Annual Cloud Seeding Report

Northern Utah Program

2023-2024 Winter Season

Prepared For:

Bear River Water Conservancy District

Box Elder County

Cache County

State of Utah, Division of Water Resources

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WEATHER MODIFICATION

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.

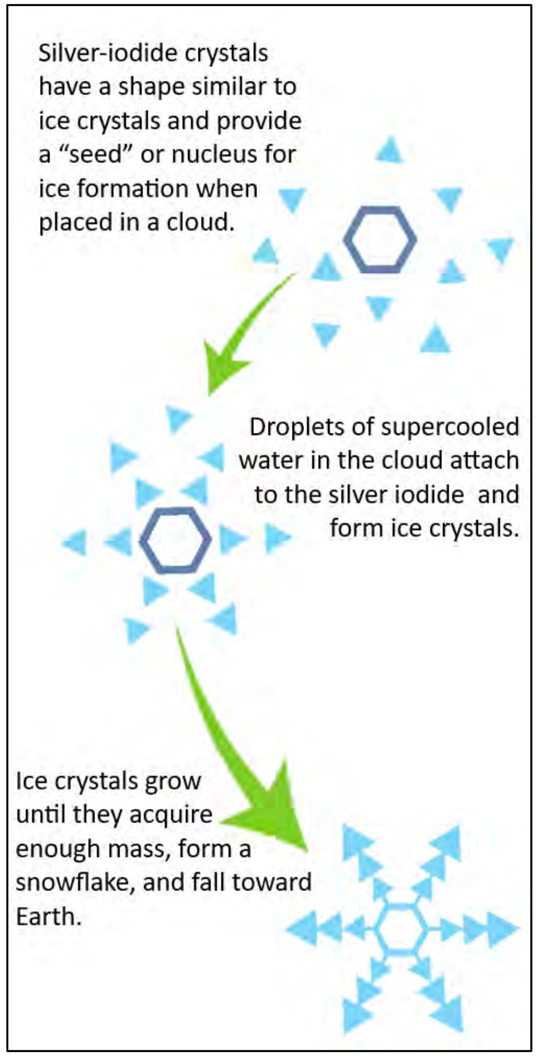
Silver iodide has been selected for its environmental safety and superior efficiency in producing ice in clouds. Silver iodide adds microscopic particles with a structural similarity to natural ice crystals. Ground-based and aircraft-borne technologies can be used to add the particles to the clouds.

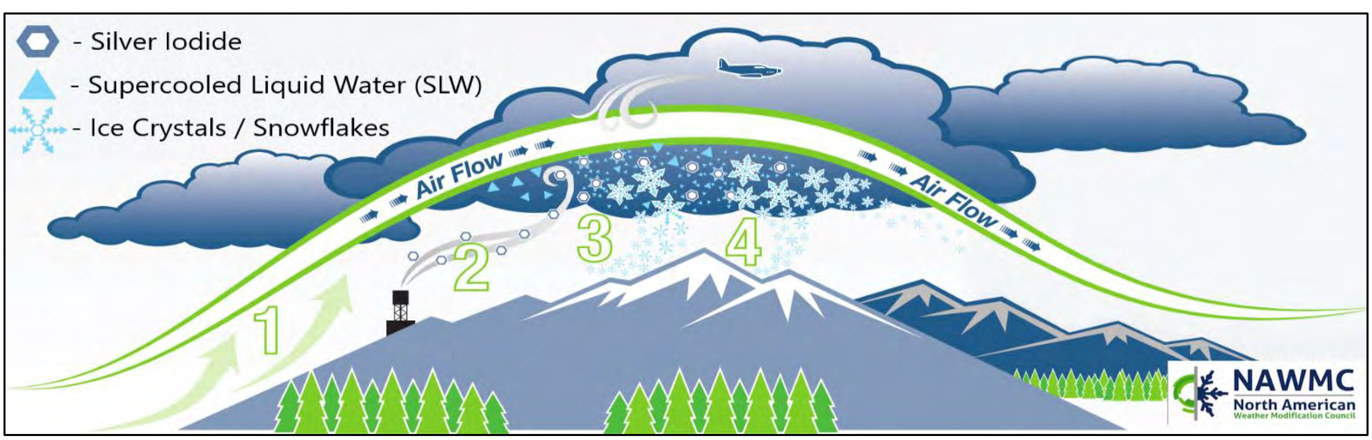
Safety

Research has clearly documented that cloud seeding with silver-iodide aerosols shows no environmentally harmful effect. Iodine is a component of many necessary amino acids. Silver is both quite inert and naturally occurring, the amounts 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.





CLIMATE TRENDS

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

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

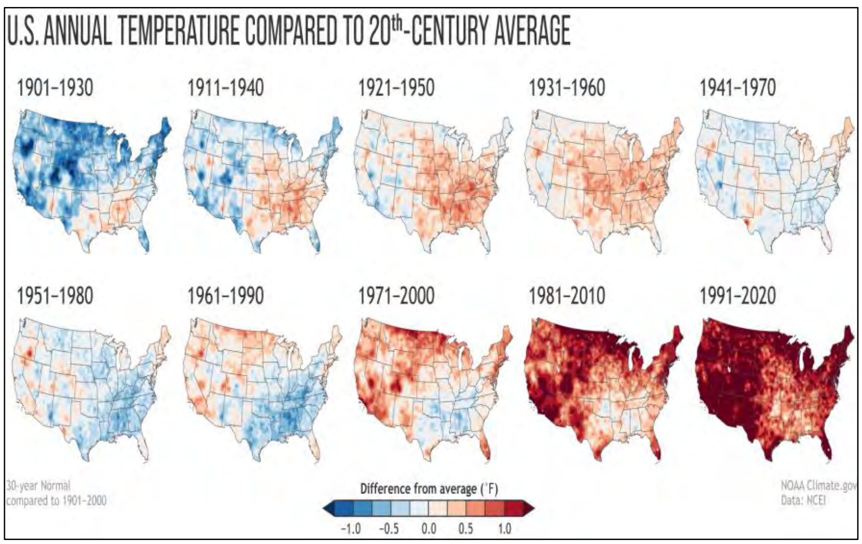


Figure 1 **U.S. Annual Temperature compared to 20th-Century Average**

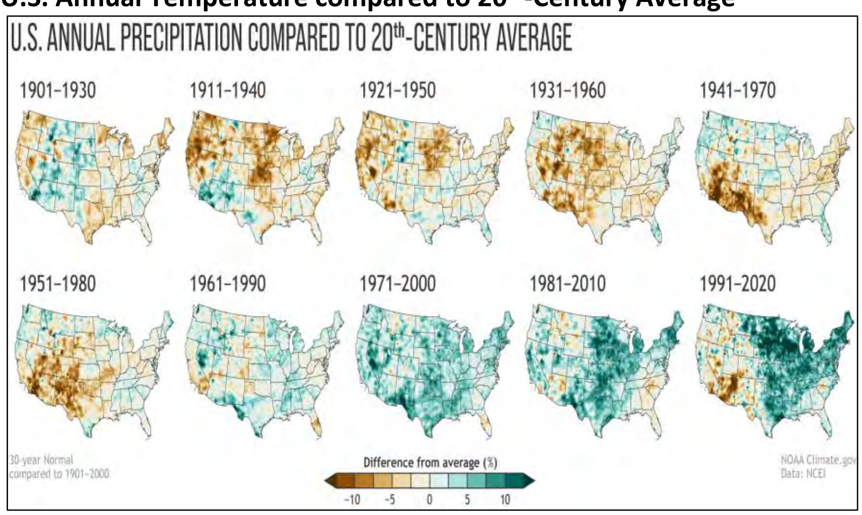


Figure 2 **U.S. Annual Precipitation compared to 20th-Century Average**

The 2023-2024 water year was again above average in terms of precipitation and snowpack, although to a lesser degree than the previous season which was extremely wet. The south arm of the Great Salt Lake (as of mid-May 2024) is at roughly 4,195 feet. Figure 3 is a long term graph of lake levels for both the north and south arms of the lake. The current levels have improved to roughly pre-2021 values but are still below optimal for many ecosystems and industries (Figure 4).

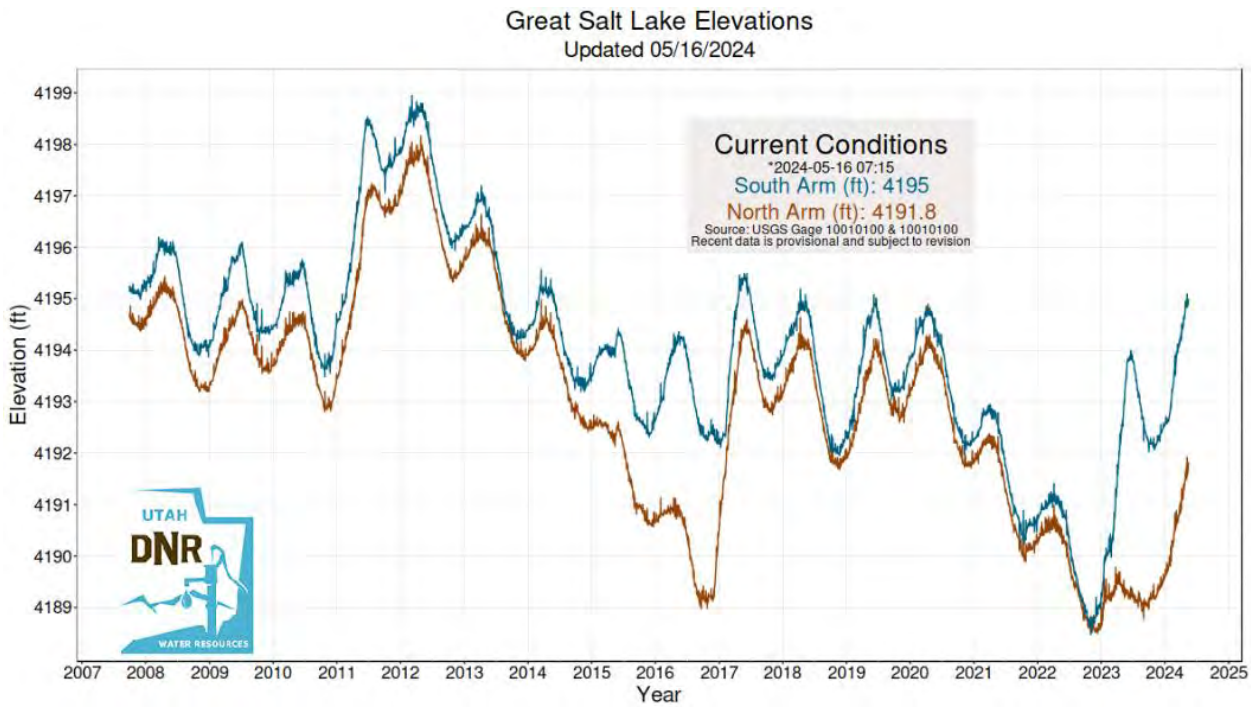


Figure 3 Great Salt Lake levels since 2007 (graph from the greatsaltlake.utah.gov website)

EXECUTIVE SUMMARY

Program History

In past winter seasons beginning in 1989, cloud seeding has been conducted in portions of northern Utah. The goal of the seeding program is to augment wintertime snowpack/precipitation over the seeded watersheds. Cost sharing for the seeding program is provided by the Utah Division of Water Resources.

The current season's cloud seeding program began on December 1, 2023 and was contracted through March 31, 2024. A total of 29 storm periods were seeded during the 2023-2024 season, using a network of 9 manually operated cloud seeding generators located in northwestern Box Elder County and a network of 21 manually operated generators that were located in both eastern Box Elder County and in Cache County. In the summer of 2023, the Legislature of Utah granted the Utah Division of Water Resources (UDWR) a substantial increase in funding for cloud seeding projects across the state of Utah. A large portion of this new funding was used for the fabrication, deployment, maintenance and use of 23 new remotely operated and high-output cloud seeding generators across the state of Utah. Eleven of these new remotely operated generators were strategically placed so that they could seed the program alongside the existing manually operated generators in certain storm periods. In total, there were five seeded storm events in December, five in January, eight in February, and eleven in March. A total of 2060 cumulative hours of seeding generator operations were conducted specifically for the Northern Utah program during the season (which excludes the seeding hours of the remotely operated generators, as the hours for those are counted separate).

Precipitation and snowfall began below average for the start of the 2023-2024 winter season, but improved to above average beginning in mid-January 2024 and remained above average through March 2024. There was an El Niño pattern in place this winter season, in contrast to the past few seasons which observed a La Niña pattern. As of April 1, 2024 SNOTEL sites in northwestern Box Elder County and Cache County target areas reported snowpack water equivalent values ranging from roughly 95% to 212% of the average (median) across the Bear River Basin and from roughly 118% to 135% of the average (median) across the Raft River Basin.

Results

Target/control evaluations have been developed for the Northern Utah seeding program, utilizing NRCS Snowpack Telemetry (SNOTEL) precipitation and snow water content data. The precipitation evaluations include those utilizing both December – March period totals. Overall results of this (considering the historical 1989-2022 seasons in the current program) suggest an average approximately 8% increase in precipitation and/or snowpack, likely adding an additional 1.4-2.5 inches of SWE to the target area in an average season. The 2023 water year was excluded from the results due to large precipitation anomalies and program suspensions, and a new seeding program affecting a primary control site was initiated in the most recent season. Additional regression equations, correlating streamflow in Blacksmith Fork (in Cache Valley near Hyrum) and Dunn Creek (in Box Elder County near Park Valley) to SNOTEL precipitation and SWE data, suggest that seasonal (March – July) streamflow increases of 7-9% could likely be obtained by the seeding program. These results are discussed in more detail in Section 5.4 of the report.

1.0 INTRODUCTION

Cache County and Box Elder County have, for many years, sponsored a winter cloud seeding program over portions of the high-elevation watersheds within each county. The program continued this past winter with the goal of augmenting the natural precipitation in mountainous areas of each county. Statistical analysis of cloud seeding effectiveness in past years has generally indicated an estimated 5-15% increase in winter precipitation and snowpack in the project target areas.

Box Elder and Cache Counties again contracted with North American Weather Consultants, Inc. (NAWC) for the operational cloud seeding services for their mountain watersheds during the 2023-2024 winter season. NAWC has been active in cloud seeding since 1950, with operational programs in Utah since the mid-1970s, and is the longest standing private weather modification company in the world. The State of Utah, through its Division of Water Resources (UDWR) regulates cloud seeding activities within Utah and provides cost sharing funds to project sponsors.

The target area of the program consists of the mountainous portions of Cache and Box Elder Counties above approximately 6,000 feet MSL. These areas represent significant snowpack accumulation zones, which provide substantial spring and summer streamflow. Figure 1.1 shows the average annual precipitation for the State of Utah, delineating these higher-yield areas.

Utah law requires both a license and a project-specific permit be issued to the organization conducting the cloud seeding. The law also requires that a notice of the intent be made available to the public prior to the start of a cloud seeding project. NAWC complied with these requirements in the conduct of the program.

This report covers the operational cloud seeding conducted over the project watersheds during the 2023-2024 winter season. Section 2 contains a brief background on cloud seeding technology and the design of the seeding program. Section 3 discusses the types of real-time and forecast meteorological data that are used for conduct of the seeding programs. Section 4 summarizes the seeding operations conducted this past season. Section 5 details on the historical evaluations of the effects of the cloud seeding program, including some new regression equations relating snowpack/precipitation increase to resulting streamflow increases.

