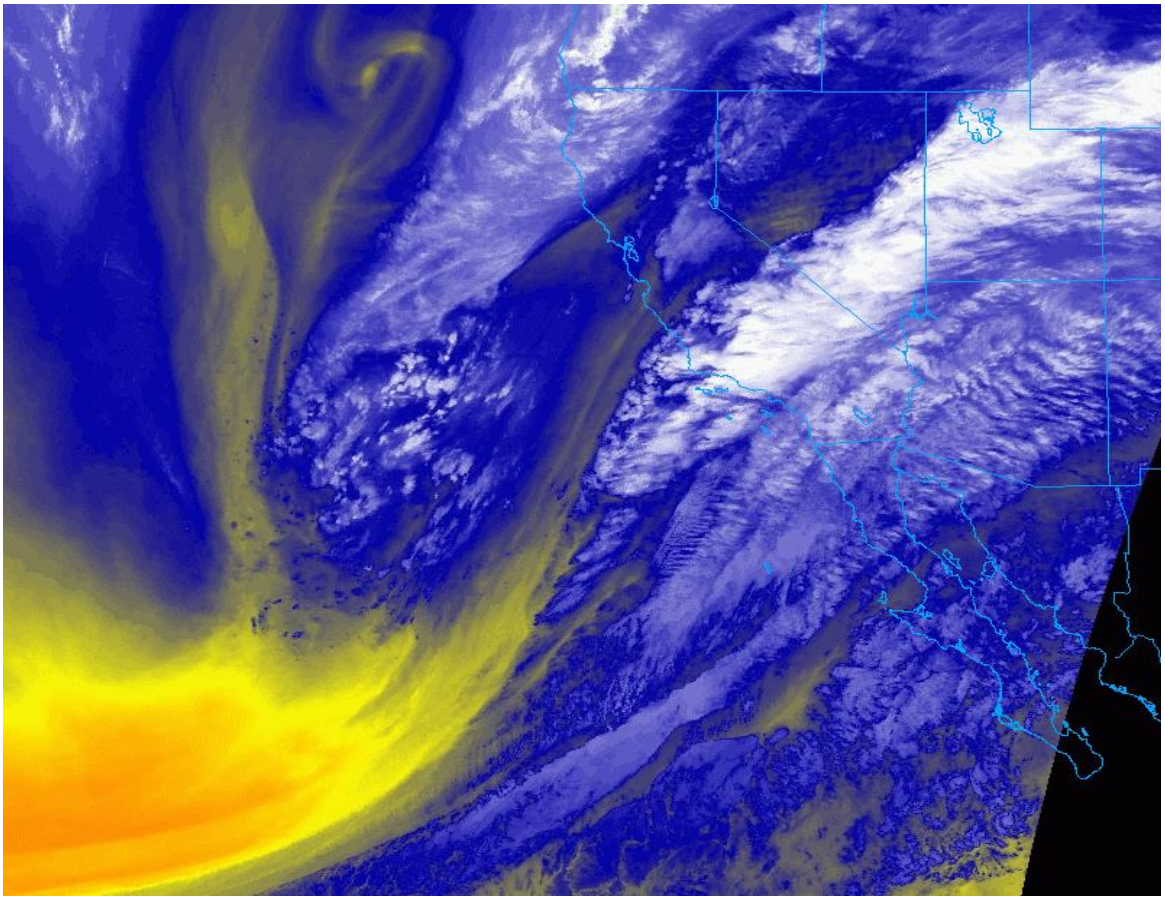

Figure 4.24. **Water vapor imagery from 1251 PST on February 5, 2024, showing subtropical moisture (blue/white shading) flowing into southern California ahead of trough.**

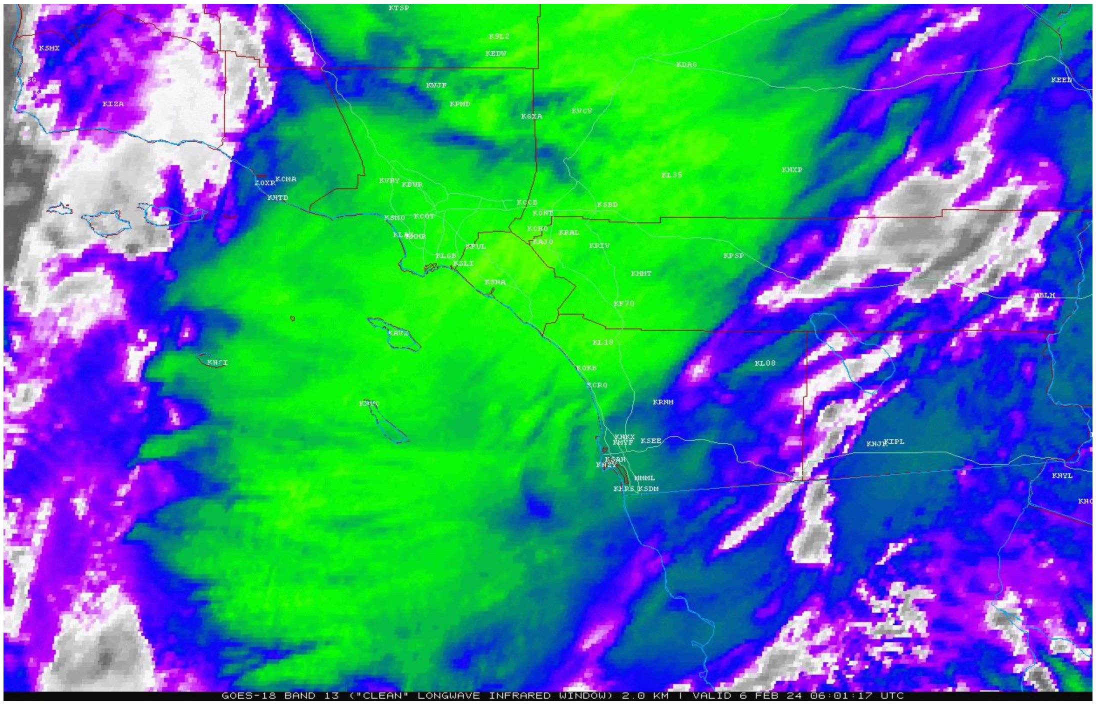

Figure 4.25. **Infrared satellite image from 2200 PST on February 5 showing colder cloud tops (green color indicating cloud top temperatures -45°C to -50°C) over the area.**

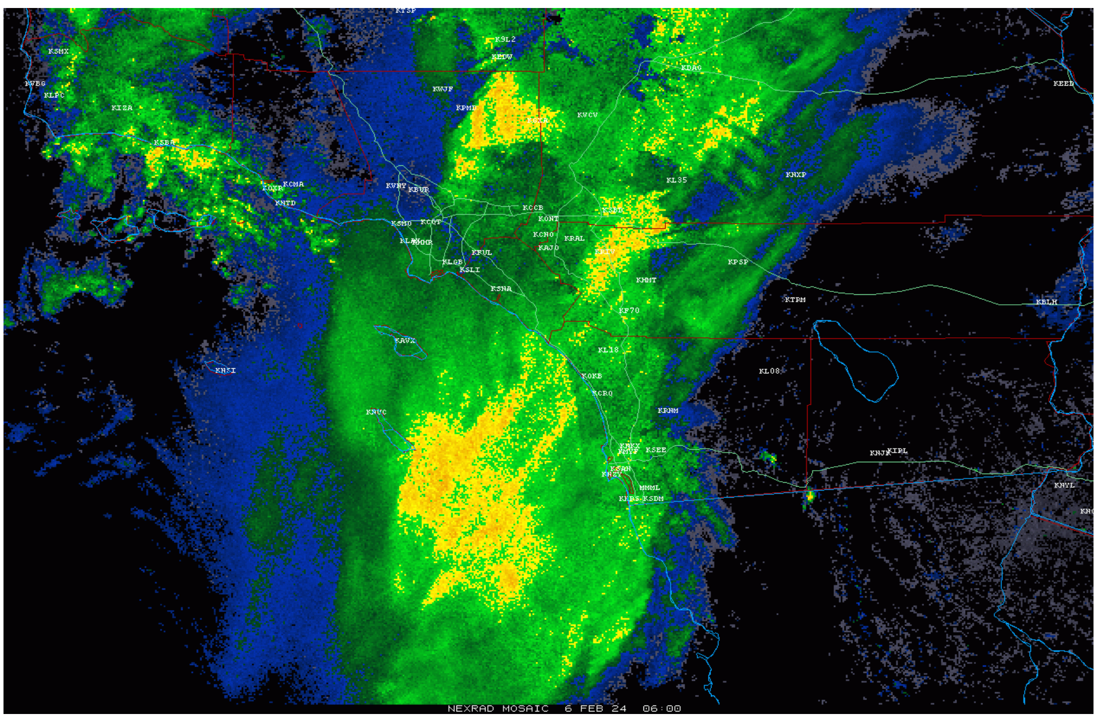

Figure 4.26. **Radar image from 2200 PST on February 5 showing precipitation band over the area.**

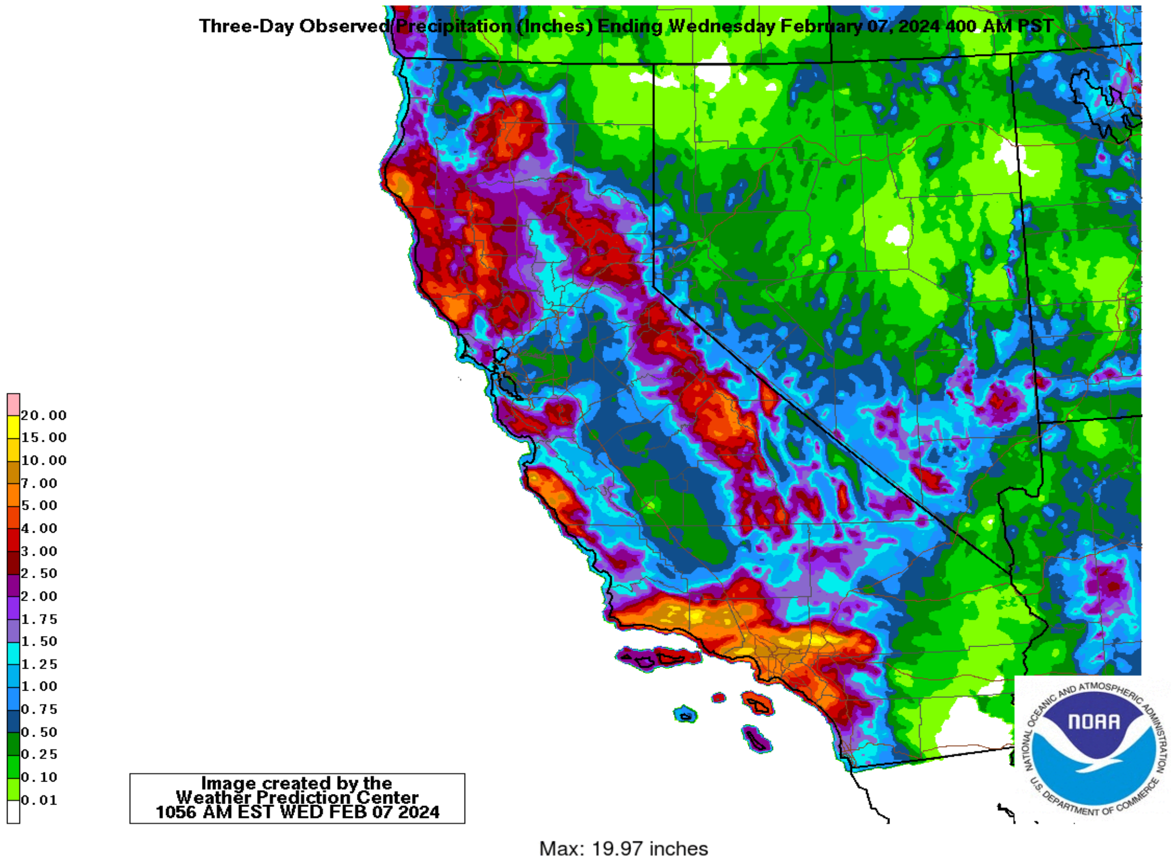

Figure 4.27. **Three-day precipitation totals for California, valid at 0400 PST on February 7, 2024.**

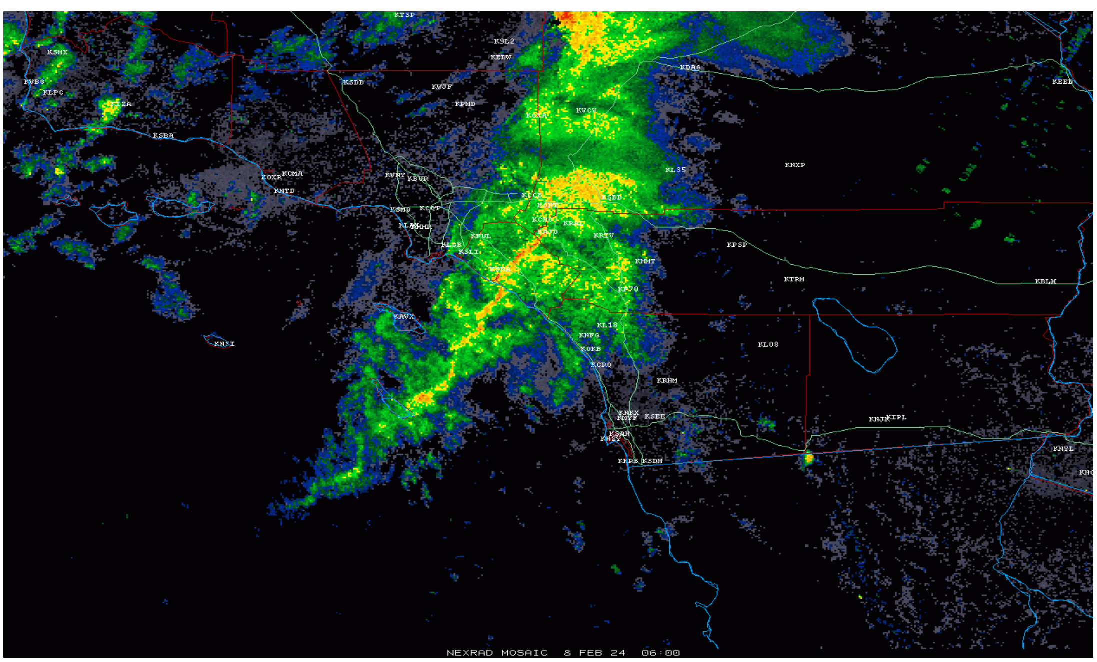

Figure 4.28. **Radar image from 2200 PST on February 7 showing the cold front at the western edge of the SAWPA area.**

<u>February 19-21</u>

A large upper level low and associated trough were in the eastern Pacific on the morning of February 19. A plume of moisture within a strong jet stream was affecting the Central Coast and portions of southern California west of the area. As the trough pushed slowly east, this moist plume reached the project area during the afternoon with snow above 8000 feet. Area soundings indicated a relatively warm airmass in place (700 mb temperatures were around 0°C) with stable conditions which were not conducive for seeding. Precipitation had remained light through early evening, but by mid-evening, another shortwave disturbance embedded within the jet stream approached the coast with precipitation rates and coverage increasing through the rest of the evening and overnight. Rain and higher elevation snow continued into February 20. The morning sounding from San Diego indicated decreasing stability and slowly cooling mid-level temperatures, while upstream conditions suggested improved seeding potential. This improvement was confirmed by the San Diego sounding in the late afternoon of February 20. Given the continuation of precipitation and increased ideal conditions for seeding transpiring across the area, CNG sites were activated in the afternoon. Rain and higher elevation snow continued into the evening with activity waning during the overnight period, only to increase once again just before dawn as the cold front and core of the upper-level trough began to push across the area. Figure 4.29 shows the probability of icing (indicative of supercooled water) at 9000 feet MSL valid at 2208 PST on February 20; note the higher probabilities in place over southwestern California. Figure 4.30 is a radar image from 0425 PST on February 21. Rain and mountain snow tapered off during the morning, with some wraparound showers continuing into the afternoon before ending in the evening. Figure 4.31 shows the active sites during the storm. **Note that no seeding was done for the SW target area as AHOGS were not to be used due to antecedent moist soil conditions, and modeled plume dispersion indicated that none of the sites would properly target the SE Target area.**

Seedability: GOOD. The first part of the storm event on February 19 – early February 20 saw mid-level temperatures near freezing along with a rather chaotic wind field and some stable layers present that would hinder seeding plumes from rising to cloud base. As the event progressed, additional ideal seeding conditions began to move in on the evening of February 20 with mid-level temperatures cooling to -3°C/-4°C and wind flow becoming more uniformly southwesterly areawide; additionally, any stable layers were able to get mixed out so that seeding plumes were able to rise to cloud base.

Problems/issues: The propane company was unable to reach site NE5 due to wet ground from recent excessive rain and would try again after the storm concludes. At site NE8, a solution leak could not be fixed by the operator, so the site was left off and the field technician was informed.

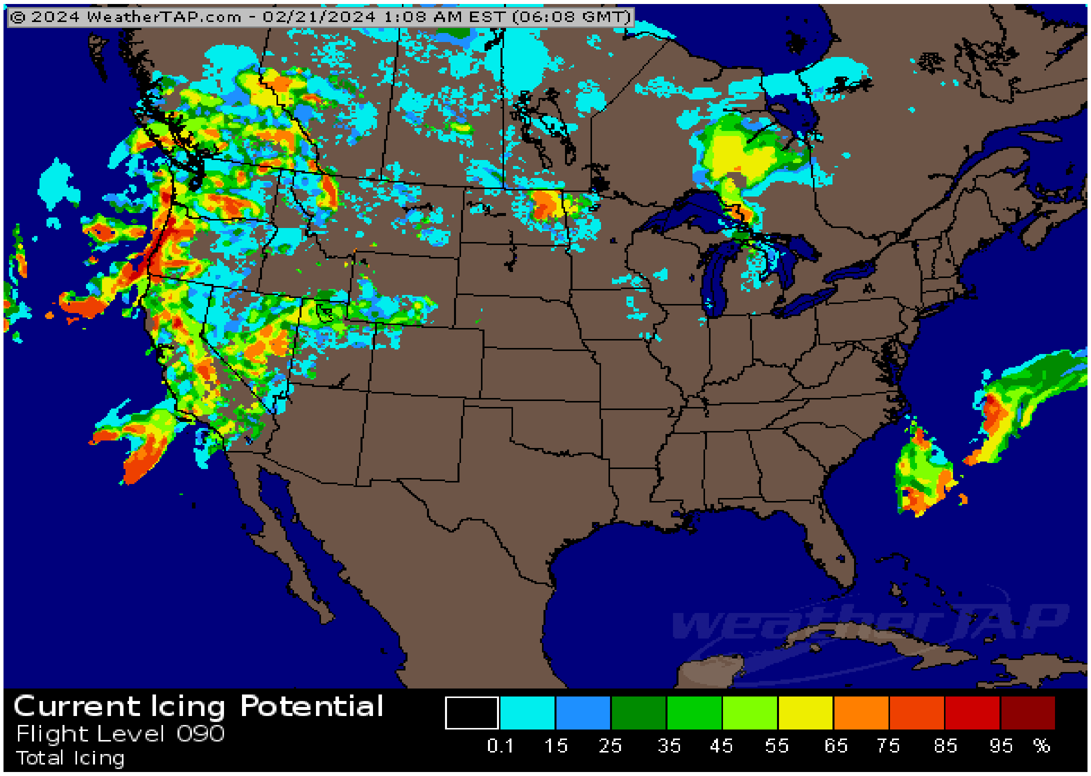

Figure 4.29. **Potential for icing at 9000 feet MSL, given as a percent probability. Courtesy of Weathertap.com website.**

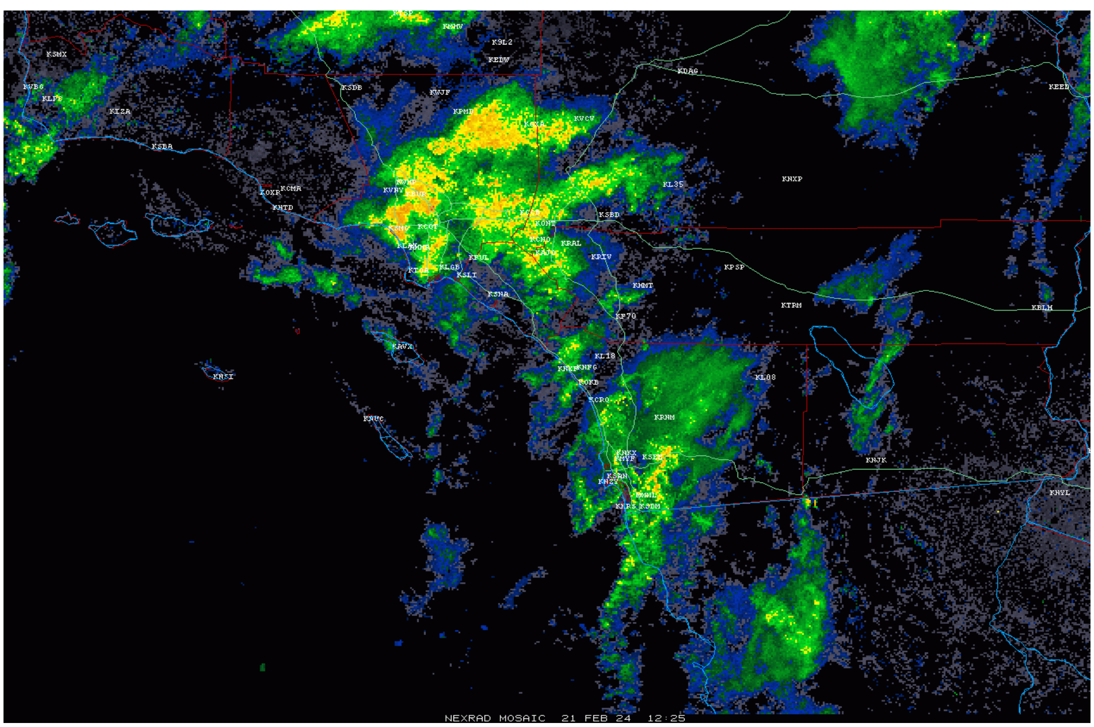

Figure 4.30. **Radar image from 0425 PST on February 21, the back end of the storm period but the most seedable portion of the storm.**

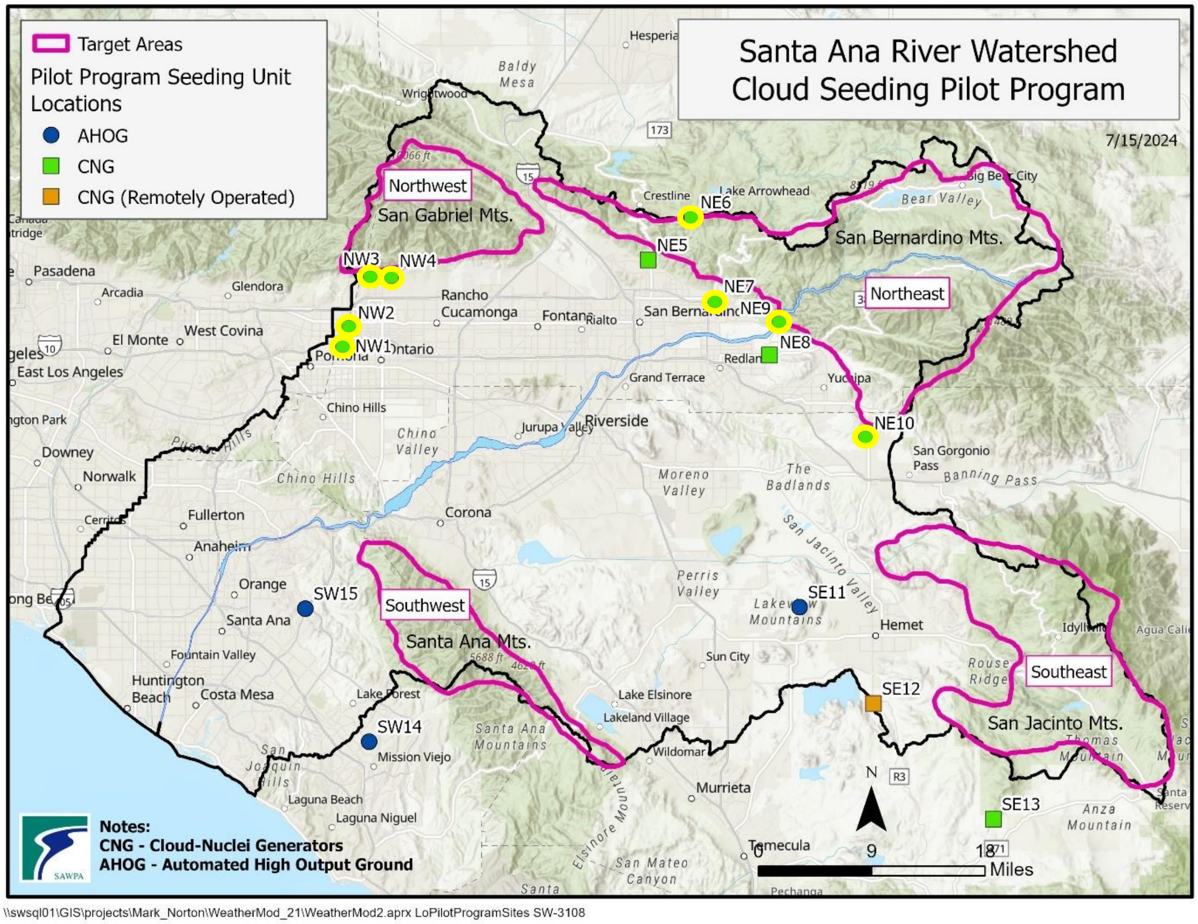

Figure 4.31. Map showing active seeding sites on February 20-21, 2024, indicated by yellow circles.

February 26 (no seeding)

An upper-level low west of the area was attempting to push showers into the project area during the day but was battling forcing from a passing trough of low pressure north of the area. Although showers did eventually push into and across the area during the day and into the early evening hours, most of the moisture was below 8000 feet with little snow above that. Because of the lack of moisture for areas that would see snow, seeding operations were not viable for this event. Figure 4.32 shows a visible satellite image from the afternoon.

Seedability: POOR. The moisture was shallow and below 8000 feet, which did not bode well for snowfall in the mountains. Temperatures aloft were near freezing, and lightly warmer than what is ideal for seeding operations.

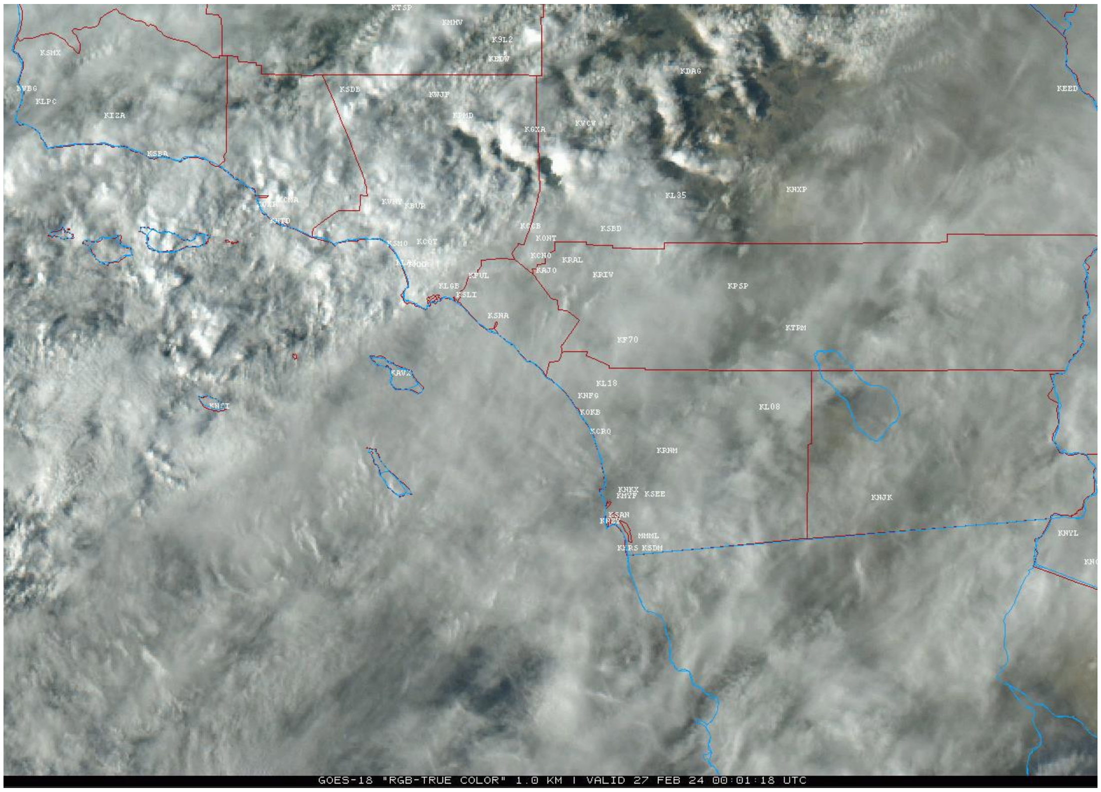

Figure 4.32. Visible satellite imagery from 1600 PST on February 26, during the latter part of the storm.

MARCH 2024

March 2-3 (no seeding)

A trough of low pressure was located over the West Coast states, with southern California situated at the base of the trough. Strong southwesterly flow was in place with mountain areas as well as San Gorgonio Pass seeing sustained 35-50 mph winds with gusts to 90 mph. Some moisture was advecting in on the southwesterly flow with precipitable water (PWAT) levels around 0.75-0.85 inches as measured on the San Diego soundings. Scattered showers, with snow above 5000-6000 feet moved across the area from the morning of March 2 through the early morning of March 3. The soundings from San Diego also revealed stable layers in the lower atmosphere between 5000 and 10,000 feet. The combination of the stable layers and strong winds precluded seeding operations from taking place. Figure 4.33 shows the effects of strong winds and stable layers present in southern California during the event, with wave clouds developing downwind of the mountains.

Seedability: POOR. Strong winds in the area would produce long, thin seeding plumes from the units that would likely overshoot the target areas. Additionally, balloon soundings indicated a stable layer from 5000-10,000 ft which would prevent seeding plumes from rising. Finally, mid-level temperatures were close to freezing, which is a little warmer than ideal for seeding operations.

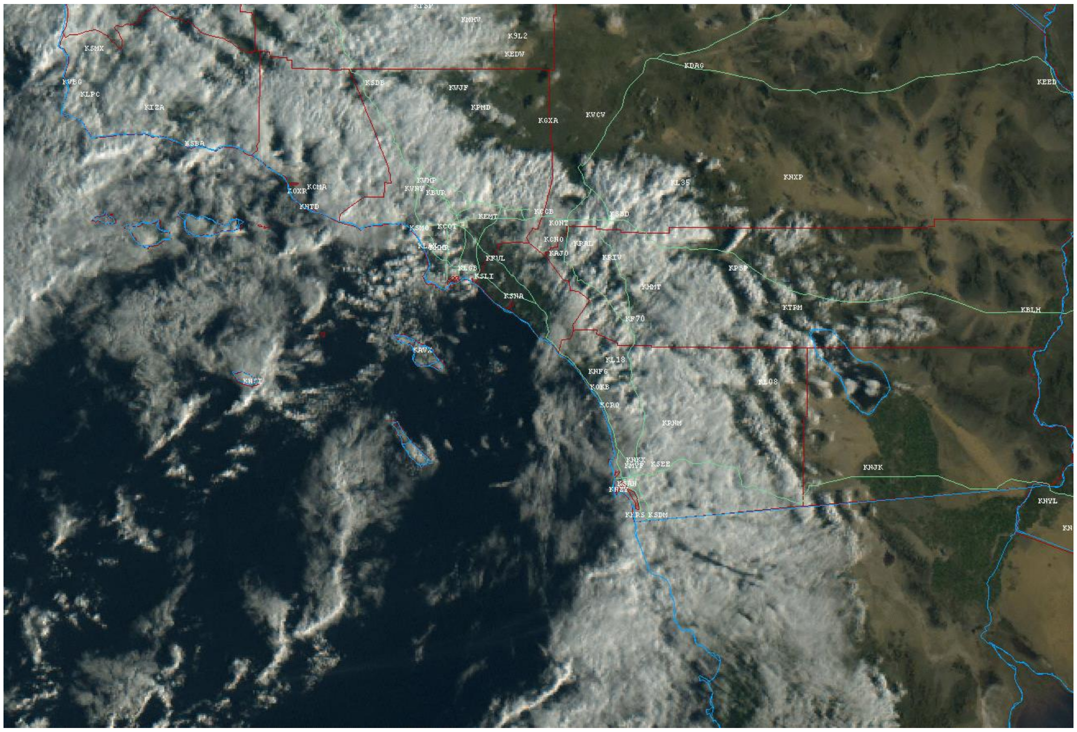

Figure 4.33. Visible satellite image from 0756 PST on March 2 showing wave clouds downwind of the southern California mountains due to strong winds and stable layers. Image from College of DuPage Weather.