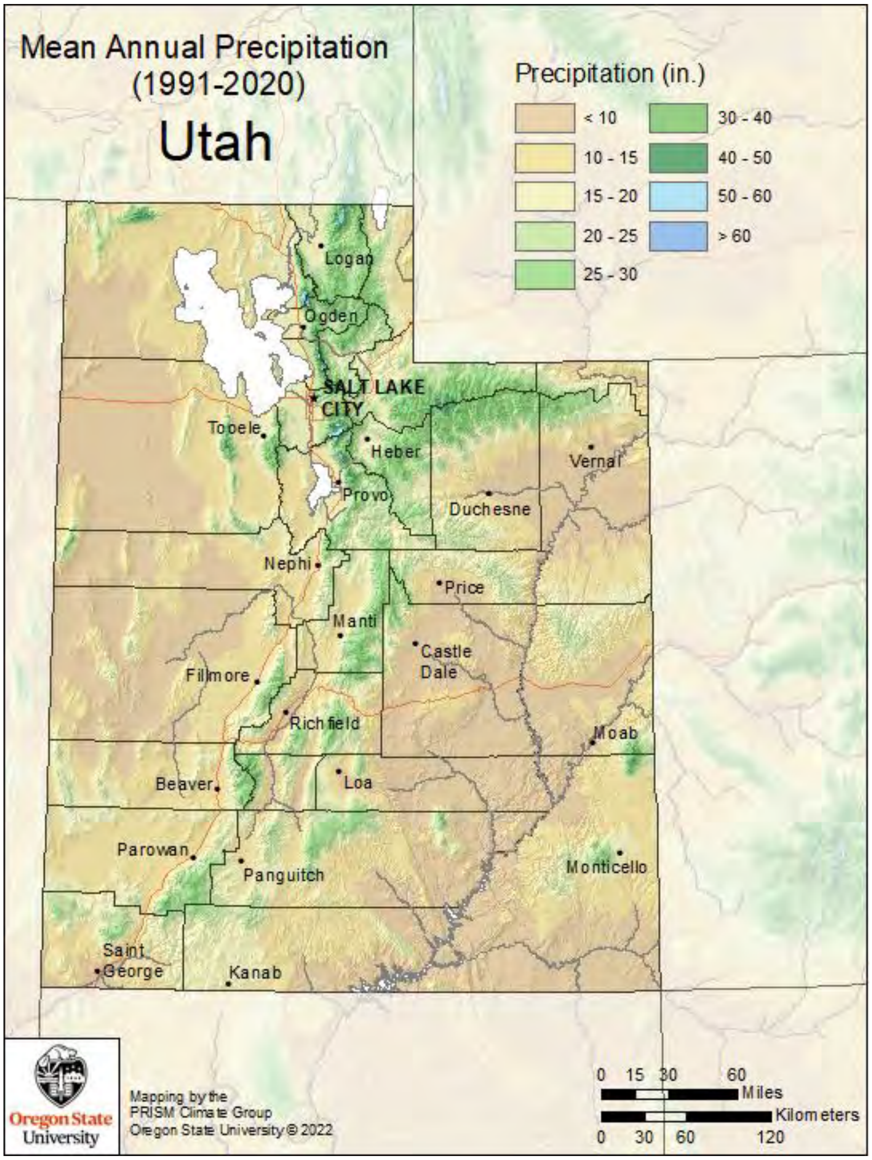


Figure 1.1 **Average annual precipitation for Utah, 1991-2020 (produced by PRISM Climate Group, Oregon Stat University)**

2.0 PROJECT DESIGN

2.1 Background

The operational procedures used in this cloud seeding project have been found to be effective during many years of wintertime cloud seeding in the mountainous regions of Utah. The results from this particular operational seeding program in northern Utah have consistently indicated increases in wintertime precipitation and snowpack water content during the periods in which cloud seeding was conducted.

2.2 Seeding Criteria

It is necessary that the silver iodide crystals become active upwind of the crest of a mountain barrier (i.e., the crest within the target area or defining its downwind boundary) so that the available supercooled liquid water (SLW) in the precipitation formation zone can be effectively converted to ice crystals, with enough time for the crystals to grow to snowflake size and precipitate within the intended target area. If the AgI crystals take too long to become active, or if the temperature upwind of the crest is too warm, the silver iodide crystals will pass from the generator through the precipitation formation zone and over the mountain crest without freezing additional water cloud droplets. Thus, an important task for the project meteorologists is to identify the seedable portions of the cloud systems which traverse the project area.

Operations have utilized a selective seeding approach, which has proven to be the most efficient and cost-effective method, providing the most beneficial results. Selective seeding means that seeding is conducted only during specific time periods, and in specific locations, where it is likely to be effective. This decision is based on several criteria which determine the seedability of the storms affecting the region. These criteria deal with the nature of the atmosphere (temperature, stability, wind flow, and moisture content) both in and below the clouds, and are summarized in the following list.

Winter Orographic Ground Based Seeding Criteria

- Cloud bases are near or below the mountain barrier crest.
- Low-level wind directions and speeds would favor the movement of the silver iodide particles from their release points into the intended target area.
- No low-level atmospheric inversions or stable layers that would restrict the upward vertical transport of the silver iodide particles from the surface to at least the -5°C (23°F) level or colder.
- Temperature at mountain barrier crest height expected to be -5°C (23°F) or colder.
- Temperature at the 700mb level (approximately 10,000 feet) expected to be warmer than -15°C (5°F).

Use of this focused seeding methodology has yielded consistently favorable results at very attractive benefit/cost ratios.

2.3 Equipment and Project Set-Up

NAWC installed 30 ground-based cloud seeding equipment in November of 2023 at locations which are typically upwind (generally on the west sides) of the mountain ranges in Cache County, and in easternmost and northwestern Box Elder County. These mountain ranges generally have crest elevations between 7,000 and 8,000 feet, although some peaks exceed 9,000 feet.

In the summer of 2023, NAWC deployed 23 new remotely operated and high-output cloud seeding generators across the state of Utah. Eleven of these new remotely operated generators were strategically placed across northern Utah and were operated simultaneously alongside the manually operated generators during certain storm periods. The intended target area of the cloud seeding program includes the areas that exceed 6,000 feet in elevation. The locations of the manually operated and remotely operated cloud nuclei generator sites are also shown in Figure 2.1. Pertinent site information is listed in Table 2-1.

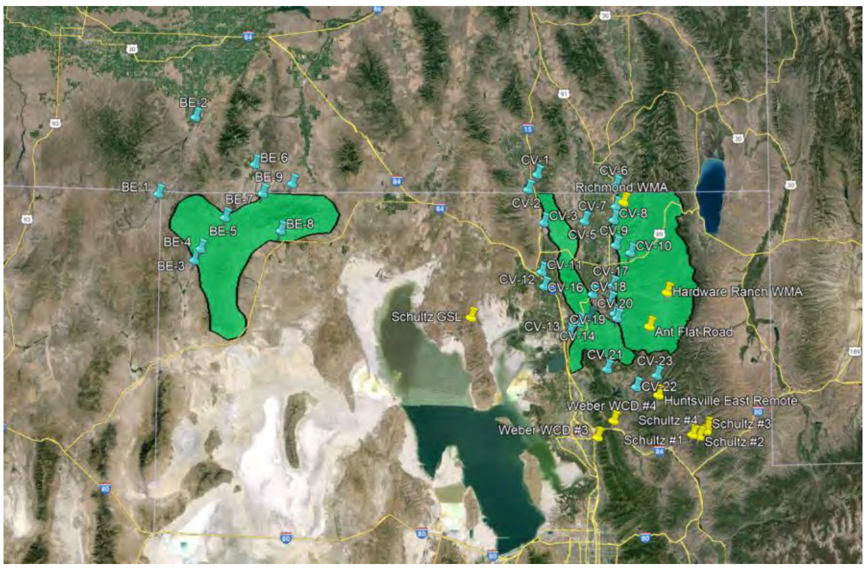


Figure 2.1 **CNG sites and seeding target areas for the 2023-2024 Northern Utah Program; yellow pins are the new remotely operated sites**

The process of choosing seeding sites involves studying topographical maps and identifying general areas most suitable, considering the typical wind flows and terrain effects during storm periods. Most sites are restricted to populated areas, since most cloud nuclei generators are manually operated.

Most winter storms that affect the northern Utah mountains are associated with synoptic weather systems which move into Utah from the southwest, west, or northwest. They often consist of a frontal system and/or an upper trough, with south or southwesterly winds ahead of these features. In meteorology, wind directions are reported as the direction the wind is blowing from, in advance of the system. As the front and/or trough moves through the area, the wind flow typically becomes more northwesterly as time passes. Clouds and precipitation may precede, as well as follow, the front/trough passage, and thus seeding sites are situated to enable seeding operations in southwesterly, westerly, or northwesterly flow situations.

Table 2-1

Northern Utah cloud seeding sites; sites having ID beginning with 'D' are remotely operated

ID	Site Name	Elevation (ft)	Lat (N)	Long (W)
BE-1	Trout Creek	5070	41° 57.00'	114° 04.00'
BE-2	Oakley	4570	42° 14.04'	113° 53.55'
BE-3	Grouse Greek	5334	41° 42.54'	113° 52.94'
BE-4	Grouse Creek N	5484	41° 45.08'	113° 51.07'
BE-5	Lynn	5930	41° 52.00'	113° 44.00'
BE-6	Almo	5340	42.10.00'	113.35.20'
BE-7	Yost	5986	41° 57.40'	113° 33.01'
BE-8	Rosette	5640	41° 49.29'	113° 27.49'
BE-9	Standrod	5811	41° 59.61'	113° 24.34'
CV-1	Malad South	4450	42° 02.00'	112° 12.00'
CV-2	Portage	4500	41° 58.71'	112° 14.68'
CV-3	Plymouth	4417	41° 51.45'	112° 10.09'
CV-5	Newton	4662	41° 51.78'	111° 58.12'
CV-6	Cove	4577	41° 59.65'	111° 48.81'
CV-7	Richmond	4600	41° 54.96'	111° 48.84'
CV-8	Smithfield	4694	41° 51.96'	111° 49.50'
CV-9	Logan	4580	41° 46.41'	111° 48.94'
CV-10	Logan Canyon	4971	41° 44.77'	111° 44.72'
CV-11	Tremonton	4295	41° 40.69'	112° 10.75'
CV-12	Bear River City	4265	41° 37.49'	112° 09.96'
CV-13	Perry	4404	41° 27.21'	112° 02.67'
CV-14	Brigham City	4690	41° 29.54'	111° 59.77'
CV-15	Mantua	5200	41° 30.89'	111° 56.34'
CV-16	Wellsville	4884	41° 35.72'	111° 55.80'
CV-17	Hyrum	4816	41° 37.58'	111° 49.92'
CV-18	Paradise	4875	41° 34.19'	111° 50.62'
CV-19	Avon	5059	41° 31.45'	111° 49.39'
CV-20	Avon South	5079	41° 30.47'	111° 48.70'
CV-21	Liberty	5107	41° 19.31'	111° 51.70'
CV-22	Huntsville	5066	41° 15.37'	111° 43.21'
CV-23	Red Rock Ranch	5473	41° 17.86'	111° 37.17'
DN_0001	Richmond WMA	5274	41° 55.93'	111° 46.6'
DN_0002	Hardware WMA	5565	41°36.09'	111°34.02'
DN_0003	Schultz GSL	5920	41° 30.70'	112° 31.41'
DN_0004	Ant Flat Road	7370	41° 28.69'	111° 39.25'
DN_0005	Huntsville East	8179	41° 13.62'	111° 36.74'
DU_0006	Schultz 1	7252	41° 4.90'	111° 26.87'
DN_0007	Schultz 2	7934	41° 4.52'	111° 24.96'
DN_0008	Schultz 3	7946	41° 5.71'	111° 22.84'
DN_0009	Schultz 4	8115	41° 6.49'	111° 22.65'
DN_0010	Weber WCD 4	4958	41° 8.07'	111° 49.80'
DN_0011	Weber WCD 3	4657	41° 4.47'	111° 54.48'

2.4 Suspension Criteria

NAWC conducts its projects within guidelines adopted to ensure public safety. Accordingly, NAWC has a standing policy and project-specific procedures for the suspension of cloud seeding operations in certain situations. Those criteria can be found in Appendix A and are an integral part of the seeding program.

3.0 WEATHER DATA AND MODELS USED IN SEEDING OPERATIONS

NAWC maintains a fully equipped operations center at its Sandy, Utah headquarters. Meteorological information is acquired online from a wide variety of sources, including some subscriber services. This information includes weather forecast model data, surface observations, rawinsonde (weather balloon) upper-air observations, satellite images, radar information and weather cameras. NAWC's meteorologists have access to all meteorological products from their homes, allowing continued monitoring and conduct of seeding operations outside of regular business hours. This wide variety of available products and information helps NAWC meteorologists to determine when conditions are appropriate for cloud seeding.

Figures 3.1 – 3.4 show examples of some of the available weather information that was used in this decision-making process during the 2023-2024 winter season. These include global and regional forecast model data, weather radar images, satellite images, and surface wind and temperature maps.

Figure 3.5 illustrates the predictions of ground-based seeding plume dispersion using the National Oceanic and Atmospheric Administration's HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) 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 fields contained in the weather forecast models.

During the summer of 2022, NAWC built an in-house Python script that has the ability to ingest 3-km HRRR model data readily available online. This script allows the user to define a grid where seeding operations and liquid water could be occurring. The user can specify a cross section over any location in the continental U.S. or Canada. This model data was used during cloud seeding operations as a guidance. In these cross sections, liquid water is plotted as a function of distance and height, with temperatures (red dashed lines), wind directions and speed (wind barbs) and potential temperatures (solid black lines) also being displayed. This model was utilized on a variety of different areas where NAWC conducts cloud seeding operations. The script has the ability to be run for one specific forecast hour. Figure 3.6 shows an example of the cross-section plot during a seeded event from this past winter season that includes liquid water occurrence, temperature, wind direction, wind speed, and potential temperature as a function of height. The map inset located in the upper left corner of the cross-section plot shows a map of where the cross section was taken within the state of Utah. It is important to notice how much of the predicted liquid water is tied to underlaying terrain due to orographic forcing (lifting of the airmass as winds force it over the underlaying terrain). Also notice that much of the predicted liquid water is at temperatures of -5° C or colder which is an important feature since the silver iodide nuclei released from the remote generators mush reach this level in order for the nuclei to become active freezing nuclei. This model will continue to be utilized in future winter seasons and possibly lead to further verification techniques.