__March 6-7__

On March 6, low pressure was located a couple hundred miles west of Point Conception. On the forward side of the low, lift and ample moisture (San Diego PWAT 0.51" early morning sounding) was poised to spread across the area in conjunction with a pocket of cold air aloft associated with the low. The low and its components moved across southern California during the afternoon and evening hours with showers. Figure 4.34 shows a visible satellite image from mid-afternoon on March 6. Figure 4.35 shows a radar image from early evening on March 6. Seeding operations began in the afternoon hours and continued overnight. Snow levels started out around 6000 feet but lowered to 5000 feet by the night of March 6 and remained there. As the low passed just south of the project area, showers began to taper off and by dawn on March 7, had ended with drier northwest flow moving into the area. Figure 4.36 shows the sites used for seeding during the event. Later in the afternoon and early evening on March 7, scattered thunderstorms developed north and northwest of the area and moved southward through the project area, with the main impacts to the Inland Empire. AHOGS and CNGs were not in the correct locations for targeting this activity, so seeding operations for this part of the storm event did not occur.

Seedability: FAIR, becoming EXCELLENT. At the beginning of the event there was a temperature inversion around 850 mb, but all other factors for seeding – temperature, moisture availability, and winds – were fair to good for seeding operations. As the storm progressed, the inversion quickly mixed out and temperatures continued to cool to -6°C. While precipitation amounts remained on the lower side, the conditions in place became amenable to seeding operations.

Problems/issues: When the operator at NW2 started the CNG, it started leaking solution. The operator could not fix it, so the unit did not operate, and the field technician was notified. Similarly, at NE9, a leak was found after starting the CNG and could not be fixed, so the unit did not operate during the storm period.

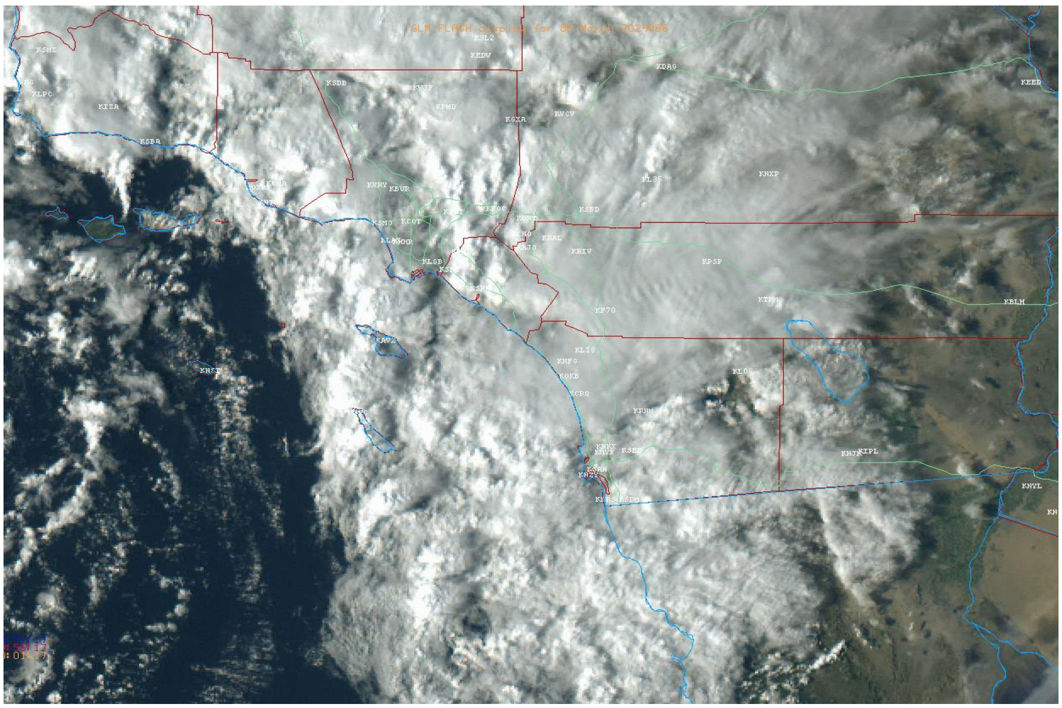

Figure 4.34. Visible satellite image from 1601 PST on March 6, showing convective clouds over the area.

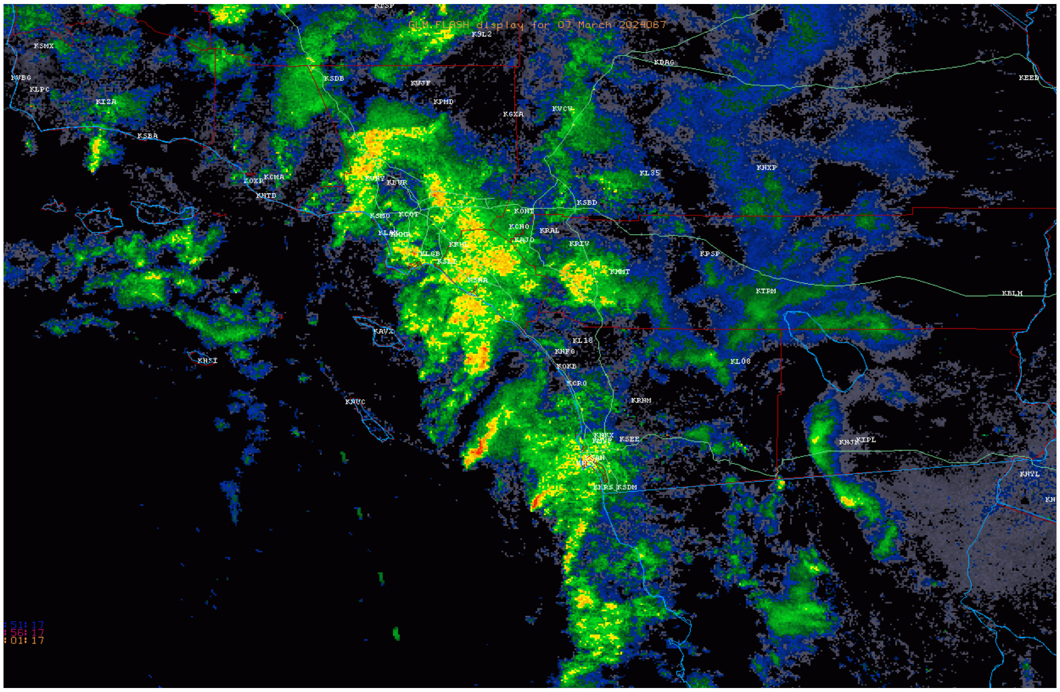

Figure 4.35. Radar image from 1805 PST on March 6, showing light to moderate showers across the area. Image taken from College of DuPage Weather website.

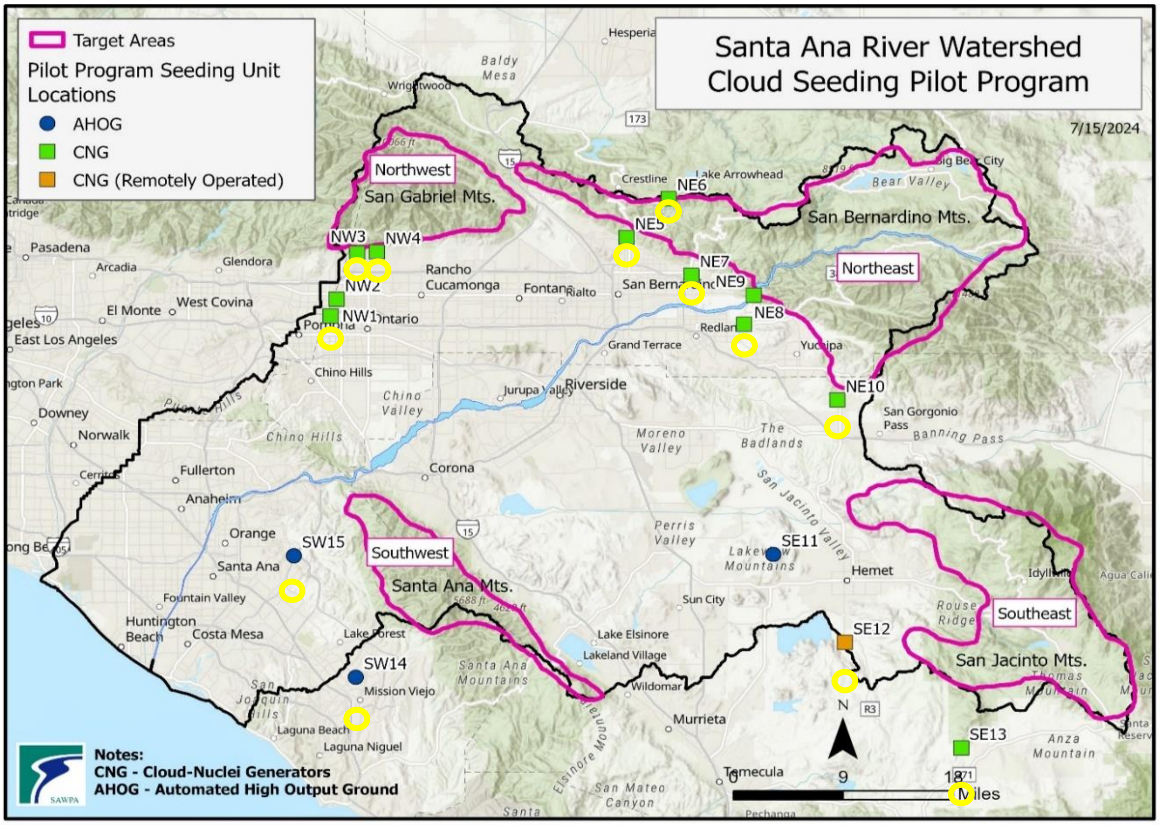

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Figure 4.36. Map showing active seeding sites on March 6-7, 2024, indicated by yellow circles.

March 14-18 (no seeding)

An atypical weather pattern set up during this four-day period, with an upper low getting cutoff from the main flow and sitting over the Desert Southwest, roaming around Arizona and southeast California. This placement put the Pilot Program under north/northeast flow throughout the period. With occasional disturbances rotating around the low, these features were accompanied by waves of showers (rain/snow) moving across primarily the mountain areas as shown in Figure 4.37; in the latter part of the period, heavier showers and thunderstorms moved across the entire area. Figure 4.38 shows lightning strikes during the late afternoon/early evening of March 15. Given that the program was designed to seed storm events for which wind flow was southeasterly, southerly, southwesterly, westerly or northwesterly, no seeding operations took place due to the predominant north to northeast flow. Snow totals in the mountains were impressive, with 1-2 feet in the higher portions of the NE target area.

Seedability: POOR (wind flow/direction). The primary hindrance to seeding operations was the wind flow across the project area due to the placement of the upper low and how its circulation affected the area, with mainly north to northeast winds, a setup not conductive to targeting as seeding units are all located south through west of the respective target areas. Despite the favorable precipitation amounts reported across the area, seeding operations would not have been able to target properly.

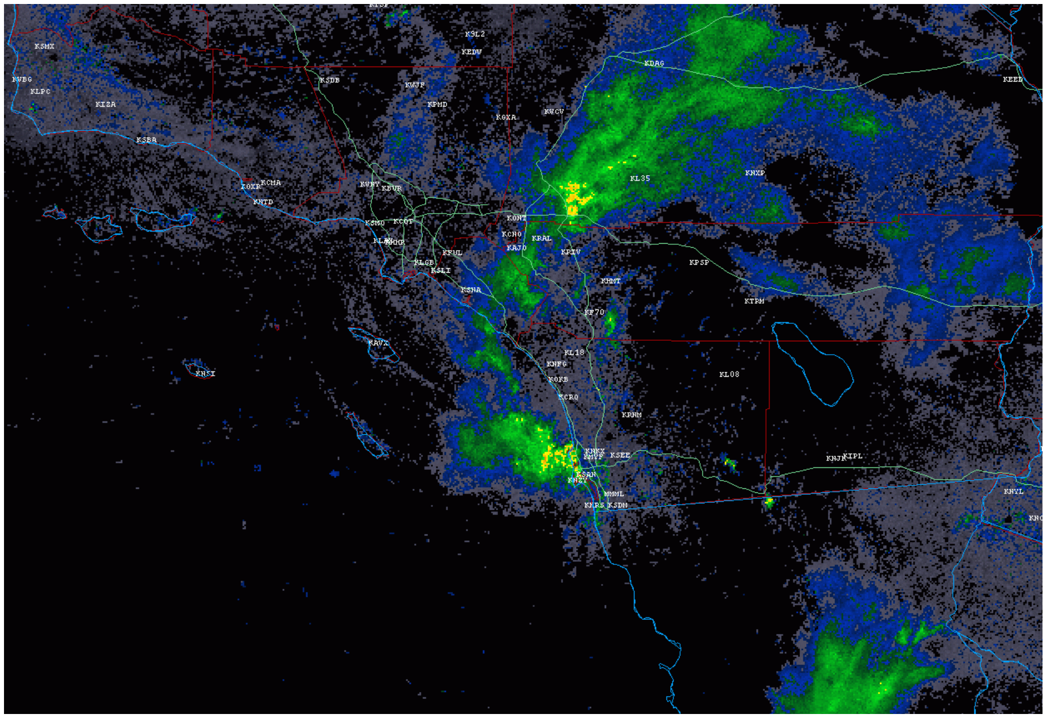

Figure 4.37. **Radar image from 0010 PDT on March 15, showing moisture flowing into the San Bernardino County Mountains from the northeast, with additional showers along the San Diego County coast.**

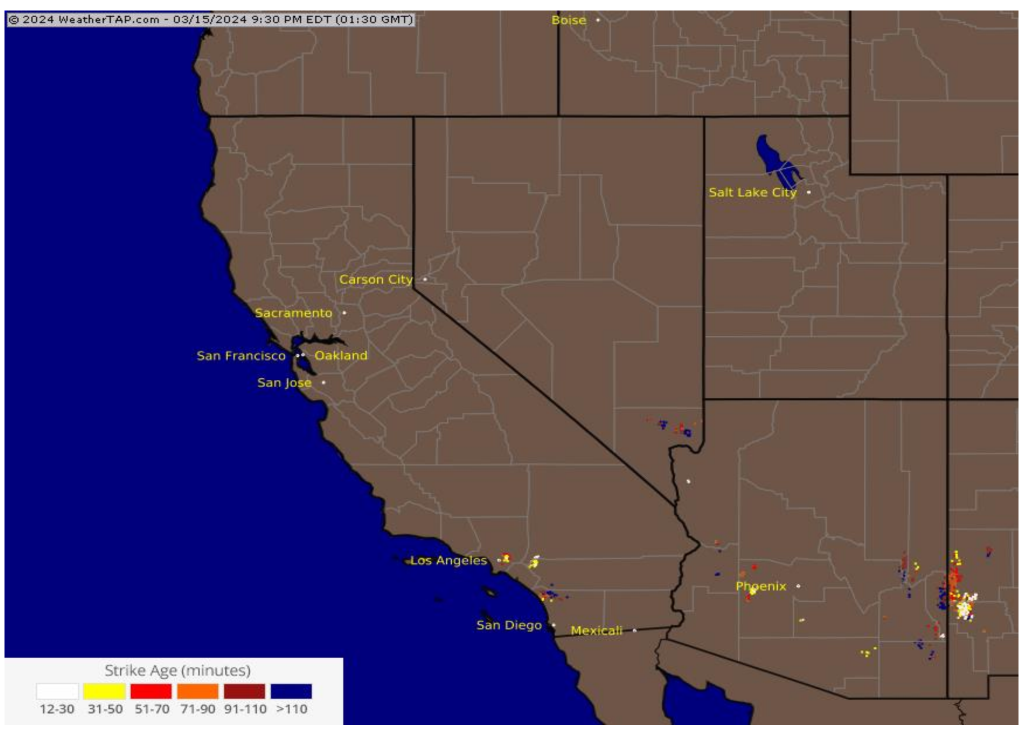

Figure 4.38. **Map showing lightning strikes over the southwest United States as of 1830 PDT on March 15. Legend explains color coding of strikes. Note the strikes in and near the SAWPA Project area. Image courtesy of WeatherTap, https://www.weathertap.com/ .**

March 23-24

An upper-level low was located off the Oregon coast on the morning of March 23, with the associated trough extending southward into waters west of southern California. Shown in Figure 4.39, the early morning sounding from San Diego showed the presence of a significant stable layer at 5000 feet ahead of the cold front, and as such any seeding activity would have to wait until this layer mixed out before seeding plumes could reach their intended target areas. The frontal band arrived during the mid to late morning hours with rain and higher elevation snow above 7000 feet. Behind the front, the airmass was more mixed and a bit unstable, and this is when seeding operations began for this storm event. Rain/snow showers and isolated thunderstorms continued through the afternoon hours, as shown in Figure 4.40. Winds were strong in the mountains, with gusts of 65-70 mph and this continued through the night, along with isolated to scattered rain and snow showers primarily affecting the eastern half of the project area. By the early morning of March 24, most activity had tapered off with just isolated mountain snow showers, but even these tapered off by mid-morning, and seeding operations were terminated. A late push of moderate to strong thunderstorms affected the northwestern parts of the project area, but their south to southeastward motion did not lead to the use of any of the AHOGS units. Figure 4.41 shows all active seeding sites for the storm event.