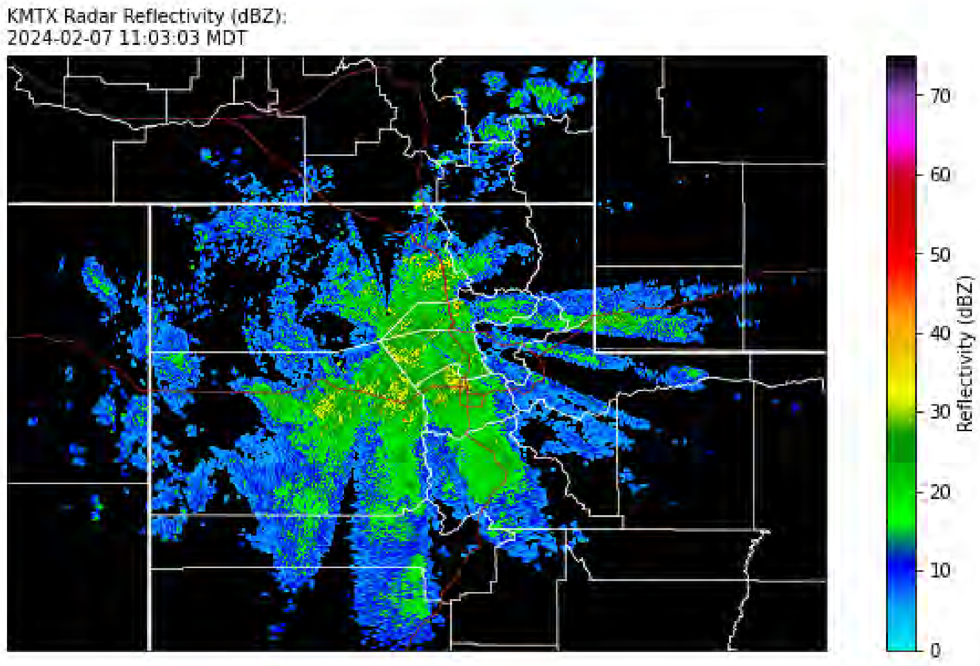


Figure 3.1 Weather radar image during a storm event over northern Utah on February 7, 2024

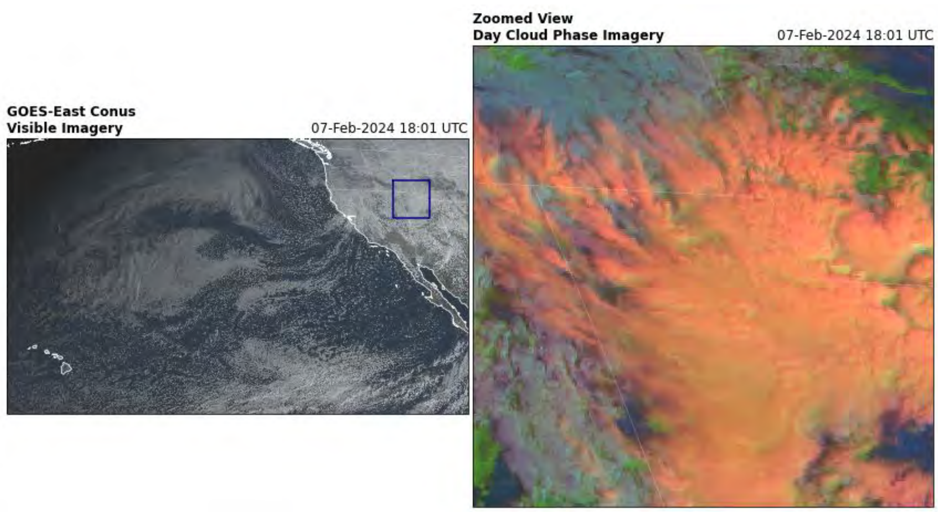


Figure 3.2 Satellite imagery during a seeded storm event on February 7, 2024

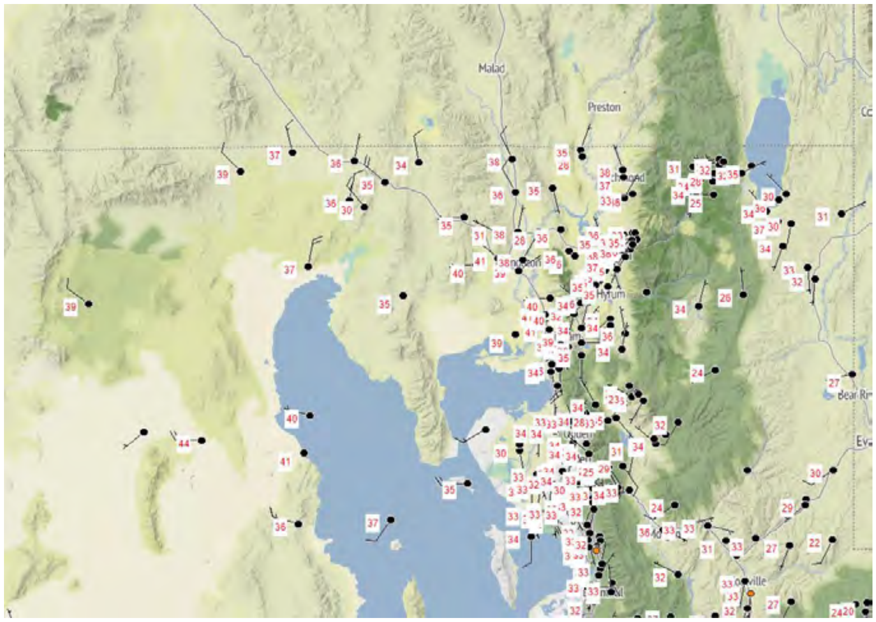


Figure 3.3 **Mesowest surface data map on February 7, 2024. Surface observations are important for diagnosing low-level wind patterns and mixing.**

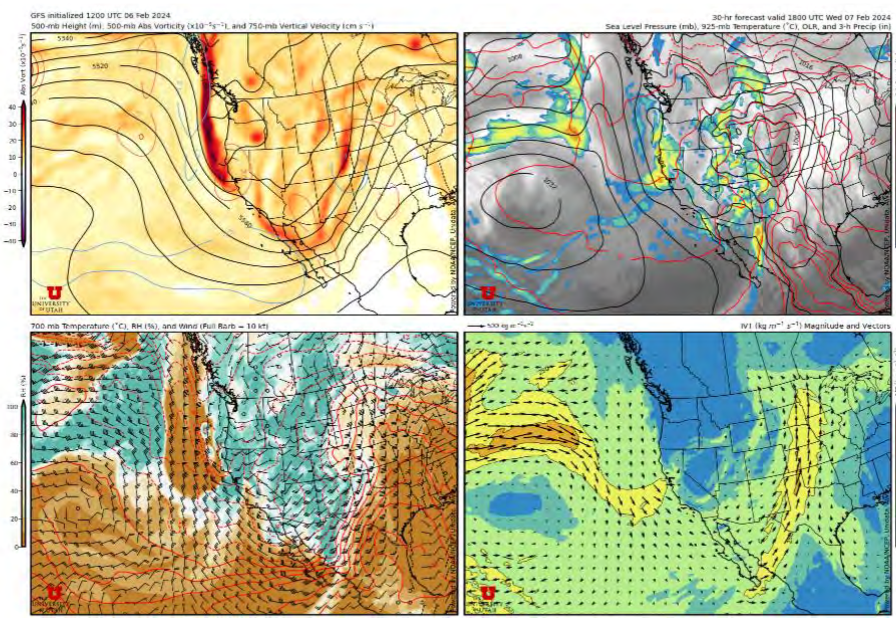


Figure 3.4 **GFS (Global Forecast Systems) forecast data plot for a storm event on February 7, 2024.**

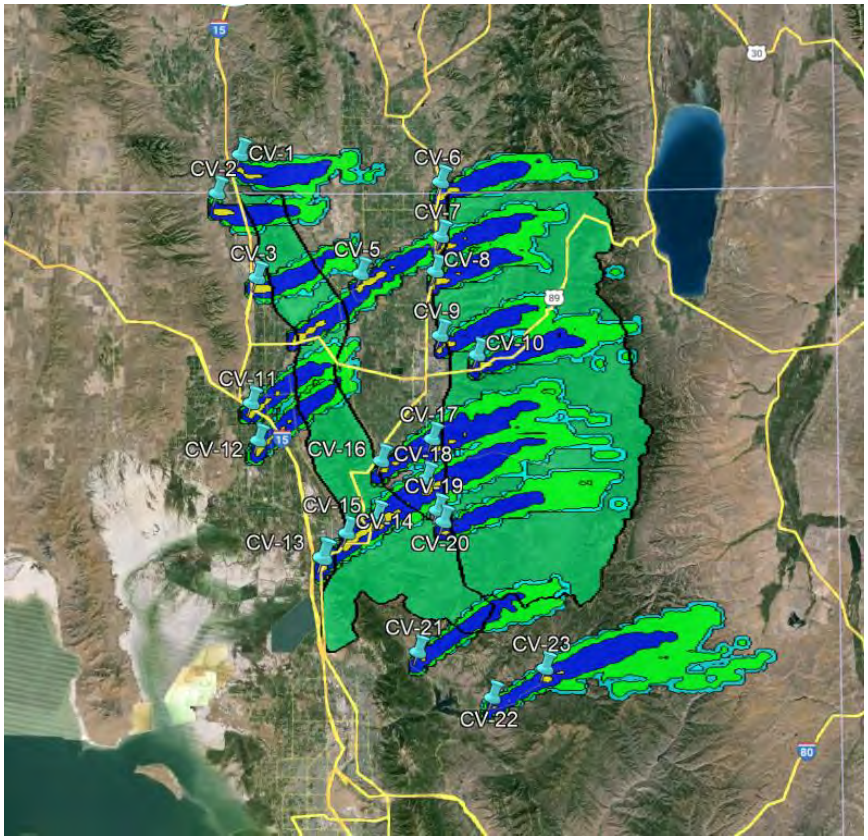


Figure 3.5 **HYSPLIT plot of forecast plume dispersion from manual sites used during a seeded storm on February 7, 2024**

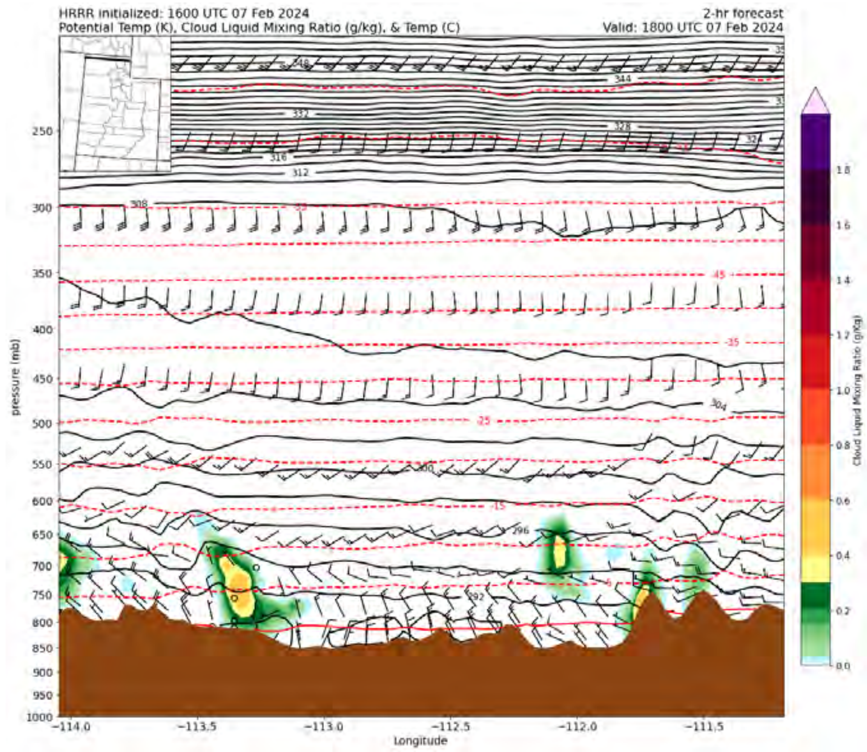


Figure 3.6 **HRRR modeled Cross Section of Liquid Water on February 7, 2024 – Valid at 1100 MST**

4.0 OPERATIONS

The 2023-2024 seeding program in Box Elder and Cache Counties began on December 1, 2023 and contractually ended on March 31, 2024. During the 2023-2024 season, there were 29 seeded storm periods conducted on portions of 35 days. Five storm events were seeded in December, five in January, eight in February, and eleven in March. A cumulative 2,060 operational hours were conducted from all manually operated generator sites during the season. In the fall of 2023, eleven new remotely operated sites were installed at select locations across northern Utah as described in an earlier section. These remotes were installed to provide additional support of the program. An additional 1164.75 generator hours of seeding were conducted from these sites; however, given that some of these remotes only impacted the program during specific storm events the hours are kept separate. Table 4-1 shows the dates and manual seeding generator usage for the storm events, with more detailed information in Appendix B. Figure 4.1 is a graph of seeding operations (manual CNG usage) this season.

Table 4-1
Storm Dates & Number of Manual Generators Used During 2023-2024 Season

Storm Number	Date(s)	No. of Generators	No. of Hours
1	December 1-2	9	135.25
2	December 2-3	5	84
3	December 7	4	20.5
4	December 7-8	11	159
5	December 22-23	5	27.5
6	January 4-5	8	62
7	January 9-10	11	139
8	January 10	7	35.75
9	January 11-12	10	120
10	January 25	16	143
11	February 2	6	35.75
12	February 6-7	18	186.25
13	February 8	2	13
14	February 9	7	13
15	February 15	4	25.25
16	February 16	10	62.75
17	February 20-21	14	113
18	February 26-27	13	183.25
19	March 2	9	31.5
20	March 3	4	21.25
21	March 4	5	18.25
22	March 12	15	81
23	March 23	14	66.25
24	March 24	10	59
25	March 25	4	15.75
26	March 26	11	76.5
27	March 28	12	48.75
28	March 30	3	34.5
29	March 31	3	25
Season Total	---	---	**2060**

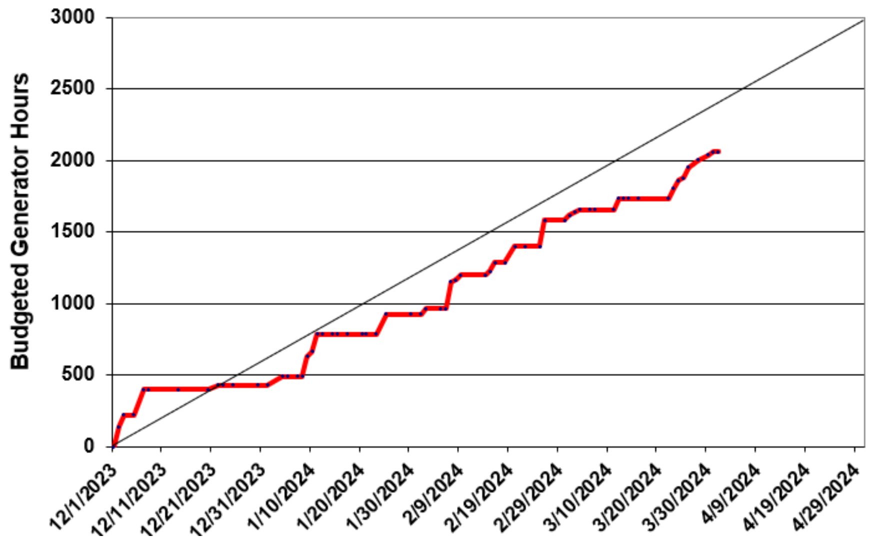


Figure 4.1 **Seeding operations during the 2023-2024 season (red), compared with a linear usage of total budgeted manual generator hours (diagonal black line).**

Precipitation and snowfall began below average for the start of the 2023-2024 winter season but improved to above average beginning in mid-January 2024 and remained above average through March 2024. There was an El Niño pattern in place this winter season, in contrast to the past few seasons which observed a La Niña pattern. As of April 1, 2024 SNOTEL sites in northwestern Box Elder County and Cache County target areas reported snowpack water equivalent values ranging from roughly 95% to 212% of the average (median) across the Bear River Basin and from roughly 118% to 135% of the average (median) across the Raft River Basin. Figures 4.2 to 4.4 show snow water content and precipitation this season, compared to various historical measures, at the Tony Grove Lake, Bug Lake, and Monte Cristo SNOTEL sites.