Seedability: GOOD. A stable layer/inversion existed early on around 5000 feet MSL but this did weaken/mix out as the storm progressed across the area. Wind flow was good for seeding plumes to target their respective areas for most of the storm event. Mid-level temperatures were a little warm at the start of the event but cooled to -4°C late in the day on March 23, and further to -10°C the following morning.

Problems/issues: Upon starting up site NE9, the operator reported that the CNG appeared to be lightly releasing solution; lowering the flow pressure fixed this. A few hours after starting up, remote site SE12 went out and could not get restarted. A visit later revealed a clogged nozzle that needed to be cleared.

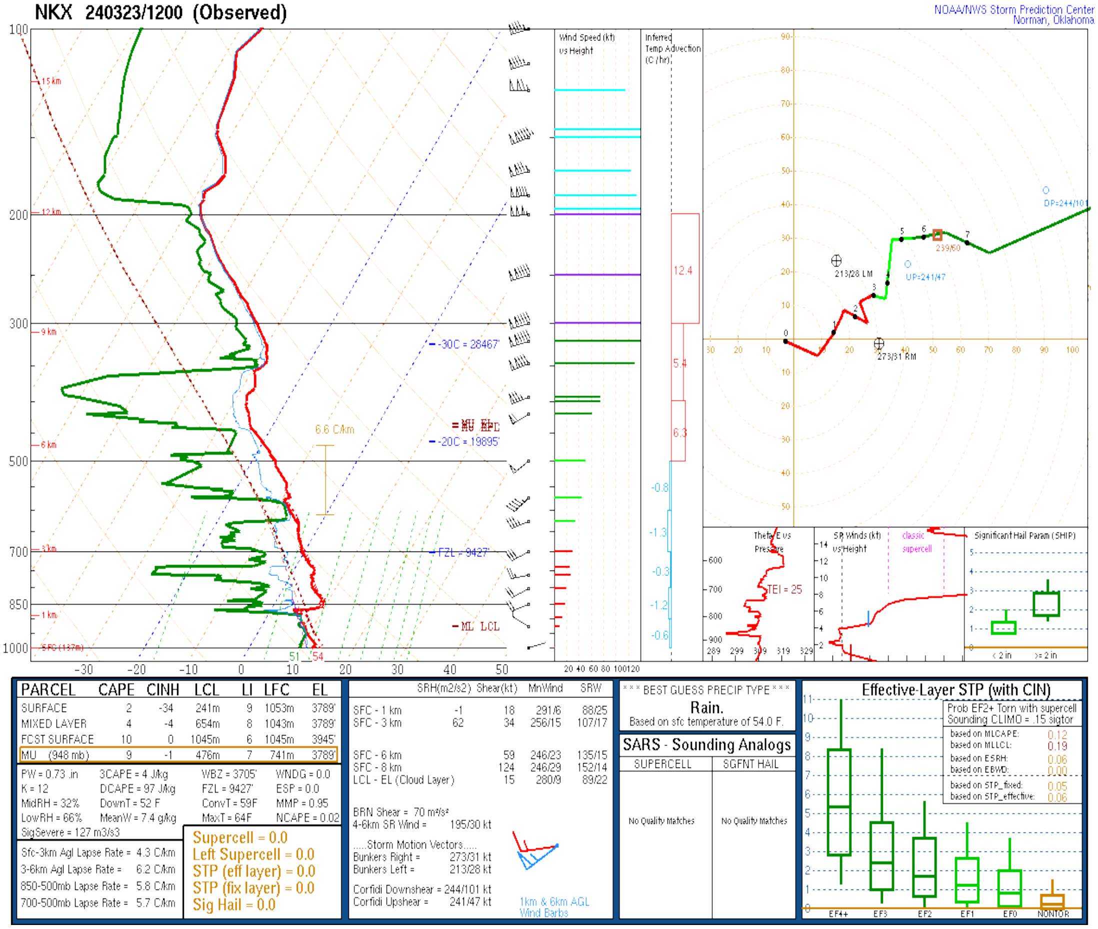

Figure 4.39. **Upper air balloon sounding from San Diego from 12Z (5 AM PDT) on March 23. Of interest is the upper left panel, showing the temperature (red line) and dewpoint (green line) with height. Note the abrupt turn to the right of the temperature profile at 850 mb and the abrupt left turn of the dewpoint profile, signifying a strongly stable/dry layer. Image courtesy of Storm Prediction Center website, https://www.spc.noaa.gov/ .**

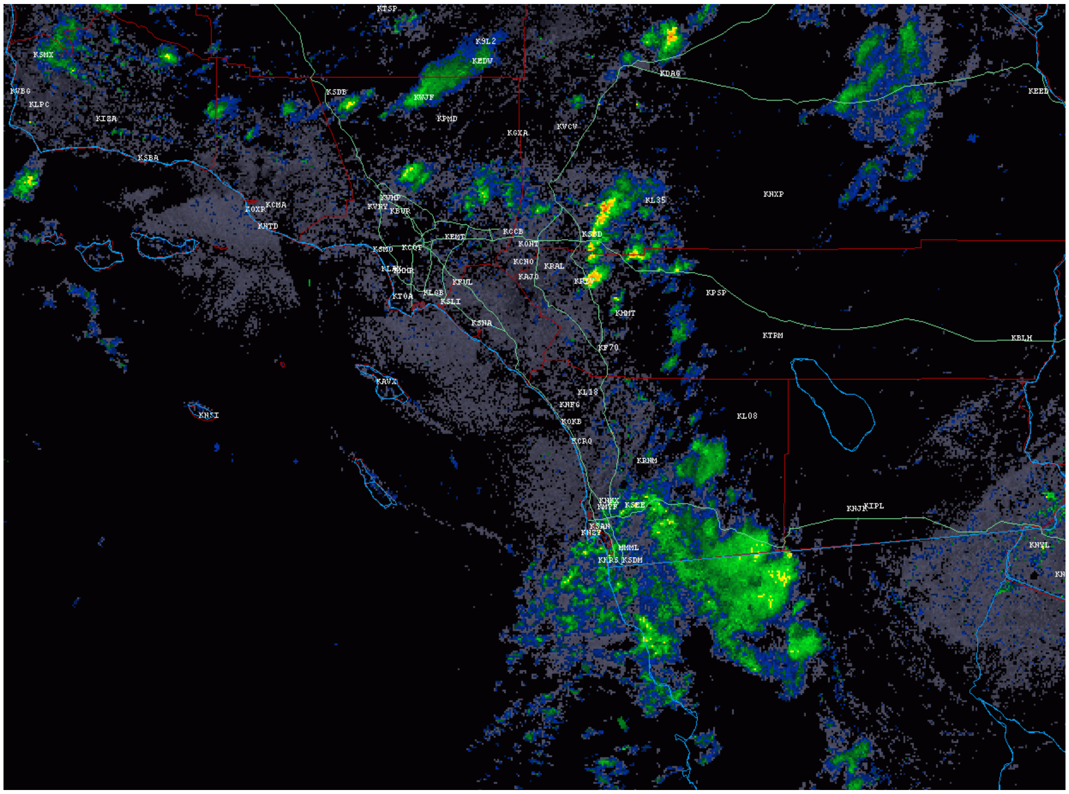

Figure 4.40. **Radar image from 1540 PDT on March 23, showing scattered showers and even a small band of thunderstorms affecting the SAWPA area.**

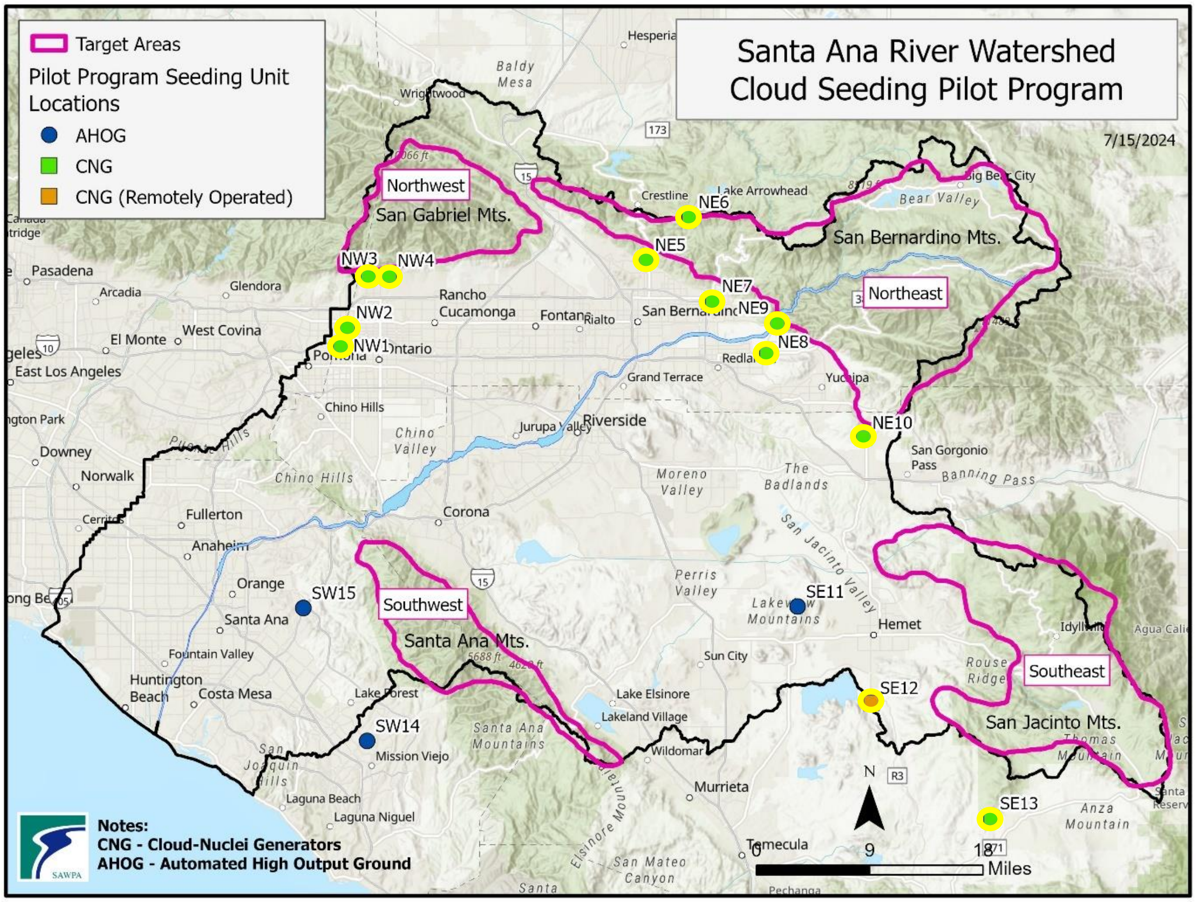

Figure 4.41. **Map showing active seeding sites on March 23-24, 2024, indicated by stars.**

March 30-31

A deep, cold upper-level low was located off the central California coast on the morning of March 30. A shortwave disturbance accompanied by a cold front was rotating around the south side of the low and moved across southern California during the morning and afternoon hours with a band of moderate to locally heavy rain and higher elevation snow. Figure 4.42 shows a radar image from mid-morning of March 30 as the cold front was crossing the area, with snow levels lowering behind the front to around 4500 feet, evidence of which was seen on the Lake Gregory (4554 feet) webcam showing heavy snow falling. Once the band of precipitation exited to the east by late afternoon, there was a period during the evening where a dry slot moved in, and precipitation was at a relative lull. In the evening, convective cells, including thunderstorms, hovered offshore with a few light showers making their way inland. The upper low was located west-southwest of Point Conception, as shown in Figure 4.43, and continuing to move southward. During the overnight period, showers moved inland across much of the area with snow showers in the mountains. By dawn on March 31, the upper low was located southwest of Los Angeles and was beginning to make a turn toward the east to move toward the coast. Scattered rain and snow showers continued to spread across the area during the morning and early afternoon hours, with low level winds becoming less conducive for proper targeting as the afternoon progressed. Seeding sites were gradually shut off in the afternoon. Figure 4.44 shows the active seeding sites for the March 30-31 event.

Seedability: GOOD. Despite the presence of weak stable layers at times and moderate winds, all other parameters for seeding were ideal, including mid-level temperatures, wind direction and moisture availability.

Problems/issues: Two sites, NW2 and NE8 were left off during the storm event due to low solution levels.

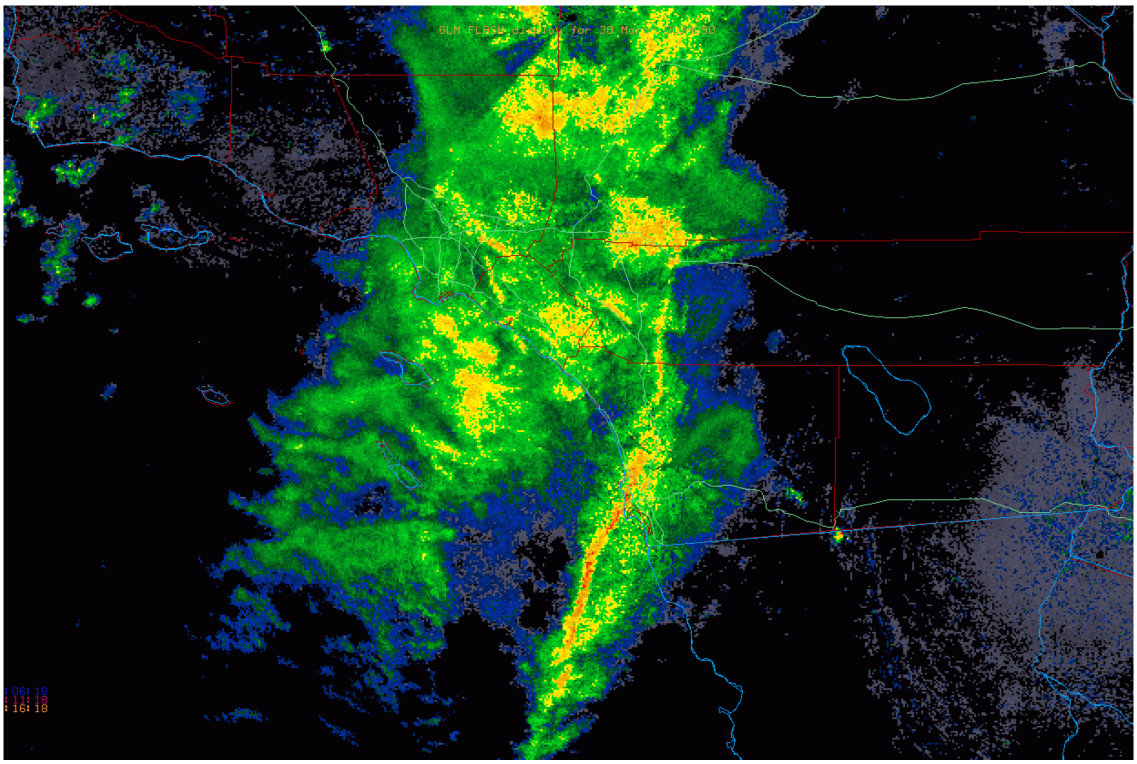

Figure 4.42. Radar image from 0920 PDT on March 30. The cold front can be seen on radar as a fine line stretching from near San Bernardino southward through San Diego and offshore.