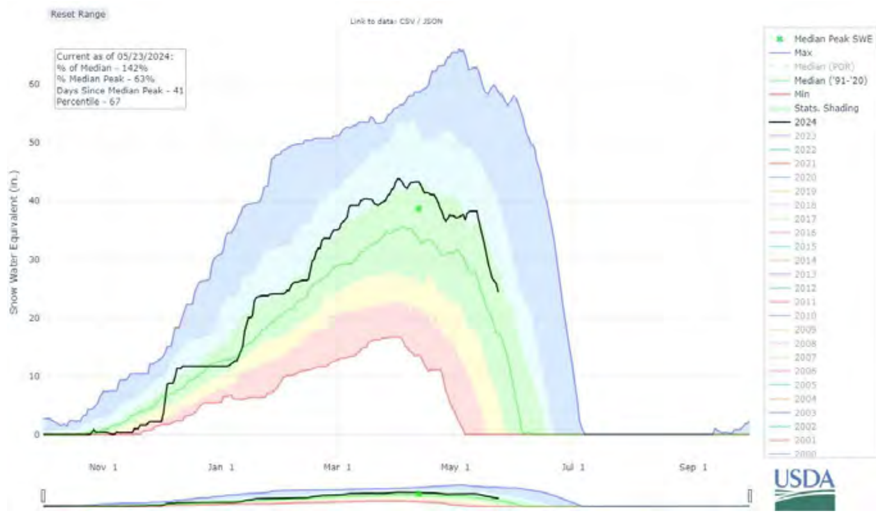


Figure 4.2 SNOTEL snow and precipitation plot for October 2023 through May 23, 2024 for Tony Grove Lake, UT. Black line is the current water year, and green represents the median values. Purple and red lines represent maximum and minimum historical values, respectively.

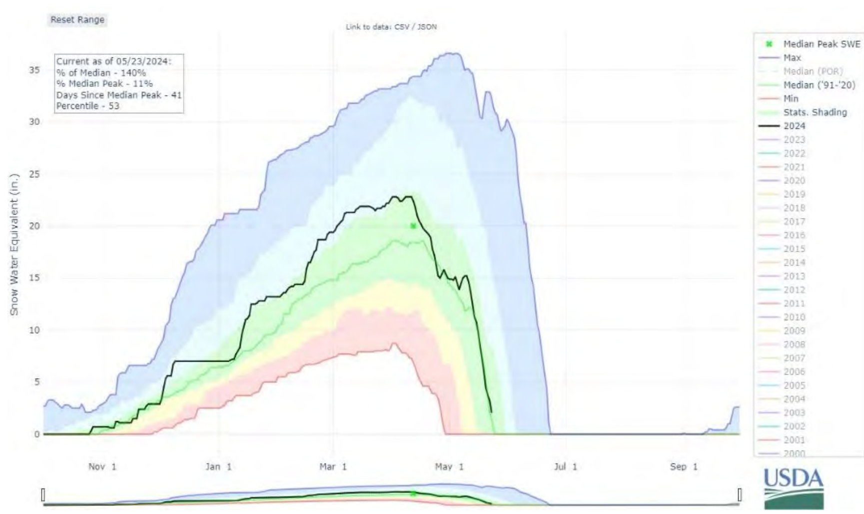


Figure 4.3 SNOTEL snow and precipitation plot for October 2023 through May 23, 2024 for Bug Lake Lake, UT. Black line is the current water year, and green represents the median values. Purple and red lines represent maximum and minimum historical values, respectively.

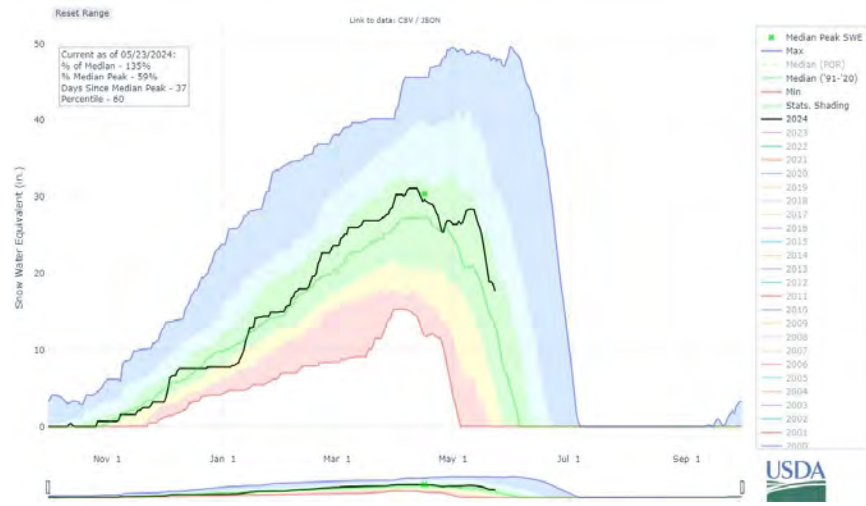


Figure 4.4 **SNOTEL snow and precipitation plot for October 2023 through May 23, 2024 for Monte Cristo, UT. Black line is the current water year, and green represents the median values. Purple and red lines represent maximum and minimum historical values, respectively.**

4.1 Operational Procedures

During the operational period, the project meteorologist monitored each approaching storm with the aid of continually updated online weather information. If the storm parameters met the seedability criteria presented in Section 2 and if no seeding curtailments or suspensions were in effect, an appropriate array of seeding generators were ignited and then adjusted as evolving conditions required. Seeding continued as long as conditions were favorable and precipitating clouds remained over the target area. The operation of the seeding sites is not a simple “all-or-nothing” situation. Individual seeding sites are selected and run based on their location, and targeting considerations based on storm attributes.

4.2 Operational Summary

A synopsis of the atmospheric conditions during operational seeding periods is provided below. All times reported are local, either in MST or MDT. This synopsis describes seeded storm periods, as well as some significant storm periods that were not seeded.

December 2023

The program officially became active on December 1, 2023. December precipitation was quite variable over the area (Figure 4.5), with five seeded storm events during the month.

A disorganized trough swept northwest to southeast across the state of Utah on the evening of the 1st into the morning of December 2nd. The weak trough brought periods of light to moderate precipitation, with brief embedded convection being observed at times. Cooler temperatures filtering in with this system allowed 700mb temperatures to lower from near -10°C on the 1st to near -12°C on the morning of the 2nd. Temperature inversions and lower level stability that were in place on the afternoon of the 1st weakened by mid-evening, which allowed seeding operations to begin after 1900 MST. Seeding continued overnight and through the morning hours of the 2nd before ending after 1200 MST as precipitation tapered off. This storm brought between 0.7-1.3 inches of snow-water content in the eastern portions of the program area.

An atmospheric river began to push into Utah on the afternoon of December 2nd which brought an increase in moisture along with a strong warm advection southwesterly flow pattern, 700mb temperatures climbed from -12°C on the morning of the 2nd to near -6°C during the evening hours with 700mb winds gusting upwards of 45-55 knots. Seeding operations began from the most southern generator sites in Cache Valley after 1700 MST on the 2nd just as precipitation started increasing in coverage and intensity. Moderate to heavy precipitation continued overnight into the morning hours of December 3rd with the flow decreasing in strength. Seeding operations ended after 1200 MST on the 3rd, after it was determined that temperatures had become too mild for seeding to continue and that stability in the lower levels was becoming an issue. developed on the evening hours of December 2nd as. Precipitation totals for the Northern Utah target area ranged from 2.0 to over 5.0 inches of water content in some locations.

A fast moving cold front swept eastward across northern Utah during the morning and early afternoon hours of December 7th. Seeding operations began as the frontal band of precipitation first moved through the program area around 0800 MST and continued through the early afternoon hours as some weak convective and orographic enhanced showers persisted over the terrain in the cold, post frontal environment. The flow was largely west to northwesterly in direction and 700mb temperatures were around -7°C to -8°C. Seeding operations ended around 1300 MST as showers tapered off with roughly 0.1-0.3 inches of accumulated precipitation occurring during this event.

A secondary portion of a large trough moved through the area on the evening of December 7th into the afternoon of December 8th. This trough brought an additional push of moisture along with colder temperatures, which lowered 700mb temperatures from -8°C on the 7th to near -14°C on the 8th. Increasing moisture combined with the cold and unstable northwesterly flow pattern to produce orographic enhanced showers and some weak convective showers on the evening of December 7th into the early afternoon hours of December 8th. Seeding was conducted from numerous sites in Box Elder and Cache County beginning around 2200 MST on the 7th and continued until shower activity dried out around 1500 MST on the 8th. SNOTEL observations showed that between 0.5-1.2 inches of snow water equivalent had fallen across the program.

The last seeding event of December 2023 took place from 1900 MST on December 22nd until 1230 MST on December 23rd as a cold front swept southeast through northern Utah. The front reached far northwest Utah 1900-2000 MST on the evening of the 22nd with a band of moderate to light snowfall filling in over the Raft Rivers. The front then slowly pushed eastward overnight, where it reached the eastern portions of the target area around 0700-0800 MST on the 23rd. Winds turned from southwesterly to northwesterly behind the frontal passage and 700mb temperatures lowered from near -4°C on the 22nd to near -12°C on the morning of the 23rd. The front then pushed off into eastern Utah after midday on the 23rd, and conditions began to dry out. This storm system generated 0.1-0.3 inches of precipitation over the northern Utah target areas.

Figure 4.5 shows December precipitation across the area as a percentage of normal (median) values. The northwestern portions of the target area received well below normal precipitation amounts for the month of December while the eastern portions observed anywhere from about 70 – 110% of normal precipitation.

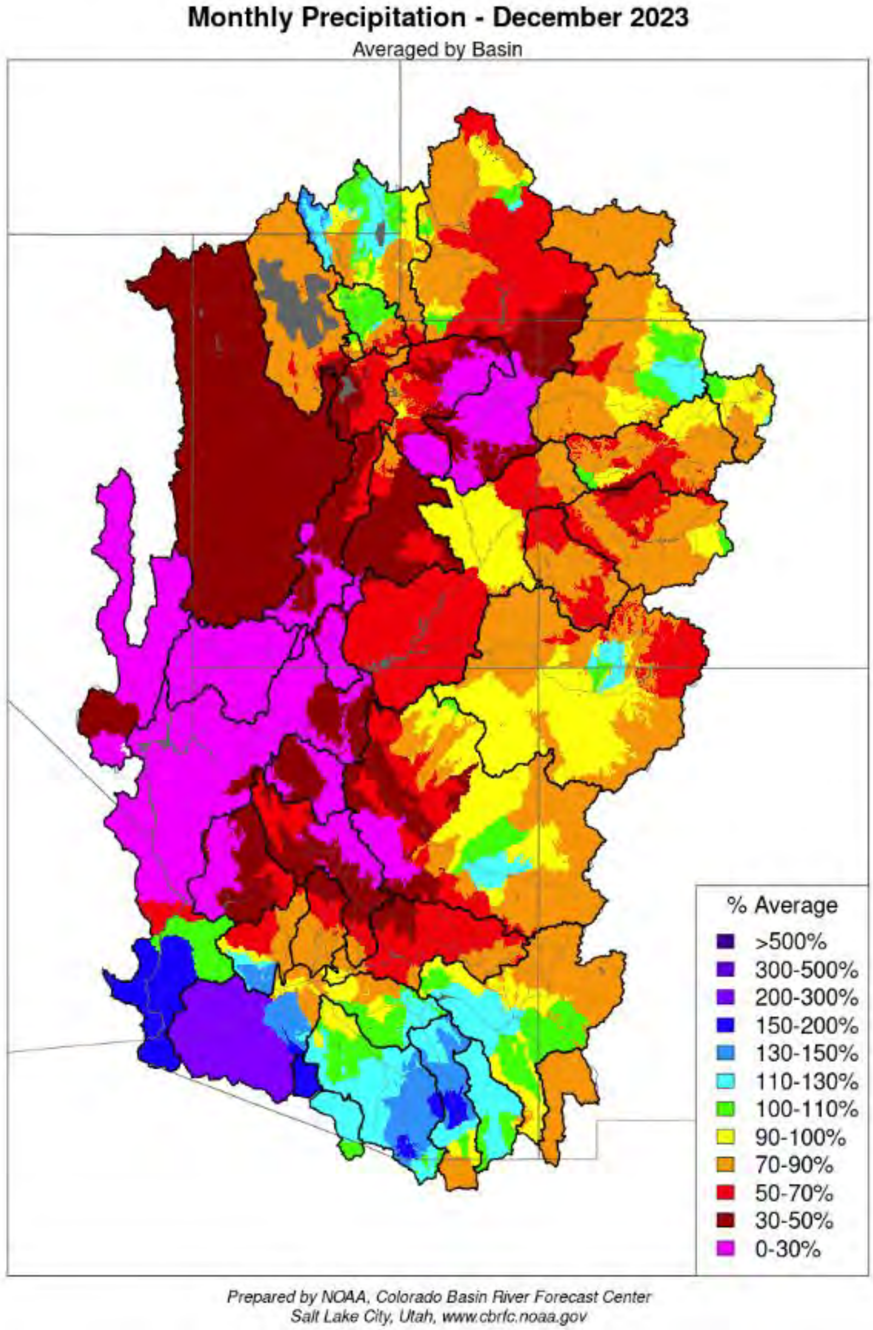


Figure 4.5 December 2023 precipitation, percent of normal

January 2024

January was an active weather month with precipitation and snowpack trending from below normal at the start of the month to above normal by the end. Northern Utah was favored in terms of storm events despite an El Nino pattern being in place which typically favors a more southern storm track. Overall, there were five seeded storm events through the month, which are summarized below.

A weak short-wave trough approached northern Utah form the northwest on the evening of January 4th with the flow being northwesterly and 700mb temperatures hovering around -10°C. Some weak convective type showers developed over the far northwestern portions of Utah late in the evening with limited super cooled liquid water being observed. Seeding was activated from a few sites located in northwest Box Elder County around 2100 MST with seeding continuing from those sites overnight into the morning of January 5th. Analysis on the morning of the 5th revealed that the system was moving a bit slower than forecast and archived radar data revealed that precipitation had largely remained focused near the Utah/Nevada/Idaho triple point overnight. Precipitation finally developed over the eastern portions of the target area by mid-morning however, visual observations and satellite imagery indicated that precipitating clouds had a general lack of supercooled liquid water. This was additionally confirmed by a seeded flight that took place from Logan, Utah around midday. Seeding operations ended over far northwest Utah by mid-morning as showers tapered off there and were later ended for the eastern portions of the target area by 1530 MST when conditions began drying out. Between 0.1-0.3” of SWE was observed across the program.

A deep, cold and fast-moving trough over the Pacific northwest pushed a fast-moving cold front through northern Utah during the late afternoon hours of January 9th. A band of heavy precipitation developed along the front as it moved west to east across the region, which was followed by an abrupt wind shift form southwesterly to northwesterly and rapid drop in temperatures. Seeding began from several sites around 1430 MST as the front was first moving through northwest Utah. Seeding operations then continued overnight into the early morning hours of January 10th as orographic enhanced showers and a few convective type showers persisted over the eastern target area in the post frontal environment. By 0700 MST on the 10th, precipitation began to largely taper off so seeding operations were terminated. SNOTEL sites in the region reported that the target area received between 0.4-0.9” of SWE.

Quickly following the previous storm period, another shortwave trough and band of precipitation made its way across northern Utah area during the afternoon of January 10. Weak warm advection with this next wave caused stability to develop in the lowest elevations and allowed 700mb temperatures to rise from -16°C to near -12°C. After it was observed that precipitation had become less stratiform and more orographically enhanced, seeding operations were initiated from higher elevation sites on the southern portion of the eastern target area around 1230 MST. Most sites were turned off after 1830 MST, as the band of precipitation had moved south of the area by that point. Between 0.2-0.6” of SWE was observed across the program.