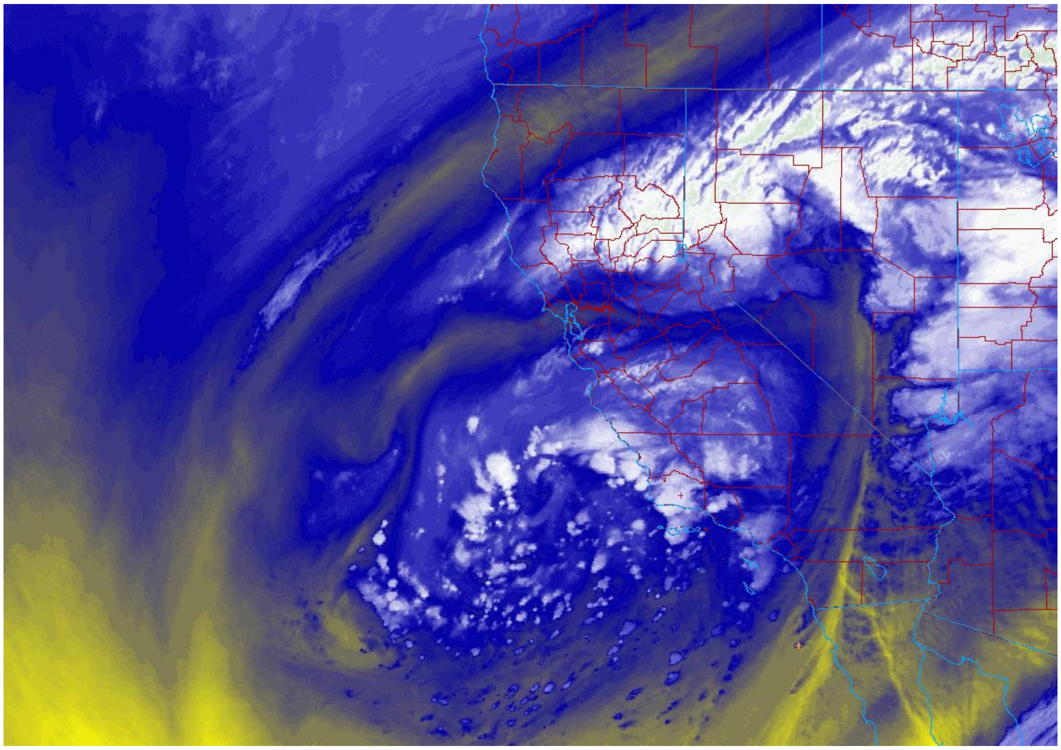

Figure 4.43. **Water vapor satellite image from 2151 PDT on March 30, showing the upper low centered to the west-southwest of Point Conception, with abundant convective cells around the low.**

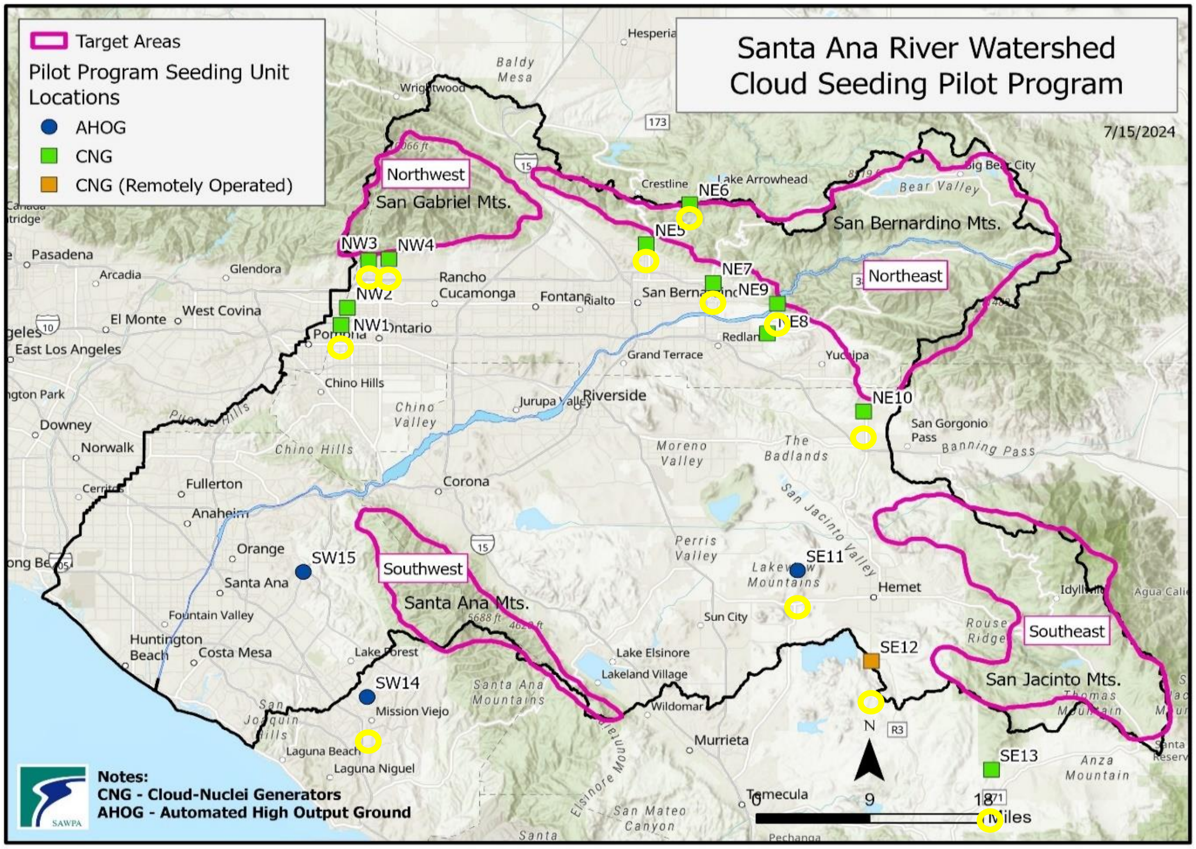

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Figure 4.44. **Map showing active seeding sites on March 30-31, 2024, indicated by yellow circles.**

APRIL 2024

April 5

An upper-level low was located over northern California early in the morning, with the associated trough lying across most of the state. Very cold air aloft associated with the trough had spread across the project area and was helping to destabilize the airmass. Scattered rain and higher elevation snow showers moved across the area from early morning through the afternoon and into the evening hours before tapering off. Figure 4.45 shows a visible satellite image from the morning of April 5, and Figure 4.46 shows a convectively active radar across the project area during the afternoon. Snow levels were low because of the cold air associated with the trough, with snow falling to 3000 feet. Snowfall in the mountains was generally 2-4 inches or less. Figure 4.47 shows which sites were used for seeding during the storm event.

Seedability: EXCELLENT. As the storm began, mid-level temperatures were very favorable, with the morning sounding on April 5 showing a temperature of -11°C at 700 mb. Moisture levels were on the low side but adequate for producing accumulating precipitation. Wind flow was good for proper targeting of the four areas. Convection was seeded with AHOGS flares as they moved across the area.

Problems/issues: None.

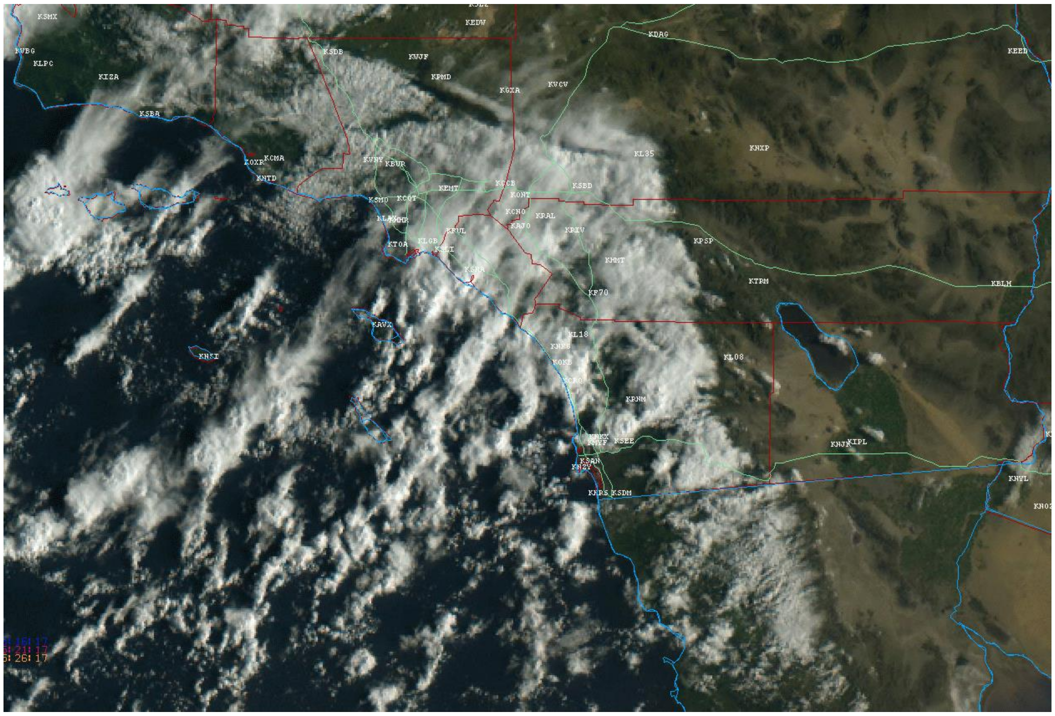


Figure 4.45. **Visible satellite image from 0831 PDT on April 5, showing convective clouds over portions of the SAWPA area. Image taken from College of DuPage Weather website.**

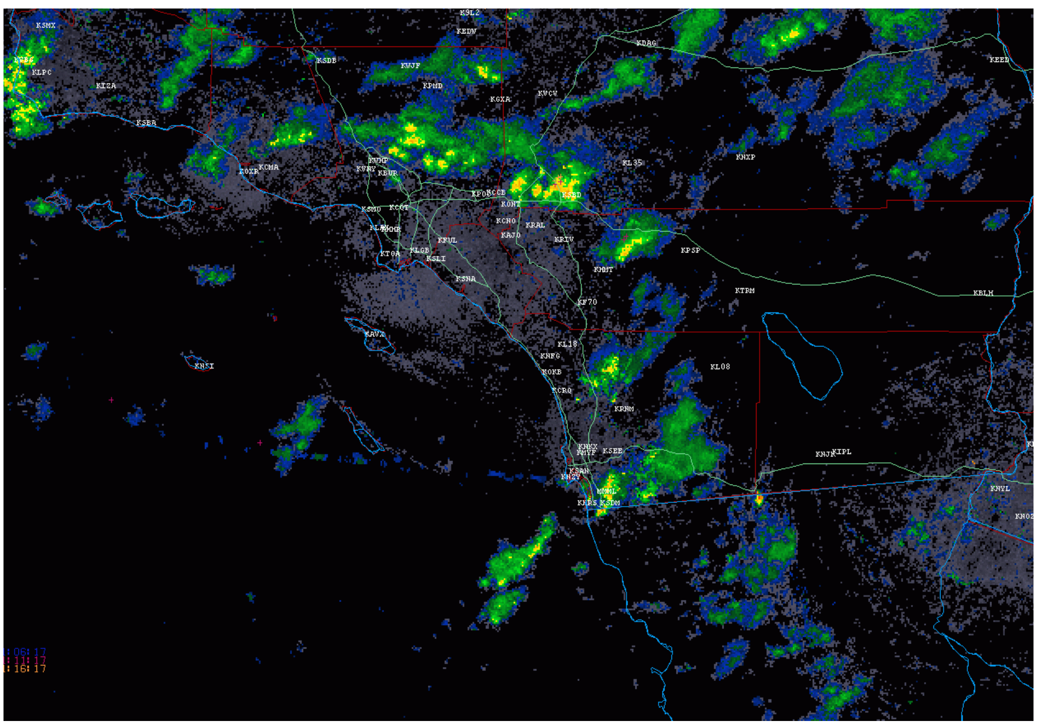
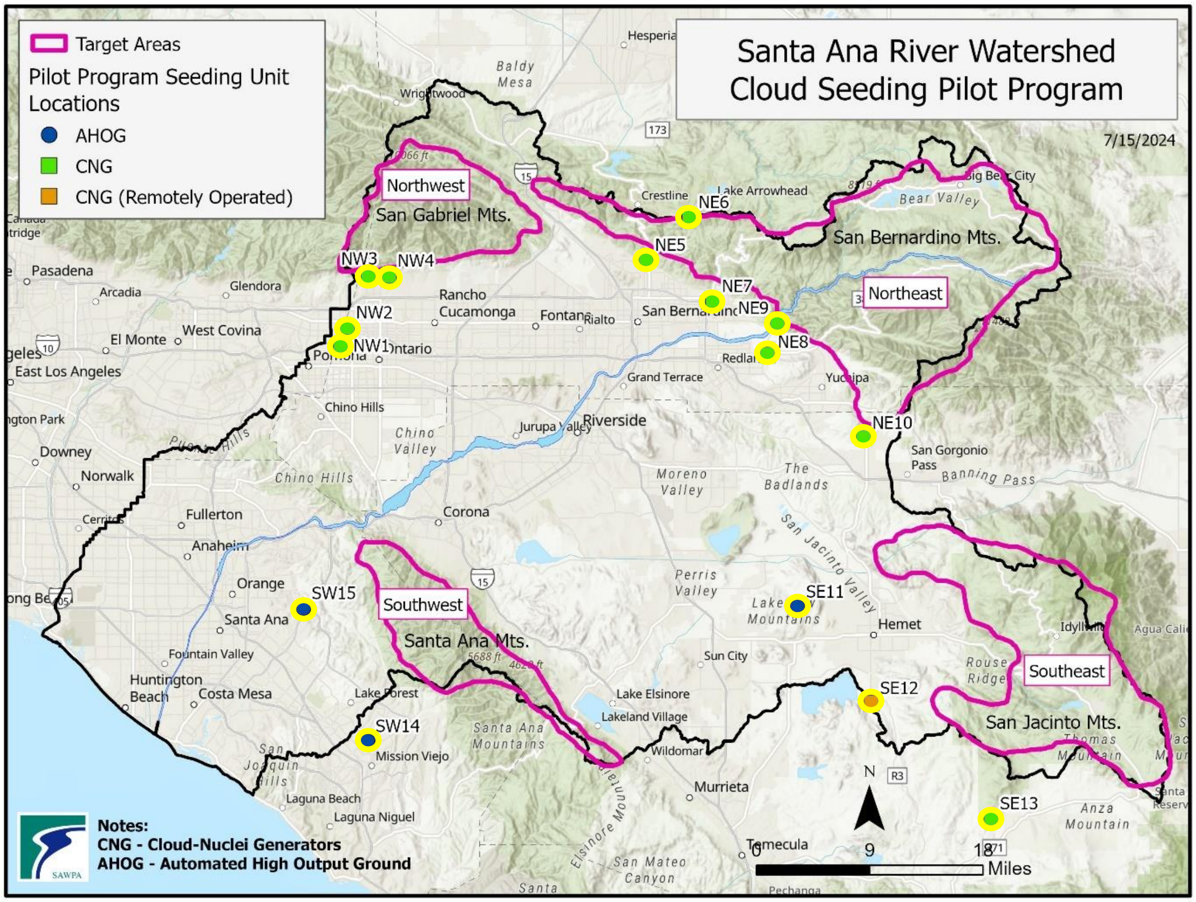


Figure 4.46. **Radar image from 1420 PDT on April 5, showing scattered showers and isolated thunderstorms across three of the four SAWPA target areas. Image taken from College of DuPage Weather website.**



\\swsql01\GIS\projects\Mark_Norton\WeatherMod_21\WeatherMod2.aprx LoPilotProgramSites SW-3108

Figure 4.47. Map showing active seeding sites on April 5, 2024, indicated by yellow circles.