During the evening hours of January 11, increasing moisture in a westerly flow pattern was observed, concentrated primarily in a stratus deck between 600 and 700 mb. Temperatures were quite cold, near -

17°C at 700 mb, though weak warm advection developed and raised them slightly overnight. Avalanche conditions were HIGH at upper elevations and CONSIDERABLE at lower elevations, yet still within the operational range for cloud seeding. Cloud tops reached 15 to 17k feet and aircraft pilot reports indicated there was moderate icing near 15k feet, despite temperatures ranging from -25°C to -30°C. This suggested some seeding opportunities through the evening and overnight hours due to increasing moisture and orographically generated supercooled liquid water. As such, seeding began from several sites around 1700 MST and continued through the overnight hours. By 0700 MST on the 12th, hints of liquid water persisted in the cloud deck, but visual observations indicated that precipitating clouds were composed mostly of ice. Additionally, the Salt Lake City 1200UTC sounding showed a very cold and dry atmosphere with cloud bases well below -15°C. Based on these parameters, seeding operations were concluded at this point. SWE values were generally in the range of 0.3-0.9".

Light stratiform precipitation developed over Utah on the morning of January 25th as a negatively tilted trough situated over Oregon induced a warm advection southwesterly flow pattern over the region. As the core of the trough pushed eastward into Utah by mid-morning, ongoing stratiform precipitation transitioned to more of convective type and continued into the early evening hours before ending. Warm air advection transitioned to a cold northwesterly advection pattern and 700mb temperatures lowered to near -9°C through the afternoon. Seeding began from numerous sites around 0900 MST and continued up until conditions dried out after 2100-2200 MST. SNOTEL sites in the area indicated that around 0.1-0.3" of SWE was observed.

Figure 4.6 shows January precipitation as a percentage of the median. Most of northern Utah received from 110% to over 150% of the median values for January.

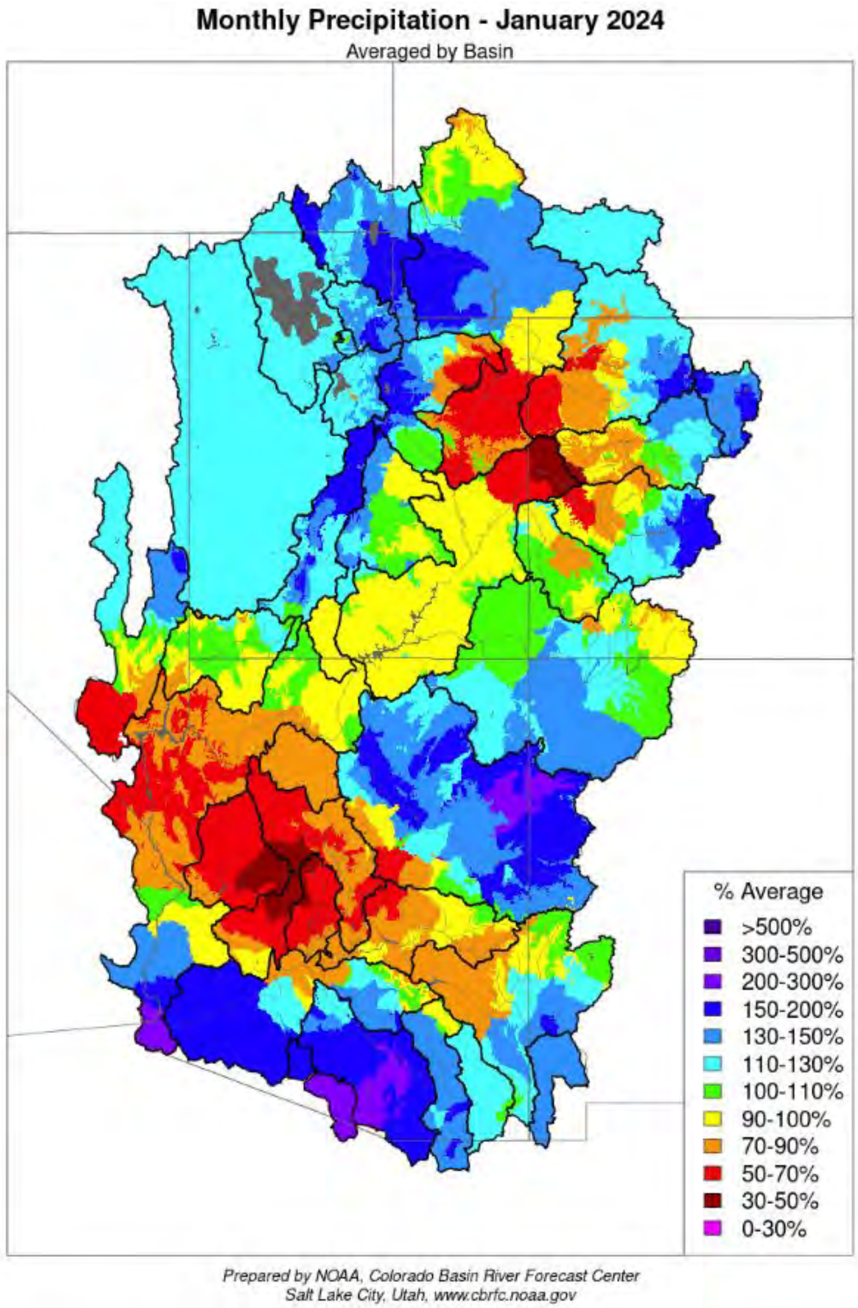


Figure 4.6 January 2024 precipitation, percent of normal

February 2024

February was an active weather month with eight storm events bringing favorable conditions for seeding. Although some of the events were very minor and/or brief in duration, there were also several larger seeded events and other significant precipitation periods that were not favorable for seeding due to cloud types or temperatures within the storm.

Early morning analysis on February 2nd indicated an upstream negatively-tilted trough axis extending from northern California southeastward into Arizona with the remnants of an atmospheric river plume causing precipitation to develop over Utah. The trough axis swung eastward through Utah later on in the afternoon hours, which was accompanied by a frontal boundary. The front reached the I-15 corridor around 1600 MST and brought increasing instability along with a wind shift from southwesterly to northwesterly. Seeding began from sites located in the eastern portions of the program and continued until snowfall ended after 2030 MST. This brief seeded storm event produced between 0.2-0.5" of liquid water content across the program area.

A relatively mild and moisture rich storm system impacted the state of Utah February 6th through February 7th. Beginning on the afternoon of February 6th, an elongated upper-level trough situated along the Pacific Coast induced a deep layer southwesterly flow downstream across Utah. Within this flow, a broad region of enhanced moisture was producing areas of valley rain and mountain snow. No seeding was conducted through the morning or afternoon hours of the 6th, as 700mb temperature were hovering around -2 to -3°C. The upstream trough began lifting inland during the evening hours of the 6th and brought an increase in large scale ascent along with a gradually cooling trend in 700mb temperatures. Seeding operations began from a few sites in northwest Box Elder County and also from a few sites in Cache Valley around 2000 MST on the 6th as precipitation increased and 700mb temperatures lowered to near -5°C. Stratiform precipitation with weak embedded convection continued overnight and through the afternoon hours of the 7th with seeding operations continuing as well. Once it was observed that radar echoes were quickly decreasing after 1800 MST on the 7th, seeding operations were terminated. Around 0.3-0.7" of liquid water equivalent were recorded across the target area.

Another Pacific storm system made its way southeastward through northern Arizona and New Mexico on the 8th of February. The focus for heaviest precipitation was over southern Utah throughout the day, although, there was enough instability and low-level moisture in place across northern Utah to drive the development of scattered convective showers during the late morning and afternoon hours. In general, the flow was northwesterly and 700mb temperatures were around -10°C. Seeding was conducted from a couple of centrally located sites along the I-15 corridor from roughly 1000 MST through about 1830 MST. Storm totals SWE values range from around 0.1-0.2".

A bit of a messy and disorganized pattern was in place across Utah on the morning of February 9th where several shortwave troughs were rotating around the Great Basin region. One such shortwave made its way eastward across the Utah and Idaho border early in the morning and was producing numerous convective type showers over the program, which continued on and off at times through the early afternoon hours. Seeding operations began from several sites located in the eastern portions of the program around 0900 MST after it was determined that showers contained high values of super cooled liquid water. 700mb temperatures were a bit cooler than the previous day and hovered around -13°C and winds were westerly to northwesterly in direction. Seeding operations continued until showers tapered off after 1600 MST. Total snow water equivalent (SWE) for this event ranged from 0.1-0.3".

A weakening, low amplitude trough crossed Utah on the 15th of February. Widespread precipitation in a warm advection pattern developed in advance of the approaching trough prior to dawn, but dry lower levels in place kept most precipitation from reaching the surface through mid-morning. As the trough axis pushed east of the I-15 corridor by late morning, partial clearing on its back side allowed numerous convective type showers to develop over northern Utah. Additionally, winds shifted from southwesterly to northwesterly and 700mb temperatures lowered from -4°C to near -8°C. Seeding sites were turned on around 1200 MST to target these convective type showers and ran until skies began clearing out after 1700 MST. Local observations show that the area picked up between 0.6-1.3" of SWE from this storm event.

A northwesterly flow pattern was in place across Utah on the morning of February 16th as another trough was digging southeast through Idaho. Ample moisture streaming into the area in the lower to mid-levels of the atmosphere was generating strong orographic lift and leading to the development of moderate precipitation over the terrain of the program. Numerous seeding sites were turned on around 0800 MST and remained on until shower activity tapered off after 1500 MST. 700mb temperatures were around -8°C in the morning but gradually lowered to near -10°C in the afternoon, just as precipitation was ending. SNOTEL sites in the region reported that the target area received between 0.5-1.5" of SWE.

A large longwave trough remained centered near the Oregon coast on the morning of February 20th. Downstream of this large trough, a southwesterly flow pattern was pumping subtropical moisture into Utah and was causing widespread precipitation to occur over the state. 700mb temperatures around -4°C were considered on the warm side for seeding, although weak embedded convective activity developed later in the afternoon and led to initiation of seeding operations after 1300 MST. The longwave trough axis ejected inland to the Desert Southwest on the evening of the 20th into the afternoon of the 21st. A jet streak on the southern side of this large low pivoted across the Desert Southwest and an associated cold front was forced west to east across Utah. Strong lifting dynamics from this complex system kept widespread and heavy precipitation going across northern Utah with intermittent periods of seeding activity continuing overnight and throughout the morning and afternoon of February 21st. 700mb temperatures additionally lowered throughout the event, dropping from near -4°C on the 20th to near -7°C on the 21st. Seeding operations finally ended around 1700 MST on the 21st after snow showers activity tapered off. Observations revealed that the program received between 0.8-1.5" of liquid water content.

A cold frontal boundary made its way across northern Utah on the evening of February 26, causing 700 mb temperatures to drop from -5°C to near -14°C and winds to shift from south-southwesterly to west-northwesterly. A band of moderate to heavy precipitation initially accompanied the frontal passage with orographic enhanced showers continuing through the morning of February 27 in the cold and unstable post frontal environment. CNG sites were activated around 1730 MST on the 26th to target the precipitation occurring along the frontal passage. Several sites then remained on overnight into the morning of the 27th to target lingering showers in the post frontal environment. All sites were then turned off around 1045 MST, just as precipitation was drying out. Between 0.5-1.1” of SWE was observed across the program.

Figure 4.7 shows precipitation for February of 2024 as a percentage of the median.

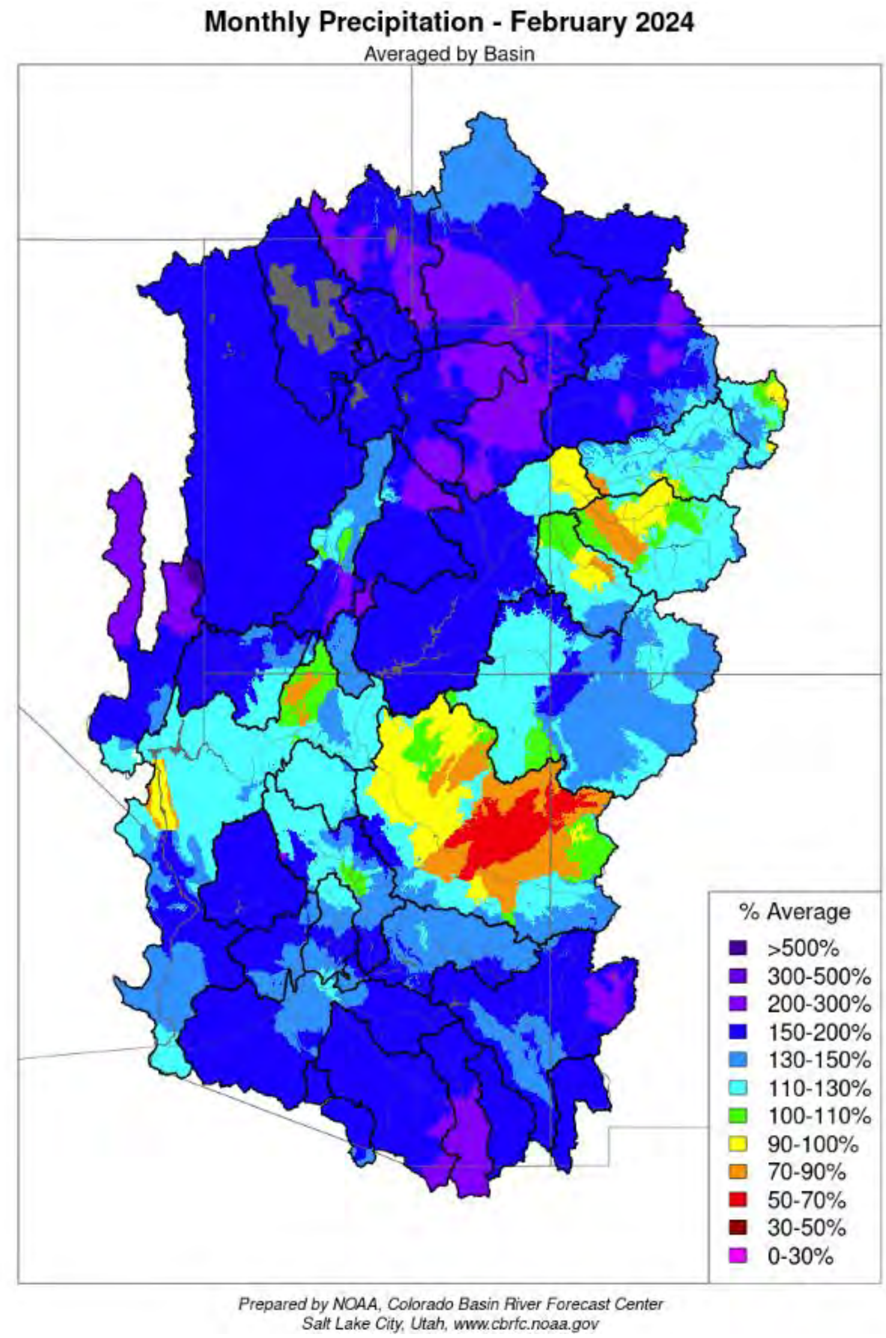


Figure 4.7 February 2024 precipitation, percent of normal

March 2024

The month of March was an active weather month and brought above average snowfall along with eleven seeded storm events. Although most of these events were very minor and/or brief in duration, there were also a few larger seeded events and other precipitation periods not favorable for seeding due to various meteorological parameters.

Very strong winds were occurring on the morning of March 2nd as a potent cold front moved into eastern Nevada. Widespread wind gusts of 55-70 mph were being observed ahead of the front, with a snow squall feature developing along the leading edge of the boundary as it moved into eastern portions of the program area by midday. Strong winds are a major problem both for targeting of material and site operations, with high wind warnings and thunderstorm/snow squall warnings along the front. No seeding sites were activated in the morning hours to target the passage of the front given the severe wind conditions and likely limited band of super cooled liquid water, being concentrated right along the frontal zone. Strong winds dropped off rapidly behind the passage of the frontal boundary however, with orographic enhanced showers developing in its departure. Given the drop in winds speeds and favorable orographic showers developing, seeding sites were turned on around 1300 MST and continued up until snow shower activity ended after 1700 MST. Total snow water equivalent (SWE) for this event ranged from 0.5-1.1”.

A large and cold trough over the Pacific Northwest on March 3rd induced a moisture rich westerly flow pattern over Utah, allowing areas of scattered snow and orographic enhanced showers to develop over northern Utah. As such, a few seeding sites were activated and ran from about 1100 MST to 2000 MST. All in all, the seeding area picked up between 0.1-0.4” of snow water equivalent.

Snow showers redeveloped across portions of northern Utah after 0700 MST on March 4th as a weak trailing wave moved through the region. Conditions were initially stable in the lower levels of the atmosphere through the morning hours but as daytime heating became maximized by midday, instability increased and several convective type showers developed. Several seeding sites in the eastern target area were turned on after 1100 MST and ran until skies cleared out after 1600 MST. Upwards of 0.4” of SWE was observed across the program target area.

The front edge of a Pacific Northwest trough approached northern Utah on the morning of March 12 with an initial frontal boundary having already moved into northwest Utah as of 0400 MDT. This first boundary brought a swath of valley rain/snow and mountain snow to the program area, but strong stability in the lower levels and 700mb temperatures around -3°C kept seeding operations from occurring. As the core of the trough moved into western Utah later on in the afternoon, a secondary frontal feature swept eastward across the West Desert. This secondary frontal boundary experienced frontogenesis as it moved eastward across northern Utah and prompted a snow squall to develop along its leading edge. Numerous seeding sites were activated to target the passage of the snow squall/cold front and remained on in the post frontal environment as additional snow shower activity continued to linger. Shower activity then began to dwindle and dry out after 2000 MDT, after which seeding operations ended. Total snow water equivalent (SWE) for this event ranged from 0.3-0.7".

A strong cold front pushed eastward across northern Utah between 1700 MDT and 2100 MDT on the 23rd of March. The front was accompanied by moderate to heavy precipitation, a quick transition from southwest to northwesterly winds and a drop in temperatures. 700mb temperatures fell from -1°C ahead of the front to near -8°C behind it. Seeding began from several sites around 1700 MDT as the front was first pushing into the eastern portions of program and continued until conditions dried out after 2200 MDT. This storm system produced a quick 0.4-0.8" of liquid water content across the program.

A broad longwave trough upper-level trough encompassed the entire western United States on the morning of March 24th with Utah remaining under a moist northwesterly flow pattern in the wake of the frontal passage that moved through on the evening of March 23rd. The deep and moisture rich northwesterly flow pattern that was in place combined with daytime heating and caused scattered convective showers to pop up during the afternoon hours. Conditions were favorable for using several seeding sites to the north of the target areas, from roughly 1030 MDT until shower activity tapered off after sunset near 2000 MDT. Between 0.1-0.3" of SWE was observed across the program with this shower activity.

A broad trough continued to remain over the Pacific Northwest March 25th through the 26th with Utah being stuck in a cold, and moist northwesterly flow pattern. Diurnal shower activity was observed during the afternoon and early evening hours of each day which brought ideal conditions for seeding operations. As such, seeding activity was conducted from roughly 1300-1800 MDT on the 25th and again between 1030-2000 MDT on the 26th. 700mb temperatures averaged around -10°C through both days and precipitation totals were in the 0.2-0.7" range.

Another large trough centered off the Pacific Northwest coast brought a frontal passage to northern Utah during the morning and afternoon hours of March 28. A good frontal precipitation band was noted with the 700 mb temperature dropping to around -7 C behind the front. Seeding was conducted at numerous sites from approximately 0900 MDT to 1500 MDT, with drying later in the evening. Precipitation totals ranged from about 0.3 – 0.8 inches of water equivalent.

Another large trough moving onshore near California brought some precipitation in southerly flow on March 30. Although temperature were considered somewhat warm, seeding was conducted beginning early in the morning of the 30th from sites that are favorable at targeting the program in southerly flow. Seeding continued through the early evening hours before precipitation began tapering off. Precipitation for this storm period ranged from about 0.3 – 0.6 inches of water content at SNOTEL sites.

The same large trough that brought precipitation to the program on the 30th, slowly rotated southeastward into southern California on the 31st. A shortwave disturbance rotating around this large trough lifted northeast and pinched off into a closed low over northwestern Utah on the morning of the 31st. The position of this closed low continued to induced a southerly flow pattern over the program with increasing dynamics generating precipitation. Seeding was once again conducted from sites that target the program well in southerly flow beginning around 1000 MDT and lasted until showers ended after 1900 MDT. Between 0.3-0.7” of SWE was observed across the program with this last seeded storm of the season.

Figure 4.8 shows March 2024 precipitation as a percentage of the historical median values, with nearly all of northern Utah being over 130% of the March median.

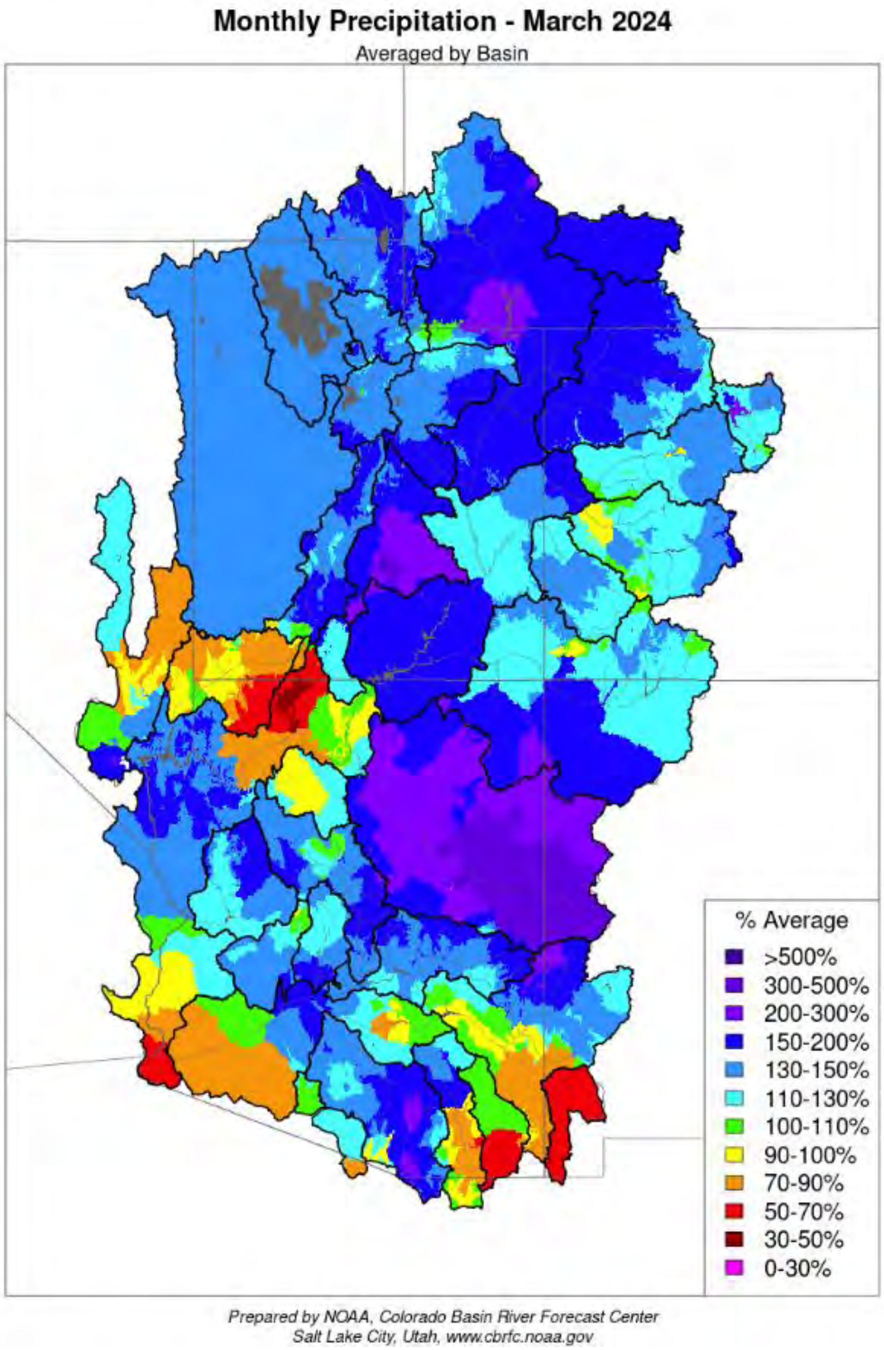


Figure 4.8 **March 2024 precipitation, percent of normal**

5.0 ASSESSMENT OF SEEDING EFFECTS

5.1 Background

Determining the effects of cloud seeding has received considerable attention over the years. Evaluating the results of a cloud seeding program is often a rather difficult task, especially when considering single-season results. The primary reason for this difficulty stems from the large natural variability in the amounts of precipitation that occur in a given region. The ability to detect seeding effects is a function of the size of the seeding increase relative to the natural variability in the precipitation pattern. Larger seeding effects can be detected more readily and with a smaller number of seeded cases than are required to detect smaller increases.

Historically in weather modification, the most significant seeding results have been observed in wintertime seeding programs for snowpack augmentation in mountainous areas. The apparent increases due to seeding are generally less than 20% for individual seasons and in the range of 5-15% for the long-term average. This section of the report summarizes statistical evaluations of the effects of the cloud seeding on the precipitation and snowpack within the higher elevations of this program's targeted areas. When expressed as percentages, the increases may not initially appear to be particularly high. However, when considering that these increases are area-wide averages covering thousands of square miles, the volume of the increased runoff can be very significant.

NAWC has historically utilized a commonly employed evaluation technique, referred to as a target and control evaluation. This method evaluates the effects of seeding on a variable that would be affected by seeding, such as precipitation or snow. Records of the variable to be evaluated are acquired for an historical (unseeded) period of sufficient duration, 20 years or more if possible. These records are partitioned into those that lie within the designated seeded target area of the project and those in a nearby control area. Ideally the control area consists of sites well-correlated with the target area sites, but which would be unaffected by the seeding. All the historical data, for example, precipitation in both the target and control areas are taken from a period that has not been subject to cloud seeding activities, since past seeding could affect the development of a relationship between the target and control areas. These two sets of data are analyzed mathematically to develop a regression equation which estimates the most likely amount of natural target area precipitation, based on the amount of precipitation observed in the control area. This equation is then used during the seeded period to estimate what the target area precipitation should have been in the absence of cloud seeding. A comparison can then be made between the estimated natural target area precipitation and that which actually occurred.

This target and control technique works well where a good statistical correlation can be found between the target and control area variables. Generally, the closer the control sites are to the seeding target area, the higher the correlation will be. Control sites which are too close to the target area, however, can be subject to the effects of the seeding activities at times. This can result in an underestimate of the seeding effect when using such control sites. For precipitation and snowpack assessments, correlations of 0.90 or better are considered excellent and correlations around 0.85 are good. A correlation of 0.90 indicates that over 80 percent of the variance (random variability) in the historical data set is explained by the regression equation. Correlations less than about 0.80 can still be acceptable, but it would likely take much longer (many more years of comparison for both historical data and seeded periods) to attach any statistical significance to the apparent seeding results.

5.2 General Considerations in the Development of Target/Control Evaluations

With the establishment of the Natural Resources Conservation Service's (NRCS) Snow Telemetry (SNOTEL) automated data acquisition system in the late 1970's, access to precipitation and snow water equivalent data in mountainous locations became routine. Before the automated system was developed, these data had to be acquired by having NRCS personnel visit the site to make measurements, which is still done at some sites. Precipitation and snowpack data used in the analysis were obtained from the NRCS website. The current season NRCS data are considered provisional and subject to quality control analysis. Figure 5.1 is a photo of a SNOTEL site with the major components labeled.

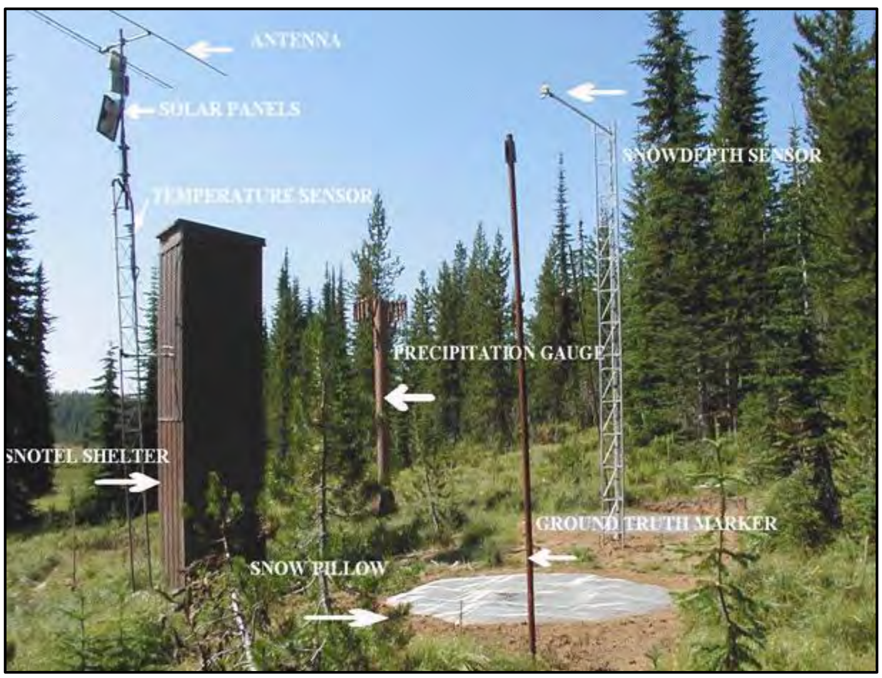


Figure 5.1 SNOTEL site photo

There are multiple cloud seeding programs conducted in the State of Utah. Consequently, potential control areas that are unaffected by cloud seeding are somewhat limited. This is complicated by the fact that the best correlated control sites are generally those closest to the target area, and most measurement sites in this part of the state have been subjected to likely impacts by the numerous historical and current seeding programs. This renders such sites of questionable value for use as control sites. The potential effects of other cloud seeding projects beyond (downwind of) their intended target areas are a consideration, especially when selecting control sites. Some weather modification research has indicated that the precipitation can be affected in areas substantially downwind of the intended target areas. Analyses of some of seeding programs has indicated increases in precipitation in these downwind areas out to distances of 50-100 miles. Thus, control sites for evaluation of the northern Utah seeding program have been located in areas that are not expected to be significantly affected by any current or historical seeding operations. Geographic spread of the control sites is also important to minimize the effects of seasonal variations in weather patterns.

Another consideration in the selection of control sites for the development of an historical target/control relationship is one of data quality. A potential control site may be rejected due to poor data quality, which usually manifests itself in terms of missing data. A site would be excluded if it has significant amounts of missing data. If a significant measurement site move is indicated in the station records, for example more than a mile or a change in elevation of a least a few hundred feet, this may also be a factor. The double-mass plot, an engineering tool, will indicate any systematic changes in relationships between the two stations. If changes shown as inflections in the slope of the line connecting the points are significant, a site(s) may be excluded from further consideration.