April 13-14

An upper low approached the Bay area during the afternoon hours of April 13. A lobe of energy rotating cyclonically/counterclockwise around the low moved across southern California during the afternoon and evening hours accompanied by a wave of showers within southwest flow. Figure 4.48 shows radar imagery during this portion of the event. Snow levels with this first round of precipitation were around 6500 feet, but colder air behind this wave of showers helped lower snow levels to 4500 feet. There was a break in the precipitation during the overnight hours as the first lobe of energy pushed east of the area. The upper low moved into northern and central California on April 14 and began to weaken. A second lobe of energy rotating around the low moved across southern California during the afternoon and early evening hours. With the colder air aloft in place, a few isolated thunderstorms mixed in with the moderate showers that developed and moved across the project area. Figure 4.49 shows radar imagery during this portion of the event. A couple of flares were burned at the SW15 AHOGS site. Activity with this second impulse ended during the evening as it pushed east of the area. Figure 4.50 shows all active seeding sites during the storm event.

Seedability: POOR to FAIR first wave, FAIR to GOOD second wave. Initially, temperatures were rather warm (+1°C at 700 mb) and a significant inversion was in place as observed on the sounding from San Diego, indicative of the seeding plumes having difficulty reaching cloud base. As the storm continued and the colder portion moved closer, temperatures became more favorable at -3°C (though still marginal for seeding) and stable layers/inversions were mostly mixed out. Also, the SE target area was not in a position for favorable targeting from the seeding units and, as such, sites SE11-13 were not activated.

Problems/issues: NW1 and NW2 were not activated for the first wave of precipitation. Initially, the operator said they could turn them on, but later informed meteorologist, after the event had started, that they were not going to be able to get to the sites. The operator was able to start and stop both sites during the second wave of precipitation.

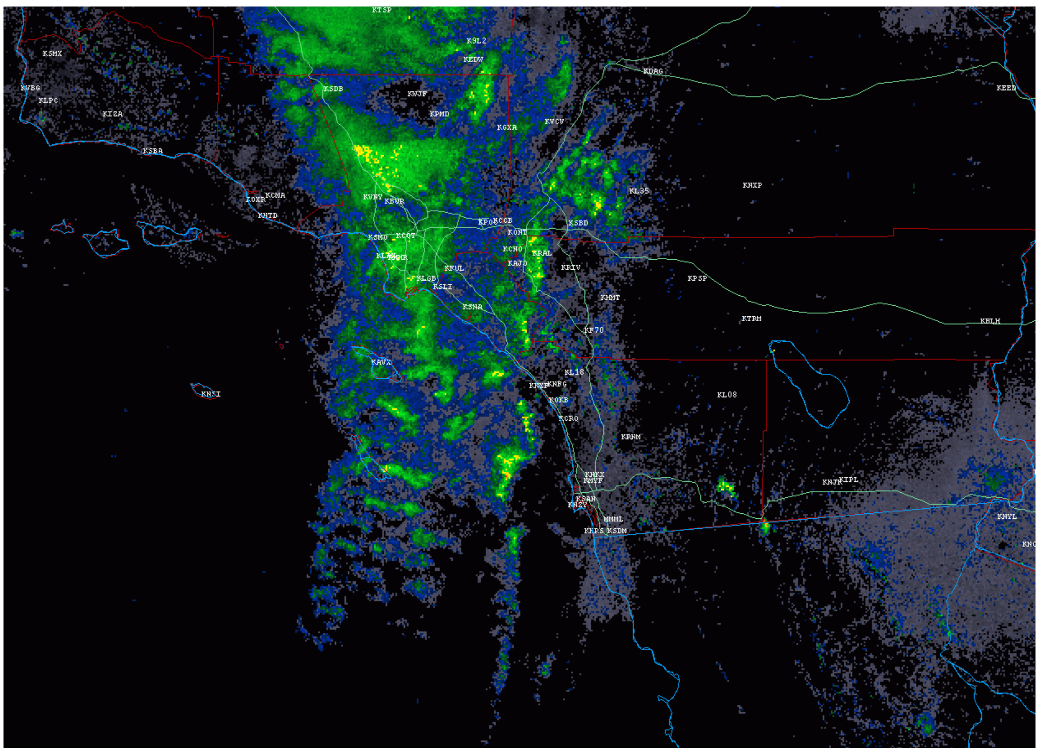


Figure 4.48. **Radar image from 1945 PDT on April 13 showing first wave of showers moving into the SAWPA area.**

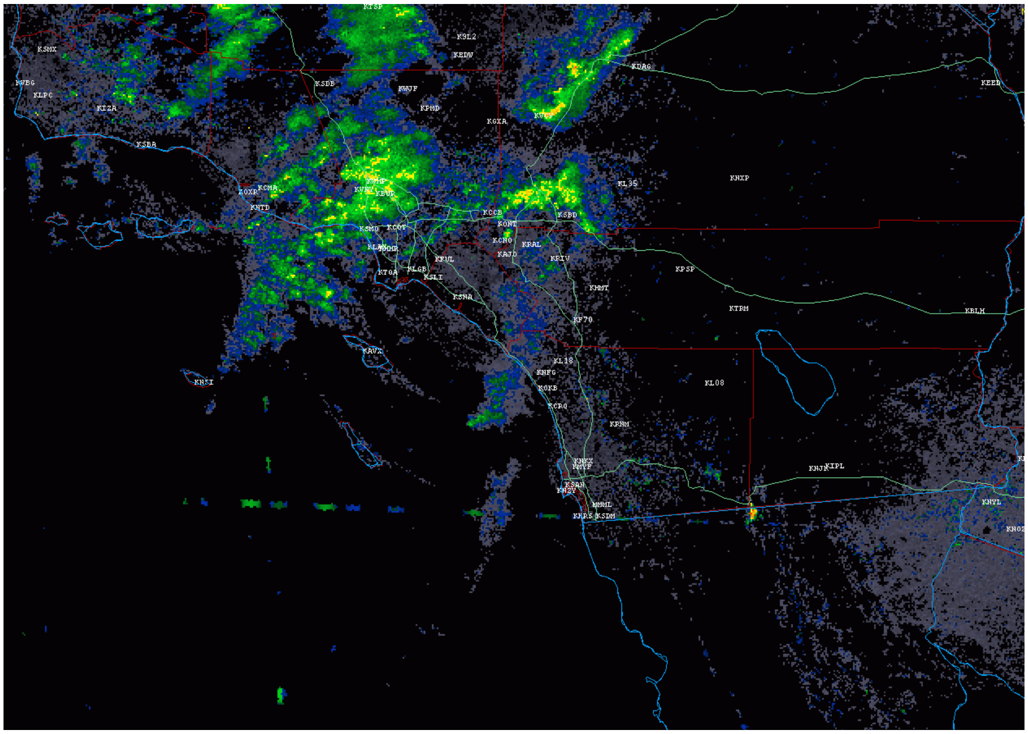


Figure 4.49. **Radar image from 1415 PDT on April 14 showing the second wave of showers moving into the SAWPA area.**

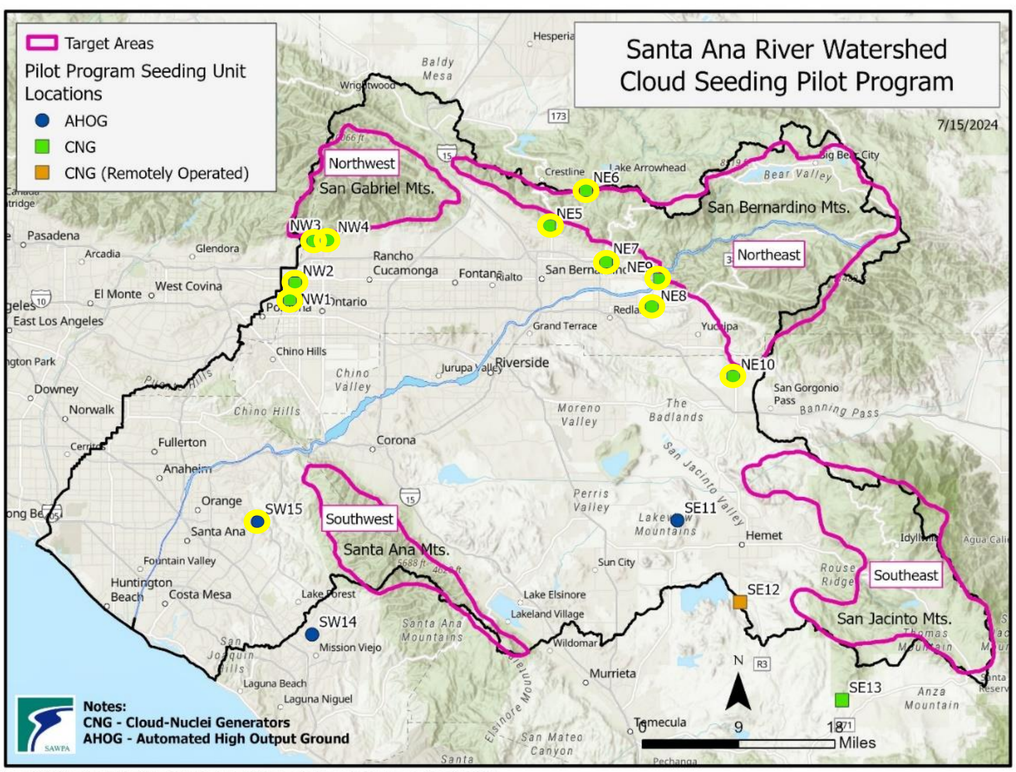


Figure 4.50. **Map showing active seeding sites on April 13-14, 2024, indicated by yellow circles.**

4.2 Summary of Materials Used

November 2023

Date	Location	Time on	Time off	Total Hours	AgI (g)	Acetone (gal)
17-18-Nov	NW3	18/0045	18/1200	11.25	90	1.41
	NW4	17/2330	18/1245	13.25	106	1.66

November Total	**24.50**	**196**	**3.07**
Season	**24.50**	**196**	**3.07**

December 2023

Date	Location	Time on	Time off	Total Hours	AgI (g)	Acetone (gal)
21-22-Dec	NW3	21/1815	22/1615	22.00	176	2.75
	NW4	21/1845	22/1530	20.75	166	2.59
	NE5	21/1630	22/1900	26.50	212	3.31
	NE6	21/1900	22/1630	21.50	172	2.69
	NE7	21/2045	22/1930	22.75	182	2.84
	NE8	21/1615	22/1430	22.25	178	2.78
	NE9	21/1545	22/1445	23.00	184	2.88
	NE10	21/2015	22/2030	24.25	194	3.03
	SE12	22/0030	22/0915	8.75	70	1.09
	SE13	21/1830	22/1330	19.00	152	2.38

Date	Location	Time on	Time off	Total Hours	AgI (g)	Acetone (gal)
29-30-Dec	NW1	29/1630	30/1530	23.00	184	2.88
	NW2	29/1615	30/1515	23.00	184	2.88
	NW3	29/1715	30/1415	21.00	168	2.63
	NW4	29/1645	30/1445	22.00	176	2.75
	NE5	29/1845	30/1600	21.25	170	2.66
	NE6	30/0530	30/1430	9.00	72	1.13
	NE7	29/1915	30/1615	21.00	168	2.63
	NE8	29/1800	30/1245	18.75	150	2.34
	NE9	29/1815	30/1300	18.75	150	2.34
	NE10	29/1945	30/1700	21.25	170	2.66
	SE12	30/0700	30/1230	5.50	44	0.69
	SE13	30/0600	30/1230	6.50	52	0.81

December Total	**421.75**	**3374**	**52.72**
Season	**446.25**	**3570**	**55.79**

Date	Location	First Flare	Last Flare	Total Flares	AgI (g)
21-22-Dec	SE11	22/1115	22/1220	5	100
	SW14	22/0046	22/0046	1	20

Date	Location	First Flare	Last Flare	Total Flares	AgI (g)
30-Dec	SW14	30/0550	30/1400	3	60

December Total	**9**	**180**
Season	**9**	**180**

January 2024

Date	Location	Time on	Time off	Total Hours	AgI (g)	Acetone (gal)
Jan 03	NW1	0545	1215	6.50	52	0.81
	NW2	0530	1230	7.00	56	0.88
	NW3	0630	1215	5.75	46	0.72
	NE5	0730	1615	8.75	70	1.09
	NE6	0515	1730	12.25	98	1.53
	NE7	0745	1645	9.00	72	1.13
	NE8	0600	1545	9.75	78	1.22
	NE9	0630	1600	9.50	76	1.19
	NE10	0830	1745	9.25	74	1.16
	SE12	0630	1615	9.75	78	1.22
	SE13	0600	1400	8.00	64	1.00

Date	Location	Time on	Time off	Total Hours	AgI (g)	Acetone (gal)
Jan 20-21	NE5	20/1600	21/0915	17.25	138	2.16
	NE6	20/1515	21/0815	17.00	136	2.13
	NE7	20/1630	21/0930	17.00	136	2.13
	NE8	20/1345	21/0815	18.50	148	2.31
	NE9	20/1415	21/0830	18.25	146	2.28
	NE10	20/1730	21/1015	17.75	142	2.22
	SE13	20/1700	21/0815	15.25	122	1.91

Date	Location	Time on	Time off	Total Hours	AgI (g)	Acetone (gal)
Jan 21-22	NE5	21/1830	22/1900	24.50	196	3.06
	NE6	22/0500	22/1915	14.25	114	1.78
	NE8	21/1900	22/1815	23.25	186	2.91
	NE9	21/1915	22/1830	23.25	186	2.91
	NE10	21/1915	22/2000	24.75	198	3.09
	SE13	21/1915	22/1945	24.50	196	3.06

January Total	**351.00**	**2808**	**43.88**
Season	**797.25**	**6378**	**99.66**

Date	Location	First Flare	Last Flare	Total Flares	AgI (g)
Jan 03	SE11	1635	1645	2	40

Date	Location	First Flare	Last Flare	Total Flares	AgI (g)
Jan 20	SW14	1250	1250	1	20

Date	Location	First Flare	Last Flare	Total Flares	AgI (g)
Jan 22	SE11	1523	1548	4	80
	SW14	1042	1603	3	60

Jan Total	**10**	**200**
Season	**19**	**380**

February 2024

Date	Location	Time on	Time off	Total Hours	AgI (g)	Acetone (gal)
Jan 31-Feb 01	NW1	01/0645	01/1645	10.00	80	1.25
	NW2	01/0715	01/1615	9.00	72	1.13
	NW3	31/1730	01/1700	23.50	188	2.94
	NW4	31/1715	01/1615	23.00	184	2.88
	NE6	01/0515	01/1700	11.75	94	1.47
	NE8	01/0700	01/1445	7.75	62	0.97
	NE9	01/0715	01/1515	8.00	64	1.00
	NE10	01/0730	01/1900	11.50	92	1.44
	SE12	01/0415	01/1815	14.00	112	1.75
	SE13	01/0615	01/1830	12.25	98	1.53

Date	Location	Time on	Time off	Total Hours	AgI (g)	Acetone (gal)
Feb 20-21	NW1	20/1715	21/1000	16.75	134	2.09
	NW2	20/1745	21/1000	16.25	130	2.03
	NW3	20/1600	21/1130	19.50	156	2.44
	NW4	20/1630	21/1215	19.75	158	2.47
	NE6	20/1530	21/0945	18.25	146	2.28
	NE7	20/1445	21/1345	23.00	184	2.88
	NE9	20/1315	21/0945	20.50	164	2.56
	NE10	20/1415	21/1430	24.25	194	3.03

February Total	**289.00**	**2312**	**36.13**
Season	**1086.25**	**8690**	**135.78**

Date	Location	First Flare	Last Flare	Total Flares	AgI (g)
Feb 01	SE11	2255	2255	1	20

February Total	**1**	**20**
Season	**20**	**400**

March 2024

Date	Location	Time on	Time off	Total Hours	AgI (g)	Acetone (gal)
Mar 06-07	NW1	06/1700	07/0900	16.00	128	2.00
	NW3	06/1730	07/0730	14.00	112	1.75
	NW4	06/1700	07/0700	14.00	112	1.75
	NE5	06/1545	07/0845	17.00	136	2.13
	NE6	06/1500	07/0500	14.00	112	1.75
	NE7	06/1515	07/0900	17.75	142	2.22
	NE8	06/1430	07/0530	15.00	120	1.88
	NE10	06/1445	07/1000	18.75	150	2.34
	SE12	06/1415	07/0715	17.00	136	2.13
	SE13	06/1715	07/0600	12.75	102	1.59