Using the target-control comparison described above, regression equations were developed whereby the amount of precipitation or snowpack observed in the unseeded (control) area was used to estimate the amount of natural precipitation in the seeded (target) area. This estimated value is the amount of precipitation or snowpack that would be expected in the target area without seeding. The difference between the estimated amount and the observed amount in the target area (during a seeded season) is the excess, which may be the result of the seeding. Statistical tests have shown that such increases have very little statistical significance for an individual season, and usually fall within one standard deviation of the natural variability. However, an excess obtained by averaging the results of multiple seeded seasons is much more meaningful.

5.3 Evaluation of Precipitation and Snowpack in the Target Areas

Precipitation data used in these analyses were obtained from the NRCS and/or from the National Climatic Data Center and represent the official published records of those organizations. Similar snow water equivalent records used in the snowpack analysis were also obtained from the NRCS. As noted in the discussion of control sites for these analyses, NAWC elected to utilized a different evaluation technique this season for Utah ground-based programs. This is described further in Section 5.5.

5.3.1 Precipitation Analysis

Precipitation measurements are available from several locations within the mountain watersheds of the Eastern Box Elder and Cache County portions of the target area. In northwestern Box Elder County, precipitation sites with sufficient historical records are not available, so no precipitation analysis has been conducted for that area. However, snowpack analyses from snowcourse and SNOTEL sites in the northwestern Box Elder target are included in the analyses.

Target sites

The selected target sites extend southward from near the Idaho/Utah border (west of Bear Lake), along the crest of the Wasatch mountains between Cache and Rich Counties, to the southeast corner of Cache County, near Monte Cristo R.S.). The precipitation sites extend westward along the mountains between Weber and Cache Counties to the Ben Lomond Peak area. The latter is in the Weber/Ogden watershed, but is very likely affected by the seeding generators in southeastern Box Elder County and should represent seeding affecting the Little Bear River and Davenport Creek drainages. The seven precipitation gauge sites that constitute the target area are shown in Figure 5.2. These sites range in elevation from 6,000 to 8,960 feet above mean sea level (MSL). The average elevation of the target sites is 7,744 feet above MSL. The names, locations, and elevations of the sites are listed in Table 5-1.

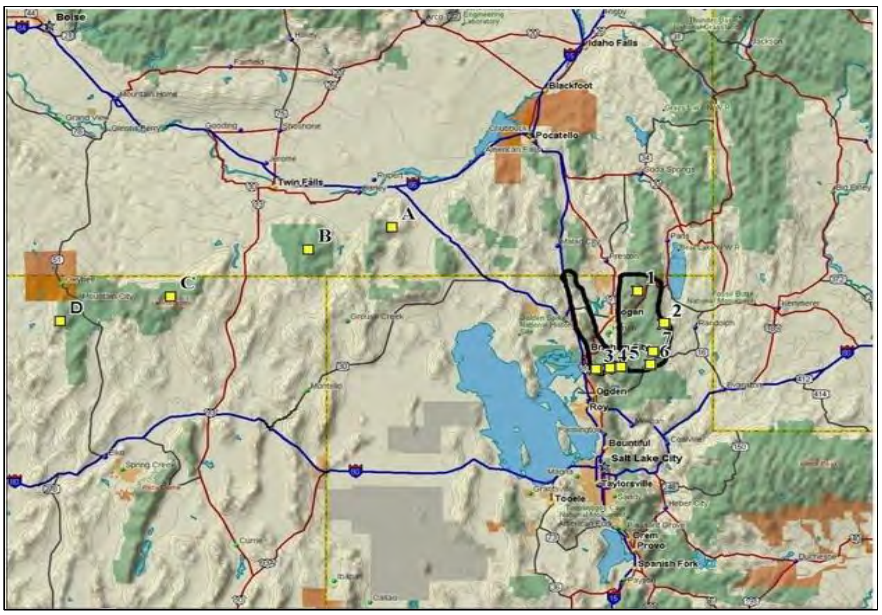


Figure 5.2 Precipitation gauge sites used in evaluation, eastern Box Elder and Cache Counties, with site data in Table 4-1. The target area is outlined in black. The target sites are numbered; the control sites have letter ID's.

Table 5-1
Target and Control Precipitation Gauge Locations, Eastern Box Elder/Cache County Evaluation

ID	Site Name	Site No.	Elev. (Ft)	Lat. (N)	Long. (W)
Control Sites					
A	Howell Canyon, ID	I13G01	7,980	42° 19'	113° 32'
B	Bostetter RS, ID	I14G01	7,500	42° 10'	114° 11'
C	Pole Creek RS, NV	N15H14	8,330	41° 52'	115° 15'

D	Fawn Creek #2, NV	N16H10	7,050	41° 49'	116° 06'
Target Sites					
1	Tony Grove Lake	U11H36	8,400	41° 54'	111° 38'
2	Bug Lake	U11H37	7,950	41° 41'	111° 25'
3	Ben Lomond Peak	U11H08	8,000	41° 22'	111° 57'
4	Ben Lomond Trail	U11H30	6,000	41° 23'	111° 55'
5	Little Bear Upper	U11H25	6,550	41° 24'	111° 49'
6	Dry Bread Pond	U11H55	8,350	41° 25'	111° 32'
7	Monte Cristo	U11H57	8,960	41° 28'	111° 30'

Control Sites

Most of the control sites for the Northern Utah program are located in south-central Idaho and northeastern Nevada, as seen in Figure 5.2. For the 2024 winter season, the State of Utah and local sponsors significantly expanded seeding into new areas in northern Utah. Many of the SNOTEL sites used as non-seeded "control" sites for the seasonal evaluations (of many area programs) are now in areas targeted by seeding operations. Due to this situation, and given the number of years already in the seeded set, it was decided that rather than updating the precipitation and snowpack evaluation on an annual basis, the previously obtained long-term results of these evaluations would be used in combination with an additional approach to derive estimates of streamflow increases using the target/control results. This approach was applied to the Northern Utah program as well as others around the state, even though the expanded seeding operations affect some program target/control evaluations more directly than others.

Precipitation Linear Regression Results

When the target/control data combined for the 33 seeded December-March periods (1989-2022 water years, excluding water years 2023 and 2017 due to seeding suspensions and anomalous precipitation patterns as described above and in the 2017 report), the indicated average increase in the eastern Box Elder/Cache County target area is 5%. The seasonal (December-March) difference between the observed and calculated precipitation is an area-wide average of 0.9 inches more than predicted during the seeded periods. Historical precipitation data was not sufficient for this analysis in the Northwesterly Box Elder County portion, where only a snowpack analysis has previously conducted.

5.3.2 Snowpack Analysis

Snowpack data (SNOTEL and snowcourse) have been used in the past to evaluate both portions of the Northern Utah seeding program.

Target Sites

The eastern Box Elder/Cache County target group consists of seven sites. The sites are shown in Figure 5.6, and names and locations are listed in Table 5-2. The average elevation of the target area sites is 7,760 feet MSL. A snowpack evaluation was also conducted for northwestern Box Elder County, using two available snow course/SNOTEL sites. Figure 5.6 depicts these site locations as well, and Table 5-2 lists pertinent site data.

Control Sites

Figure 5.6 shows the locations of the eastern Box Elder/Cache County control area snowpack sites. The site names and locations of the five control sites are listed in Table 5-2. The average elevation of these sites is 7,298 feet MSL. The same control set used for eastern Box Elder and Cache counties has also been used to evaluate the northwestern Box Elder County portion of the program.

As described in the above section, for the Utah ground-based seeding programs a different evaluation approach has been used this season given the large set of seeded-season data (well over 30 seeded seasons in Northern Utah) that has yielded a long-term estimated of seeding increases to precipitation and snow in this area.

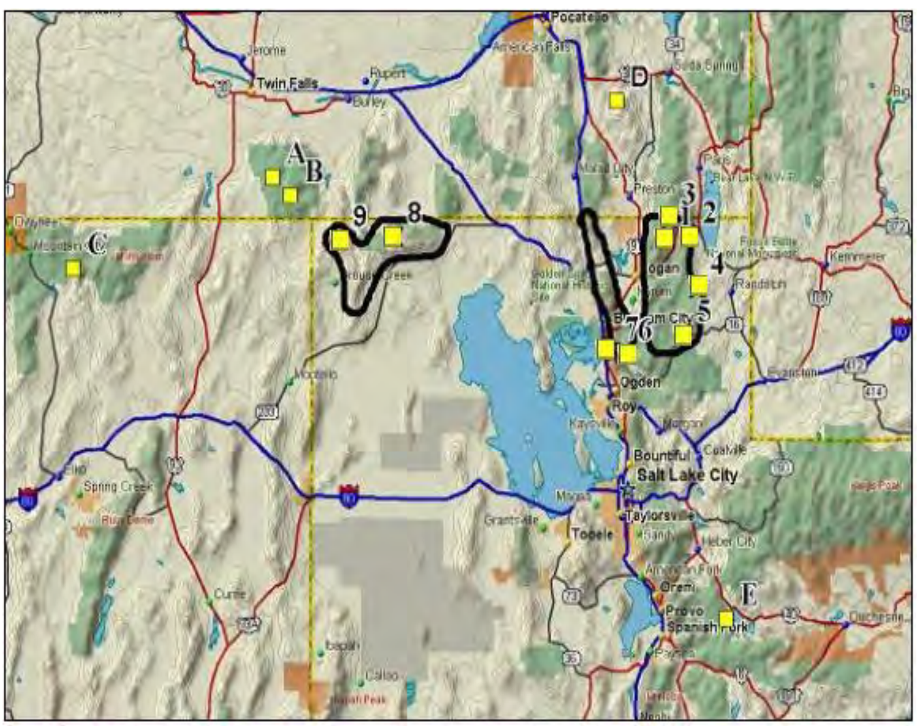


Figure 5.3 **Target and control sites used in eastern Box Elder/Cache County snowpack evaluation, with site data shown in Table 4-2. The target areas are outlined in black. The target sites are numbered; the control sites have letter ID's.**

Table 5-2
Snowpack Control and Target Measurement Sites

ID	Site Name	Site Number	Elevation (Ft)	Latitude	Longitude (W)
Control (for both areas)					
A	Magic Mountain, ID	14G02S	6,880	42° 11'	114° 18'
B	Badger Gulch, ID	14G03S	6,660	42° 06'	114° 11'
C	Big Bend, NV	15H04S	6,700	41° 46'	115° 41'
D	Sedgwick Peak, ID	11G30S	7,850	42° 32'	111° 58'
E	Strawberry Divide, UT	11J08S	8,400	40° 11'	111° 13'
Eastern Box Elder/Cache County Target					
1	Tony Grove Lake, UT	11H36	8,400	41° 54'	111° 38'
2	Garden City Summit, UT	11H07	7,600	41° 55'	111° 28'
3	Klondike Narrows, UT	11H01	7,400	41° 58'	111° 36'
4	Bug Lake, UT	11H37	7,950	41° 41'	111° 25'
5	Monte Cristo, UT	11H57	8,960	41° 28'	111° 30'
6	Ben Lomond Trail, UT	11H30	6,000	41° 23'	111° 55'
7	Ben Lomond Pk., UT	11H08	8,000	41° 23'	111° 57'
Northwestern Box Elder County Target					
8	George Creek, UT	13H05	8,840'	41°54'	113°29'
9	Vipont, UT	13H03	7,670'	41°54'	113°51'

5.4 Historic Evaluation Results for Precipitation and Snowpack

The long-term results for 33 seeded seasons in the Eastern Box Elder/Cache County portion of the target indicate 6-13% increases in April 1 snowpack (an average of 1.4-2.5 inches of additional water) and a 5-6% increase in December through March precipitation (a little under 1.0 inch of additional water). Long-term results of these evaluations are summarized in Table 5-3. These cumulative results likely constitute reasonable estimates of the true seeding effects for this program, although the reasons for a difference in results between precipitation and snowpack is not really known. The natural seasonal variability which occurs in weather patterns and precipitation between target and control areas is expected to cause much more variation in the results of the single season mathematical target/control evaluation results, than for the actual effects of the seeding from one season to another which should be relatively consistent.

Table 5-3
Comparison of Results of Linear and Multiple Linear Analyses, for the Combination of all Seeded Seasons.

Area	Ratio Observed/Predicted		Excess Water (inches)	
	Linear	Multiple Linear	Linear	Multiple Linear
Cache/E. Box Elder Dec-Mar Precipitation (33 years)	1.05	1.06	+0.9	+1.0
Cache/E. Box Elder April 1 Snowpack (33 years)	1.06	1.13	+1.4	+2.5
NW Box Elder April 1 Snowpack (29 years)	1.13	1.09	+1.9	+1.4

For the larger (eastern) portion of the program, results in Table 5-3 suggest an overall increase of perhaps 7% to snowpack/seasonal precipitation. The 13% increase for the multiple linear snowpack evaluation is a bit of an outlier among these results, so more conservatively a 6% increase to precipitation/snow might be assumed.

5.5 Determining the Impact of Cloud Seeding on Streamflow

Given the large number of seeded seasons that have been evaluated for this program (greater than the data set of historical, non-seeded seasons on which the regressions are based), NAWC elected to add some streamflow data evaluations to the mix of evaluations for this season's report instead of adding another season to the seeded evaluation set. For most of the Utah programs in general, this new approach was related to the fact that many sites previously utilized as control sites are now subject to effects of seeding operations, with the addition of remotely operated seeding sites during the past season. Adding new regressions of snowpack/precipitation vs. seasonal streamflow provides estimates of likely streamflow increases where well-correlated (e.g. natural, unregulated flow) gauge sites are available, utilizing previously obtained increase estimates to the precipitation and snow in the target areas.

5.5 Results - Impact of Cloud Seeding on Runoff

For the streamflow analyses, gauges on the Logan River near Logan and Blacksmith Fork near Hyrum were correlated to SNOTEL data in these respective watersheds. For streamflow, a seasonal period of March – July has been used in order to capture the bulk of the seasonal runoff without additional input from precipitation outside the winter season. This was found to be well correlated to April 1 snow and seasonal

(November – April) precipitation. The streamflow versus snowpack and precipitation relationships are essentially independent of seeding effects, so both seeded and non-seeded years can be included in these regression.

For the Logan River gauge, correlation to April 1 snowpack to Tony Grove (the best correlated SNOTEL site) produced an R value of 0.85 (R^2 = 0.73). Results suggest that a 5% increase in seasonal snowpack (due to seeding) would produce a roughly 7% increase in runoff in the Logan River for an average season. This higher percentage increase to runoff (compared to the seeding increase to snowpack) may seem counterintuitive, but is actually an expected results of these analyses when dealing with percentages. This is due to the negative offset term in the equations, a consequence of the fact that there is some inefficiency in converting snowpack to streamflow and a certain amount of water will evaporate or be lost to other processes such as uptake by the soil and vegetation. Thus, increasing the total snowpack or seasonal precipitation by a given percentage will increase the actually runoff by a higher percentage, given that the runoff represents the excess after these other processes have occurred. Given an average base flow in the Logan River of over 100,000 acre-feet (AF) during the seasonal period of March – July, this estimated seeding increase would amount to over 7,000 AF in an average season. A similar result was obtained for the Logan River gauge when correlated to seasonal precipitation (again from the Tony Grove SNOTEL), suggesting about a 6.7% increase in streamflow or rougly a 7,000 AF increase.