Date	Location	Time on	Time off	Total Hours	AgI (g)	Acetone (gal)
Mar 23-24	NW1	23/1315	24/1115	22.00	176	2.75
	NW2	23/1345	24/1000	20.25	162	2.53
	NW3	23/1245	24/1115	22.50	180	2.81
	NW4	23/1215	24/1045	22.50	180	2.81
	NE5	23/1345	24/1230	22.75	182	2.84
	NE6	23/1430	24/0830	18.00	144	2.25
	NE7	23/1415	24/1300	22.75	182	2.84
	NE8	23/1215	24/0845	20.50	164	2.56
	NE9	23/1230	24/0845	20.25	162	2.53
	NE10	23/1515	24/1345	22.50	180	2.81
	SE12	23/1400	23/1845	4.75	38	0.59
	SE13	23/1415	24/0830	18.25	146	2.28

Date	Location	Time on	Time off	Total Hours	AgI (g)	Acetone (gal)
Mar 30-31	NW1	30/0800	31/1400	30.00	240	3.75
	NW3	30/1145	31/1430	26.75	214	3.34
	NW4	30/1115	31/1500	27.75	222	3.47
	NE5	30/0845	31/1600	31.25	250	3.91
	NE6	30/0745	31/1500	31.25	250	3.91
	NE7	30/0915	31/1630	31.25	250	3.91
	NE9	30/0700	31/1515	32.25	258	4.03
	NE10	30/0945	31/1700	31.25	250	3.91
	SE12	30/0530	31/1430	33.00	264	4.13
	SE13	30/0615	31/1500	32.75	262	4.09

March Total	**700.75**	**5606**	**87.59**
Season	**1787.00**	**14,296**	**223.38**

Date	Location	First Flare	Last Flare	Total Flares	AgI (g)
Mar 06	SW14	1526	1526	1	20
	SW15	1514	1523	2	40

Date	Location	First Flare	Last Flare	Total Flares	AgI (g)
Mar 30-31	SE11	31/1029	31/1029	1	20
	SW14	30/0706	30/0722	2	40

March Total	**6**	**120**
Season	**26**	**520**

April 2024

Date	Location	Time on	Time off	Total Hours	AgI (g)	Acetone (gal)
Apr 05	NW1	0630	1915	12.75	102	1.59
	NW2	0630	1545	9.25	74	1.16
	NW3	0930	1800	8.50	68	1.06
	NW4	0945	1815	8.50	68	1.06
	NE5	0730	1945	12.25	98	1.53
	NE6	0615	2015	14.00	112	1.75
	NE7	0745	2015	12.50	100	1.56
	NE8	0645	1945	13.00	104	1.63
	NE9	0645	1930	12.75	102	1.59
	NE10	0830	2045	12.25	98	1.53
	SE12	1000	1900	9.00	72	1.13
	SE13	0615	1900	12.75	102	1.59

Date	Location	Time on	Time off	Total Hours	AgI (g)	Acetone (gal)
Apr 13-14	NW1	14/1200	14/1900	7.00	56	0.88
	NW2	14/1230	14/1930	7.00	56	0.88
	NW3	13/1745	14/1830	24.75	198	3.09
	NW4	13/1815	14/1915	25.00	200	3.13
	NE5	13/1845	14/2015	25.50	204	3.19
	NE6	13/1745	14/0600	12.25	98	1.53
	NE6	14/1245	14/2045	8.00	64	1.00
	NE7	13/1915	14/2045	25.50	204	3.19
	NE8	13/1715	14/1815	25.00	200	3.13
	NE9	13/1700	14/2130	25.50	204	3.19
	NE10	13/2015	14/2130	25.25	202	3.16

April Total	**348.25**	**2786**	**43.53**
Season	**2135.25**	**17,082**	**266.91**

Date	Location	First Flare	Last Flare	Total Flares	AgI (g)
Apr 05	SE11	1346	1346	1	20
	SW14	0835	0856	2	40
	SW15	0802	0802	1	20

Date	Location	First Flare	Last Flare	Total Flares	AgI (g)
Apr 14	SW15	1545	1608	2	40

April Total	**6**	**120**
Season	**32**	**640**

<u>5.0 CONCLUSIONS AND RECOMMENDATIONS</u>

The first season of precipitation enhancement for the Santa Ana River Watershed Cloud Seeding Pilot Program began on November 15, 2023, and continued through April 15, 2024. A total of 13 storm events were seeded over a total period of 22 days within the operational season, with 2135.25 hours of seeding runtime from 12 ground-based CNG units and 32 silver iodide (AgI) flares deployed from three AHOGS units. The 2023-2024 season saw above normal precipitation across southern California including the project area. One suspension period was enacted due to a significant Atmospheric River event that occurred from February 3 through February 8, 2024, and brought over 15 inches of rainfall to some locations along with over seven feet of snow in others. During the operations of the Pilot Program, mechanical and logistical issues were encountered at a few of the sites during the season.

Overall, the 2023-2024 season showed that the program design for the Santa Ana River Watershed Cloud Seeding Pilot Program worked well with the weather patterns observed during the season and should continue for future seasons. There were a few operational occurrences during the season that were not anticipated, but these should be used as learning opportunities that could allow for adjustments to the program for future seasons. These are discussed in the following paragraphs.

During the first weeks of the Pilot Program, there were three incidents where local fire departments were contacted by local public members regarding a visible flame burning from the ground-based CNG units. This occurrence was perceived as fires burning in the hills since the public was not aware that there were instead active CNG units. Local fire departments were contacted and notified about the presence and locations of the CNG units within their service area initially through phone calls, followed by a memorandum developed by SAWPA. The memorandum allowed the local fire departments to respond appropriately to any future public inquiries/calls regarding the units**. It is recommended that for future seasons, these memorandums be re-issued to all fire departments near the locations of the seeding units, including the AHOGS sites prior to the start of the seeding season.**

The field technicians that helped troubleshoot mechanical issues and repair the seeding units during the season, as well as replenish seeding solution and flares, were dispatched from NAWC's main office in Utah, often at short notice. There were a couple of instances where logistics had minor impacts on operations. **For future seasons, it is strongly recommended that a field technician local to the SARW Project Area be trained and provided with all necessary information and supplies to service both CNGs and AHOGS.** Periodic operation of the sites to ensure units are working properly was conducted during the season, and this should continue, particularly if a couple of weeks pass without operation. These site "tests" should occur more frequently, our recommendation is to test them once per week when storms are not anticipated.

The 2023-2024 season demonstrated that the seeding sites selected worked well with most of the storm systems that affected the project area. Overall, the sites appeared to be effective at targeting their seeding material properly into the nearby target areas, and it is recommended that most sites remain for the following season. However, there are a couple of considerations regarding the current site locations. Throughout the season, HYSPLIT modeling revealed that, at times, sites NW1 and NW2 produced seeding plumes that did not impact the nearby target areas; also, these same sites are located very close to each other (i.e., 1.5 miles apart). **For future seasons, consideration should be given to moving one of the sites further northwest closer to the NW Target area. R**egarding site location, there was a four-day storm event in mid-March that had reasonably good conditions for seeding except for one main parameter, that being wind flow; the positioning of the storm system east of the area resulted in a prolonged period of north to northeast flow with precipitation, a setup that was not accounted for when designing the program as meteorological analysis during the feasibility study indicated this to be a rare occurrence. Given that this storm event did produce abundant precipitation in the mountains, this could be viewed as a missed opportunity. **Considerations should be given to the possibility of installing seeding sites on the east and northeast sides of the NE and SE target areas to account for this pattern, with the understanding that these sites may rarely be activated.**

REFERENCES

SAWPA, 2020. Santa Ana Watershed Weather Modification and Feasibility Study Final Report, prepared for the Santa Ana Watershed Project Authority, prepared by North American Weather Consultants, Inc., Riverside, CA, November 27, 2020.

SAWPA, 2022. Santa Ana River Watershed Weather Modification Project Initial Study & Mitigated Negative Declaration, prepared for the Santa Ana Watershed Project Authority, prepared by Catalyst Environmental Solutions, Riverside, CA, June 2022.

APPENDIX A

STORM EVENT CRITERIA TABLES 2023-24

November 15, 2023

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	N	The airmass with this storm was too warm for seeding operations.
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).		Convective regime suggests AHOGS, but too warm.
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	N	Supercooled water too high in cloud (see "D")
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	N	Temps at 700 mb were +4°C to +5°C.
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N	Stable low levels as measured on soundings.
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	N	Supercooled water too high in cloud (see "D")
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y	Winds were blowing from sites to target areas

November 17-18, 2023

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	N	Although temperatures eventually became marginally ideal, moisture did not.
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).		Had there been more moisture, may have had both CNGs and AHOGS.
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	N	Clouds not very tall/thick, and moisture appeared to be lacking.
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	N/Y	Not favorable at start of storm, became marginally favorable towards end of event.
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N/Y	Stability layers in place near ground but did mix out.
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	N	Had there been more moisture, may have had nucleation/precipitation
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y	Winds were favorable although perhaps a bit low as far as speed.

November 30, 2023

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	N	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).	Y/N	Convective cells that were mainly over the valley
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y/N	Most clouds remained on the shallow side, but some clouds did appear to have sufficient depth; some SLW
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	Y	700 mb temps were -2°C to -4°C
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N	Afternoon sounding showed shallow stable layer
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	Y	
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y/N	Winds started out favorable but became unfavorable

December 21-22, 2023

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	Y	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).	Y	Used both CNGs and AHOGS
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y	
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	Y/N	
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	Y/N	There were stable layers initially, but these mixed out eventually
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	y	
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y/N	Upper low positioning provided an uncommon flow pattern, but it was workable.

December 29-30, 2023

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	Y	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).	Y	Used all CNGs and flares from El Toro AHOGS unit.
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y	
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	N/Y	Warm at start of storm event, cooled to more ideal values during storm.
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N/Y	Stable layers present initially, mixed out later on.
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	Y	
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y	

January 3, 2024

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	Y	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).	Y	Convection and stratiform
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y	
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	Y	
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N/Y	Stable layers present initially.
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	Y	
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y	

January 7, 2024

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	N	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).		AHOGS would have been the main use
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y	
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	Y	Temps of -2°C to -6°C were in place at 700 mb.
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N/Y	Stable layers present initially, then mixed out
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	N	Wind speeds too strong for seeding, especially once plumes reach desired target areas.
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	N	Winds near AHOGS not good for seeding

January 20-21, 2024

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	Y	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).	Y	Both CNGs and AHOGS were used.
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y	
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	N/Y	Temperatures were not ideal with first wave of rain, but cooler temps aloft in place for second/third waves.
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N/Y	Stable layers present initially, mixed out later
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	Y	
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	N/Y	NW1/2 not favorable, the rest was favorable.

January 21-22, 2024

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	Y	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).	Y	Both CNGs & AHOGS used for seeding.
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y	
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	Y/N	May have been a little warm at times, would like to see at least -3 to -5°C.
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N/Y	Some early stability issues, mixed out with time.
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	Y	
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y	

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	Y	Had two sites that did not run because of low propane but this should not have impacted benefit goal.
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).	Y	There were some convective cells, did not use AHOGS due to flood issues
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y	Model data and PIREPs indicated presence of SLW.
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	N/Y	Temperatures cooled during event to favorable values
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N/Y	Stable at start, this eroded during storm
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	Y	Winds were strong in the mountains but not so at lower elevations
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y	HYSPLIT did show some plume variability but all of them affected target areas.

February 3-8, 2024

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	N	Storm period already at maximum efficiency.
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).		Both modes present.
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	N/Y	Periods with proper structure, other times not
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	N/Y	Too warm initially, later part of period more ideal temperature-wise
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N/Y	Some stability issues at times, other times it was unstable.
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	N/Y	Strong winds at times would result in long overshooting plumes
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y	

February 20-21, 2024

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	N	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).	Y	Both modes present, but no seeding with AHOGS due to wet conditions.
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y	
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	N/Y	Warm initially, temps cooled with time
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	Y/N	Stable layers present initially, mixed out over time
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	Y	
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y	

February 26, 2024

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	N	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).		Stratiform mainly
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	N	Moisture was confined to 8000 feet MSL and below.
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	N	Temps too warm aloft
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N/Y	Some stability early
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	Y	
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y	

March 2-3, 2024

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	N	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).		Both modes present
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y	
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	N	0°C at 700 mb.
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N	Significant stability present
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	N	Winds too strong
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y	Wind direction was good, just not speed.

March 6-7, 2024

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	Y	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).	Y	Both CNGs and AHOGS were employed for the storm.
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y	
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	Y	
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N/Y	Weak stable layers present initially
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	Y	
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y	

March 14-18, 2024

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	N	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).		Both modes present.
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y	
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	N/Y	Few times where temps at 700 mb were a little too warm for seeding.
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N/Y	Stable layers appeared from time to time
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	Y	IF the flow had been the opposite direction, nucleation time would have been good
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	N	North to northeast flow, not a direction program is setup for

March 23-24, 2024

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	Y	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).	Y	Mix of stratiform and convection but convection mainly avoided AHOGS sites.
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y	
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	N/Y	Warm initially, cooled as storm progressed
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	Y/N	Significant stable layer at start of storm event
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	Y	
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y	

March 30-31, 2024

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	Y	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).	Y	Both types of seeding units used
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y	
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	Y	
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N/Y	Weak stability first part of storm.
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	Y	
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y	

April 5, 2024

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	Y	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).	Y	Both AHOGS and CNGs were used.
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y	
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	N/Y	Warm at start, cooled significantly later on.
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N/Y	Stable layer present at start of event.
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	Y	
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y	

April 13-14, 2024

Criteria ID	Criteria Name	Criteria Description	Storm Met Criteria (Y/N)	Notes from NAWC (Per Storm)
A	Overall Pilot Goal	Maximum benefit for precipitation to the Santa Ana River Watershed and the four target areas.	Y	
B	Storm Type (CNG vs AHOGS)	Convective bands storm systems (lines of showers and thunderstorms) or stratiform storm systems (precipitation areas that are continuous and uniform in intensity).	Y	Both AHOGS and CNGs used for seeding.
C	Favorable Cloud Structure	Cloud type/structure favorable to seeding operations. This includes the presence of significant supercooled liquid water in cloud layers that can be reached by seeding material from available sites; these are determined from aircraft (pilot reports) and radar observations as well as model output.	Y	
D	Favorable Temperature	Temperatures favorable for transporting and mixing of seeding material to suitably cold (below -5°C) favorable cloud regions. This generally means a mountain crest height temperature near or below this value in the respective target areas from stratiform storm situations. In convective situations this temperature criterion is less important.	N/Y	Temps quite mild to start but cooled significantly later on.
E	Absence of Low-Level Layer Interference	No low-level stable layers that would severely restrict the mixing of seeding material to the necessary elevation.	N/Y	Stable layer present at start.
F	Nucleation Time	Sufficient time, given existing wind and temperature parameters, for the nucleation and precipitation process to produce seeding effects within the bounds of intended target area(s).	Y	
G	Site Specific Wind	Favorable wind direction(s) for material from a given site to traverse a reasonable portion of a seeding target area where the intended effects of seeding are being focused	Y	

APPENDIX B

SEEDING SUSPENSION CRITERIA

Certain situations require temporary or longer-term suspension of cloud seeding activities, with reference to well-considered criteria for consideration of possible suspensions, to minimize either an actual or apparent contribution of seeding to a potentially hazardous situation. The ability to forecast (anticipate) and judiciously avoid hazardous conditions is important in limiting any potential liability associated with weather modification and to maintain a positive public image.

There are three primary hazardous situations for the SAWPA program around which suspension criteria have been developed. These are:

- Rain-induced winter flooding
- Burn Scars
- Severe weather

In general, suspension will be considered when a storm is forecasted to be a 1 in 2-year event by magnitude or rainfall rates or in cases such as a series of atmospheric river events. Areas of particular concern include the Inland Empire where infrastructure may be challenged to contain runoff from a severe storm event. Areas with burn scars will be tracked and assessed as part of the multi-year program. Specifics on scenarios wherein suspensions would arise are explained below, but it should be noted that **NAWC's project meteorologists have the authority to temporarily suspend localized seeding operations due to development of hazardous severe weather conditions even if the NWS has not issued a warning**. This would be a rare event, but it is important for the operator to have this latitude.

Flooding Situations

In addition to the possibility of flooding due to extreme rainfall, the potential also exists for wintertime flooding from rainfall on existing snowpack, especially if a lower elevation snowpack exists. Precautions must be taken to ensure accurate forecasting and timely temporary suspension of operations during these potential flooding situations. The objective of suspension under these conditions is to eliminate the real and/or perceived impact of weather modification when any increase in precipitation has the potential of creating or contributing to a significant flood hazard. When a significant rain on snow event is expected, the forecast will be monitored closely to flag the potential for warm storm rain on snow, and coordination between the meteorologist and SAWPA will be appropriate in circumstances where the freezing level is >8,000 feet and the quantitative precipitation forecast (QPF) is > 3 inches in 24 hours. We expect this situation of rain on an existing snowpack to be rare for southern California, yet still possible.

Burn Scars

After a wildfire is contained, a burn scar will form in the impacted area. According to the National Weather Service, the length of time the burn scar remains a threat for debris flow "depends on the severity of the wildfire that occurred as well as how much erosion occurs. It could take many years for vegetation to become reestablished and this is the main factor in slowing the precipitation run off that creates flash flooding and debris flows. Most burn areas will be prone to this activity for at least two years." Following a wildfire, SAWPA will share the impacted areas with NAWC and coordinate the fire severity and extents of the burn scar with the applicable flood control district. If the burn scar is a threat for debris flow, NAWC will not conduct seeding operations that will affect the burn scar area.

Severe Weather

During periods of hazardous weather phenomena associated with both winter orographic and convective precipitation systems it is sometimes necessary or advisable for the National Weather Service (NWS) to issue special weather bulletins advising the public of the weather phenomena. Each phenomenon is described in terms of criteria used by the NWS in issuing special weather bulletins. Those of concern while conducting winter cloud seeding programs include the following:

- **Winter Storm Warnings** – issued by the NWS when it expects heavy snow, along with strong winds/wind chill or freezing precipitation. These are commonly issued during the winter for three of the four target areas, and do not require suspensions unless there are special considerations (e.g., a significant storm that impacts Christmas Eve travel).
- **High Wind Warnings** – issued when sustained winds of 40-45 mph or frequent gusts at or above 58 mph (75 mph above 7000 feet) are expected or occurring.
- **Flash Flood Warnings** – issued by the NWS when flash flooding is imminent or in progress, or a dam break is imminent or occurring.
- **Severe Thunderstorm Warnings** – issued by the NWS when a thunderstorm is expected to produce strong winds in excess of 58 miles per hour (mph) or hail larger than one inch in diameter.

Seeding operations may be suspended when the NWS issues a flood/flash flood warning for or adjacent to one of the target areas; flood advisories, which are issued for primarily nuisance street and small stream flooding, normally will not require a suspension. Since an objective of the cloud seeding program is to increase winter snowfall in the mountainous areas where snow commonly falls, suspensions are not generally necessary when Winter Storm Warnings are issued, unless there are special, extenuating considerations to make, for example, the effect of heavy snowfall at low elevations not typically used to heavy snow that could result in flooding situations upon melting, or heavy snowfall that is forecast to be followed by heavy rainfall over the snowpack which may also result in flooding. There is also the prospect of high winds during storms impeding seeding operations; sustained winds in excess of 30 mph at the sites may result in issues with the CNG flame remaining lit or the actual seeding plumes having long tracks such that the nucleation occurs well after the plume has moved past the target areas.

Flash Flood Warnings are usually issued when intense convective activity causing heavy rainfall is expected, or when moderate rainfall is expected for extended periods. The types of storms that may cause problems are those that have the potential of producing 2-3 inches (or greater) of rainfall in a 24-hour period, especially with high freezing levels (e.g., >8,000 feet MSL). Seeding operations shall be suspended for the duration of the warning period in the affected areas when the **24-hour rainfall is forecast to be greater than 3 inches.**

APPENDIX C

GLOSSARY OF METEOROLOGICAL TERMS

Advection: Movement of an air mass. Cold advection describes a colder air mass moving into the area, and warm advection is used to describe an incoming warmer air mass. Dry and moist advection can be used similarly.

Air Mass/airmass: A term used to describe a region of the atmosphere with certain defining characteristics. For example, a cold or warm air mass, or a wet or dry air mass. It is a fairly subjective term but is usually used in reference to large (synoptic scale) regions of the atmosphere, both near the surface and/or at mid and upper levels of the atmosphere.

Atmospheric River/AR: A long, narrow and transient corridor of strong horizontal water vapor transport that is typically associated with a low-level jet stream ahead of the cold front of a low pressure system. The water vapor in ARs is supplied by tropical and subtropical moisture sources and frequently produces heavy precipitation where they are forced upward, e.g., by mountains or dynamic lifting.

Balloon Sounding: see Sounding.

Cell: in radar usage, a local maximum in radar reflectivity that undergoes a life cycle of growth and decay, having both an updraft and a downdraft region.

Cold-core low: A typical mid-latitude type of low pressure system, where the core of the system is colder than its surroundings. This type of system is also defined by the cyclonic circulation being strongest in the upper levels of the atmosphere. The opposite is a warm-core low, which typically occurs in the tropics.

Cold Pool: An air mass that is cold relative to its surroundings and may be confined to a particular basin.

Condensation: Phase change of water vapor into liquid form. This can occur on the surface of objects (such as dew on the grass) or in mid-air (leading to the formation of clouds). Clouds are technically composed of water in liquid form, not water vapor.

Confluent: Wind vectors coming closer together in a two-dimensional frame of reference (opposite of diffluent). The term convergence is also used similarly.

Convective (or convection): Pertains to the development of precipitation areas due to the rising of warmer, moist air through the surrounding air mass. The warmth and moisture contained in a given air mass makes it lighter than colder, dryer air. Convection often leads to small-scale, locally heavy showers or thundershowers. The opposite precipitation type is known as stratiform precipitation.

Convergence: Refers to the converging of wind vectors at a given level of the atmosphere. Low-level convergence (along with upper-level divergence), for instance, is associated with lifting of the air mass which usually leads to development of clouds and precipitation. Low-level divergence (and upper-level convergence) is associated with atmospheric subsidence, which leads to drying and warming.

Cyclonic Flow: Counter-clockwise motion, primarily around low pressure (cyclone).

Deposition: A phase change where water vapor turns directly to solid form (ice). The opposite process is called sublimation.

Dew point: The temperature at which condensation occurs (or would occur) with a given amount of moisture in the air.

Diffluent: Wind vectors spreading further apart in a two-dimensional frame of reference; opposite of confluent.

Disturbance: see Low pressure, shortwave.

Dry slot: A zone of dry (and usually cloud-free) air that wraps into the southern and eastern parts of a low pressure system; easily viewed on satellite imagery.

Entrain: Usually used in reference to the process of a given air mass being ingested into a storm system.

Evaporation: Phase change of liquid water into water vapor. Water vapor is usually invisible to the eye.

El Niño: A reference to a particular phase of oceanic and atmospheric temperature and circulation patterns in the tropical Pacific, where the prevailing easterly trade winds weaken or dissipate. Often influences mid-latitude patterns as well, such as increased precipitation in southern portions of the U.S. and decreased precipitation further north. The opposite phase is called La Nina.

Front (or frontal zone): Reference to a temperature boundary with either incoming colder air (**cold front**) or incoming warmer air (**warm front**); can sometimes be a reference to a stationary temperature boundary line (stationary front) or a more complex type known as an occluded front (where the temperature change across a boundary can vary in type at different elevations).

Frontal band: A band of clouds/precipitation along a cold or warm front.

Glaciogenic: Ice-forming (aiding the process of nucleation); usually used in reference to cloud seeding nuclei.

GMT (or UTC, or Z) time: Greenwich Mean Time, universal time zone corresponding to the time at Greenwich, England. Pacific Standard Time (PST) = GMT – 8 hours; Pacific Daylight Time (PDT) = GMT – 7 hours.

Graupel: A precipitation type that can be described as "soft hail", that develops due to riming (nucleation around a central core). It is composed of opaque (white) ice, not clear hard ice such as that contained in hailstones. It usually indicates the presence of convective clouds and can be associated with electrical charge separation and occasionally lightning activity.

High Pressure (or Ridge): Region of the atmosphere usually accompanied by dry and stable weather. Corresponds to a northward bulge of the jet stream on a weather map, and to an anti-cyclonic (clockwise) circulation pattern.

Infrared (satellite): imagery sensed in the 3-13 µm wavelength region of the electromagnetic spectrum, usually referring to the thermal infrared region.

Inside Slider: A trough or area of low pressure that moves south-southeast along or parallel to the Sierra Nevada mountains before swinging east into the Great Basin or Desert Southwest. These systems typically do not have much moisture with them but can have cold to very cold air accompanying them. The track of these systems typically brings Santa Ana winds as they increase the northeast-southwest pressure gradient.

Inversion: Refers to a layer of the atmosphere in which the temperature increases with elevation, usually associated with stability.

Jet Stream or Upper-Level Jet (sometimes referred to more generally as the storm track): A region of maximum wind speed, usually in the upper atmosphere that usually coincides with the main storm track in the mid-latitudes. This is the area that also typically corresponds to the greatest amount of mid-latitude synoptic-scale storm development.

La Niña: The opposite phase of that known as El Nino in the tropical Pacific. During La Nina the easterly tropical trade winds strengthen and can lead in turn to a strong mid-latitude storm track, which often brings wetter weather to northern portions of the U.S.

Longwave (or longwave pattern): The longer wavelengths, typically on the order of 1,000 – 2,000+ miles of the typical ridge/trough pattern around the northern (or southern) Hemisphere, typically most pronounced in the mid-latitudes.

Low-Level Jet: A zone of maximum wind speed in the lower atmosphere. Can be caused by geographical features or various weather patterns and can influence storm behavior and dispersion of cloud seeding materials.

Low pressure (or low or trough): Region of the atmosphere usually associated with stormy weather. Corresponds to a southward dip to the jet stream on a weather map as well as a cyclonic (counterclockwise) circulation pattern in the Northern Hemisphere.

Mesoscale: Sub-synoptic scale, about 100 miles or less; this is the size scale of more localized weather features (such as thunderstorms or mountain-induced weather processes).

Microphysics: Used in reference to composition and particle types in a cloud.

Mid-level: the layer of the atmosphere from 10,000-20,000 feet.

Millibar (mb): a unit of pressure equal to 100 newtons per square meter (N/m^2).

MSL (Mean Sea Level): Elevation height reference in comparison to sea level.

Negative (ly) tilted trough: A low-pressure trough where a portion is undercut, such that a frontal zone can be in a northwest to southeast orientation.

Nucleation: The process of supercooled water droplets in a cloud turning to ice. This is the process that is aided by cloud seeding. For purposes of cloud seeding, there are three possible types of cloud composition: Liquid (temperature above the freezing point), supercooled (below freezing but still in liquid form), and ice crystals.

Nuclei: Small particles that aid water droplet or ice particle formation in a cloud.

Orographic: Terrain-induced weather processes, such as cloud or precipitation development on the upwind side of a mountain range. Orographic lift refers to the lifting of an air mass as it encounters a mountain range.

Precipitable Water, or PWAT: The total atmospheric water vapor contained in a vertical column of unit cross-sectional area extending between the surface and top of the atmosphere, expressed in terms of the depth to which that water substance would be if completely condensed and collected in a vessel of the same unit cross-section.

Pressure Heights (e.g., 700 millibars, or mb): Corresponds to approximately 10,000 feet above sea level (MSL); 850 mb corresponds to about 5,000 feet MSL; and 500 mb corresponds to about 18,000 feet MSL. These are standard height levels that are occasionally referenced, with the 700 mb level most important regarding cloud-seeding potential in most of the western U.S.

Positive (ly) tilted trough: A normal U-shaped trough configuration, where an incoming cold front would generally be in a northeast– southwest orientation.

Reflectivity: The density of returned signal from a radar beam, which is typically bounced back due to interaction with precipitation particles (either frozen or liquid) in the atmosphere. The reflectivity depends on the size, number, and type of particles that the radar beam encounters.

Ridge (or High Pressure System): Region of the atmosphere usually accompanied by dry and stable weather. Corresponds to a northward bulge of the jet stream on a weather map, and to an anti-cyclonic (clockwise) circulation pattern.

Ridge axis: The longitude band corresponding to the high point of a ridge.

Rime (or rime ice): Ice buildup on an object (often on an existing precipitation particle) due to the freezing of supercooled water droplets.

Shortwave (or shortwave disturbance): Smaller-scale wave features of the weather pattern typically seen at mid-latitudes, usually on the order of a few to several hundred miles; these often correspond to individual frontal systems.

Silver iodide: A compound commonly used in cloud seeding because of the similarity of its molecular structure to that of an ice crystal. This structure helps in the process of nucleation, where supercooled cloud water changes to ice crystal form.

Sounding: A measurement of the vertical distribution of physical properties of the atmospheric column such as temperature, dewpoint, pressure, wind speed and direction. Soundings are typically conducted by releasing a balloon filled with hydrogen or helium with instrumentation attached that measures different properties as the balloon rises from the surface until it pops at very high altitudes (80-100 kft).

Stable layer: A layer of given thickness in the atmosphere where temperatures are constant with height or rise with height; this results in little to no vertical movement of the air and little to no turbulence/mixing.

Storm Track (sometimes referenced as the Jet Stream): A zone of maximum storm propagation and development, usually concentrated in the mid-latitudes.

Stratiform: Usually used in reference to precipitation, this implies a large area of precipitation that has a fairly uniform intensity except where influenced by terrain, etc. It is the result of larger-scale (synoptic scale) weather processes, as opposed to convective processes.

Sublimation: The phase change in which water in solid form (ice) turns directly into water vapor. The opposite process is deposition.

Subsidence: The process of a given air mass moving downward in elevation, such as often occurs on the downwind side of a mountain range.

Subtropical/subtropics: Referring to the region of the Earth bordering on the tropics, from the Tropic of Cancer/Capricorn (23.5°N/S) to about 35°N/S. **Subtropical moisture** would refer to moisture whose source region is the subtropics. **Subtropical Jet Stream** would refer to a jet stream within the subtropics.

Supercooled: Liquid water (such as tiny cloud droplets) occurring at temperatures below the freezing point (32°F or 0°C).

Synoptic Scale: A scale of hundreds to perhaps 1,000+ miles, the size scale at which high and low pressure systems develop.

Trough (or low pressure system): Region of the atmosphere usually associated with stormy weather. Corresponds to a southward dip to the jet stream on a weather map as well as a cyclonic (counterclockwise) circulation pattern in the Northern Hemisphere.

Trough axis: The longitude band corresponding to the low point of a trough.

Unstable air mass: an air mass wherein a perturbation (wave) increases in magnitude over time. A parcel of air displaced upward in an unstable airmass will continue to rise until it reaches equilibrium. Regions where, if moisture is sufficient, convection can develop if a mechanism (e.g., heating, frontal boundary) is present to initiate lift.

Upper level: The region of the atmosphere above 20 kft and below the tropopause (approx. 60-80 kft).

Upper-Level Jet or Jet Stream (sometimes referred to more generally as the storm track): A region of maximum wind speed, usually in the upper atmosphere that usually coincides with the main storm track in the mid-latitudes. This is the area that also typically corresponds to the greatest amount of mid-latitude synoptic-scale storm development.

Upper level low/trough/disturbance: an area of low pressure located at higher altitudes, e.g., at 700 mb / 10,000 feet MSL or 500 mb / 18,000 feet MSL.

UTC (or GMT, or Z) time: Greenwich Mean Time, universal time zone corresponding to the time at Greenwich, England. Pacific Standard Time (PST) = GMT – 8 hours; Pacific Daylight Time (PDT) = GMT – 7 hours.

Vector: Term used to represent wind velocity (speed + direction) at a given point.

Velocity: Describes speed of an object, often used in the description of wind intensities.

Vertical Wind Profiler: Ground-based system that measures wind velocity at various levels above the radar site.

Wave clouds: Clouds that form on the rising branches of mountain waves created within a stable airmass in strong flow downwind of mountains. On satellite imagery, they appear as spaced bands of clouds parallel to and downwind of the mountain barrier.