For the Blacksmith Fork near Hyrum, a 5% increase in April 1 snowpack (at the Bug Lake SNOTEL, the best correlated for this gauge) results in roughly an 8% increase in streamflow. Applied to an average season, with a base seasonal flow of roughly 50,000 AF, this would amount to an additional 4,000 AF at this gauge site. A similar analysis for Bug Lake precipitation versus streamflow in Blacksmith Fork suggested a 5% increase in November – April precipitation yielding over a 9% increase in March – July streamflow, amounting to over 4,500 additional AF of runoff.

A streamgage in far northwestern Utah (Dunn Creek near Park Valley) was correlated to April 1 snowpack data from the George Creek snowcourse, within the Northwest Box Elder portion of the seeding target area. The results suggest that a 6% increase in snowpack there (the more conservative snowpack evalution result as shown in Table 5-3) would yield nearly an 11% increase in runoff during an average year. Given the average seasonal runff of close to 3,000 AF at that gauge, this would amount to perhaps 320 additional AF due to seeding.

These streamflow data represent only a fraction of the runoff from the seeding target areas, of course. The suggested increases in seasonal (March – July) streamflow of roughly 7-11% could be scaled to the total runoff for the seeding target areas as a whole. In any case, a higher **percentage** increase to streamflow (than the seasonal percentage increase to precipitation/snowpack) is an expected result, as seen in these evaluation results that resulted in an estimated 7-11% streamflow increase from a (conservative) 5-6% average seasonal precipitation and snowpack increase due to seeding.

APPENDIX A: 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 very important in limiting any potential liability associated with weather modification and to maintain a positive public image.

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

1. Excess snowpack accumulation
2. Rain-induced winter flooding
3. Severe weather

Excess Snowpack Accumulation

Snowpack begins to accumulate in the mountainous areas of Utah in November and continues through April. The heaviest average accumulations normally occur from January through March. Excessive snowpack water content becomes a potential hazard during the resultant snowmelt. The Natural Resources Conservation Service (NRCS) maintains a network of high elevation snowpack measurement sites in the State of Utah, known as the SNOTEL network. SNOTEL automated observations are now readily available, updated as often as hourly. The following set of criteria, based upon observations from these SNOTEL site observations, has been developed as a guide for potential suspension of operations.

Project & Basin	Critical Streamflow Volume (Acft) & USGS Streamgage	SNOTEL Station	SWE Value Corresponding to the Critical Flow								Ranking of SNOTEL Stations
			Jan 1 (in.)	Jan 1 (%)	Feb 1 (in.)	Feb 1 (in %)	March 1 (in.)	March 1 (in %)	April 1 (in.)	April 1 (in %)	
1. Northern Utah	185,208	Franklin Basin, Idaho	19.50	190.84	27.14	165.31	34.35	154.71	41.56	153.60	1
Logan at Logan	USGS 10109000	Tony Grove	28.73	205.94	39.44	175.56	48.06	160.38	56.34	156.56	2
		Bug Lake	17.08	218.82	21.91	180.34	26.72	165.25	31.65	162.70	3
		Average	**21.80**	**205.20**	**29.50**	**173.70**	**36.40**	**160.10**	**43.20**	**157.60**	
Weber near Oakley	176,179	Chalk Creek #1	10.09	173.13	14.73	153.66	28.77	149.85	34.15	143.41	1
	USGS 10128500	Trial Lake	20.15	207.44	26.33	180.55	33.55	173.27	38.54	162.28	2
		Smith Morehouse	10.06	186.34	13.69	137.60	17.36	146.32	21.17	160.26	3
		Hayden Fork	12.19	194.16	16.69	172.11	20.71	158.56	21.79	164.64	4
		Average	**13.10**	**190.30**	**17.90**	**166.00**	**25.10**	**157.10**	**28.90**	**157.70**	
Dunn Creek near	5,733	George Creek	17.84	187.75	18.32	143.81	28.93	163.43	34.61	153.77	1
the Park Valley	USGS 10172952	Howell Canyon, Idaho	28.71	279.96	38	223.24	44.59	205.98	50.46	191.65	2
		Average	**23.30**	**233.90**	**28.20**	**183.60**	**36.80**	**184.70**	**42.60**	**172.70**	
2. Western & High Uintah	166,861	Lily Lake	11.38	202.70	16.40	194.06	17.69	147.37	28.93	139.19	1
Bear River near Utah -	USGS 10011500	Trial Lake	20.07	206.54	26.56	182.26	33.68	173.94	38.49	162.05	2
Wyoming state line		Hayden Fork	12.41	197.65	17.06	175.83	21.03	160.98	20.90	146.02	3
		Average	**14.60**	**202.30**	**20.00**	**184.10**	**24.10**	**160.80**	**29.40**	**149.10**	
Duchesne near Tabiona	140,976	Strawberry Divide	6.92	239.23	10.87	199.25	26.77	178.78	29.75	179.05	1
	USGS 09277500	Daniels-strawberry	16.07	248.12	21.59	202.44	27.82	190.54	29.89	192.75	2
		Smith Morehouse	10.61	196.64	14.95	172.41	18.82	158.83	22.22	168.26	3
		Rock Creek	8.76	230.02	12.31	219.65	15.88	205.68	16.41	209.06	4
		Average	**10.60**	**228.50**	**14.90**	**198.50**	**22.30**	**183.50**	**24.60**	**187.30**	
Provo near woodland	183,845	Trial Lake	22.98	236.53	27.78	190.63	35.23	181.59	31.44	132.39	1
	USGS 09277500	Beaver Divide	10.29	210.39	14.11	179.49	17.45	170.83	20.18	200.3	2
		Average	**16.70**	**223.50**	**20.90**	**185.10**	**26.30**	**176.20**	**25.80**	**166.40**	
3. Central & Southern	120,473	Castle Valley	12.23	244.05	16.96	203.04	22.22	187.68	26.30	180.00	1
Sevier near Hatch	USGS 10174500	Harris Flat	8.71	298.76	15.25	273.59	24.16	222.99	21.15	209.77	2
		Farnsworth Lake	17.25	218.10	20.96	185.95	27.05	182.24	32.93	167.03	3
		Average	**12.80**	**253.70**	**17.70**	**220.90**	**24.50**	**197.70**	**26.80**	**185.60**	
Coal Creek near	38,533	Midway Valley	20.89	215.65	29.12	194.04	35.89	176.99	42.29	167.97	1
Cedar City	USGS 10242000	Webster Flat	13.57	232.46	18.70	197.95	24.30	184.64	24.93	181.12	2
		Average	**17.20**	**224.10**	**23.90**	**196.00**	**30.10**	**180.90**	**33.60**	**174.60**	
South Willow near	5,426	Rocky Basin-settlemnt	19.09	205.33	23.75	174.14	32.11	171.39	40.01	167.51	1
Grantsville	USGS 10172800	Mining Fork	16.31	243.66	20.74	177.04	27.81	171.79	32.19	168.74	2
		Average	**17.70**	**224.50**	**22.30**	**175.60**	**30.00**	**171.60**	**36.10**	**168.10**	
Virgin River at Virgin	151,286	Kolob	23.11	229.25	29.08	220.78	36.51	197.43	43.71	196.21	1
	USGS 09406000	Harris Flat	9.71	377.00	15.69	304.18	21.46	300.00	20.11	370.00	2
		Midway Valley	24.76	256.17	34.56	238.40	41.44	209.68	51.05	211.06	3
		Long Flat	9.38	265.88	13.54	286.16	19.20	286.18	18.91	187.00	4
		Average	**16.70**	**282.10**	**23.20**	**262.40**	**29.70**	**248.40**	**33.40**	**241.10**	
Santa Clare above Baker	11,620	Gardner Peak	13.00	293.90	16.82	172.15	21.70	167.36	24.45	163.95	1
Reservoir	USGS 09409100	**Average**	**13.00**	**293.90**	**16.80**	**172.10**	**21.70**	**167.40**	**24.50**	**164.00**	
		Utah State Average (%)		**230**		**197**		**183**		**178**	
		Standard Deviation		**42**		**38**		**35**		**42**	
		Upper 95%		**248**		**213**		**199**		**196**	
		Lower 95%		**212**		**180**		**168**		**160**	

Snowpack-related suspension considerations will be assessed on a geographical division or sub-division basis. The NRCS has divided the State of Utah into 13 such divisions as follows: Bear River, Weber-Ogden Rivers, Provo River-Utah Lake-Jordan River, Tooele Valley-Vernon Creek, Green River, Duchesne River, Price-San Rafael, Dirty Devil, South Eastern Utah, Sevier River, Beaver River, Escalante River, and Virgin River. Since SNOTEL observations are available on a daily basis, suspensions (and cancellation of suspensions) can be made on a daily basis using linear interpolation of the first of month criteria. There are a number of SNOTEL stations in the various basins of central and southern Utah on which these criteria are based. These include Castle Valley, Harris Flat, and Farnsworth Lake in the Sevier Basin; Midway Valley, Kolob, Harris Flat, Webster Flat, and Long Flat in southwestern Utah; and Rocky Basin Settlement and Mining Fork in eastern Tooele County.

Streamflow forecasts, reservoir storage levels, soil moisture content and amounts of precipitation in prior seasons are other factors which need to be considered when the potential for suspending seeding operations due to excess snowpack water content exists.

Rain-induced Winter Floods

The potential for wintertime flooding from rainfall on low elevation snowpack is fairly high in some (especially the more southern) target areas during the late winter/early spring period. Every precaution must be taken to insure accurate forecasting and timely suspension of operations during these potential flood-producing situations. The objective of suspension under these conditions is to eliminate both the real and/or perceived impact of weather modification when any increase in precipitation has the potential of creating a flood hazard.

Severe Weather

During periods of hazardous weather 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 and the attendant hazards. Each phenomenon is described in terms of criteria used by the NWS in issuing special weather bulletins. Those which may be relevant in the conduct of winter cloud seeding programs include the following:

- **Winter Storm Warning -** This is issued by the NWS when it expects heavy snow warning criteria to be met, along with strong winds/wind chill or freezing precipitation.

- **Flash Flood Warning -** This is issued by the NWS when flash flooding is imminent or in progress. In the Intermountain West, these warnings are generally issued relative to, but are not limited to, fall or spring convective systems.

Seeding operations may be suspended whenever the NWS issues a weather warning for or adjacent to any target area. Since the objective of the cloud seeding program is to increase winter snowfall in the mountainous areas of the state, operations will typically not be suspended when Winter Storm Warnings are issued, unless there are special considerations (e.g., a heavy storm that impacts Christmas Eve travel).

Flash Flood Warnings are usually issued when intense convective activity causing heavy rainfall is expected or is occurring. Although the probability of this situation occurring during our core operational seeding periods is low, the potential does exist, especially over southern sections of the state during late March and early April, which can include the project spring extension period. The type of storm that may cause problems is one that has the potential of producing 1-2 inches (or greater) of rainfall in approximately a 24-hour period, combined with high freezing levels (e.g., > 8,000 feet MSL). Seeding operations will be suspended for the duration of the warning period in the affected areas.

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.

APPENDIX B: SEEDING OPERATIONS TABLE

Table B-1
Seeding Hours – Northern Utah, 2023-2024, Storms 1-10

Storm	1	2	3	4	5	6	7	8	9	10
Dates	**Dec. 1-2**	**Dec. 2-3**	**Dec. 7**	**Dec. 7-8**	**Dec. 22-23**	**Jan. 4-5**	**Jan. 9-10**	**Jan. 10**	**Jan. 11-**	**Jan. 25**
SITE										
BE-1					10	15.25	5		12	8.25
BE-2										
BE-3										
BE-4										
BE-5									14.75	8.5
BE-6						10				
BE-7				4		12.5				4.75
BE-8										
BE-9										
CV-1										
CV-2			5.25	16.5			15.25		10.5	9
CV-3										11.75
CV-5	15.5			16.75			14.5		11.5	12.25
CV-6						5	14.75		11	12.75
CV-7	15.5		5	15.5		5	14.75		11.25	12.75
CV-9										
CV-10										
CV-11	16.25		5.25	16.5			14.5			9.5
CV-12	15.5		5	14.5			14.25	6	12	4.5
CV-13	16.75	18		12			13	6	13	9
CV-14		16.75						0.5		
CV-15	17.5	15.25		17.75	1		13.25	5.75	12.25	9

Storm	1	2	3	4	5	6	7	8	9	10
Dates	**Dec. 1-2**	**Dec. 2-3**	**Dec. 7**	**Dec. 7-8**	**Dec. 22-23**	**Jan. 4-5**	**Jan. 9-10**	**Jan. 10**	**Jan. 11-**	**Jan. 25**
CV-16	17.25			17		4.5	13.5			
CV-17	15.5				5.5	5	14.25	6		9.5
CV-18					5	4.75				8.5
CV-19	5.5							5.75		10.5
CV-20				17	6				11.75	12.5
CV-21		17		11.5				5.75		
CV-22		17								
CV-23										
Storm	**135.25**	**84**	**20.5**	**159**	**27.5**	**62**	**139**	**35.75**	**120**	**143**

Table B-2
Seeding Hours – Northern Utah, 2023-2024, Storms 11-20

Storm	11	12	13	14	15	16	17	18	19	20
Dates	**Feb. 2**	**Feb. 7**	**Feb. 8**	**Feb. 9**	**Feb. 15**	**Feb. 16**	**Feb. 20-21**	**Feb 26-27**	**Mar. 2**	**Mar. 3**
SITE										
BE-1		16				8				
BE-2										
BE-3		16					6			
BE-4		16					6			
BE-5						2.75	9	3		
BE-6							5			
BE-7							5.5			
BE-8										
BE-9										
CV-1								14		
CV-2	5.75	8						17		6
CV-3		6				7	10	16	1	
CV-5		7				7.5		15		
CV-6	5			6.5						
CV-7				6.5		7		9.5	4	
CV-9										
CV-10										
CV-11		7	6.5			6.5	8.25	16.5	4.5	
CV-12	6.5	9	6.5	2.5	4.75	4.75	11.5	16.75	4.25	5
CV-13		9		6.5			2.25	15		5
CV-14									2	
CV-15	7.25	8.75		4		6.25	26.5	14	4	5.25
CV-16	5.25	8.5				6.75		16		
CV-17	6	9.5					12	16.5	4	

Storm	11	12	13	14	15	16	17	18	19	20
Dates	Feb. 2	Feb. 7	Feb. 8	Feb. 9	Feb. 15	Feb. 16	Feb. 20-21	Feb 26-27	Mar. 2	Mar. 3
CV-18		6		5	10	6.25	12.5		3.5	
CV-19		9.75			5				4.25	
CV-20		5		6			11	14		
CV-21		19.5			5.5		10			
CV-22		20								
CV-23		5.25								
Storm Total	**35.75**	**186.25**	**13**	**37**	**25.25**	**62.75**	**113**	**183.25**	**31.5**	**21.25**

Table B-3
Seeding Hours – Northern Utah, 2023-2024, Storms 21-29

Storm	21	22	23	24	25	26	27	28	29	Season Total
Dates	Mar. 4	Mar. 12	Mar. 23	Mar. 24	Mar. 25	Mar. 26	Mar. 28	Mar. 30	Mar. 31	
SITE										
BE-1		5		3.25		5				**87.75**
BE-2				9						**9**
BE-3										**22**
BE-4										**22**
BE-5		5.75		5			5			**53.75**
BE-6				8						**23**
BE-7				8		4				**38.75**
BE-8										**0**
BE-9										**0**
CV-1		5.5	4.75	4		5.75	2			**36**
CV-2		7	4.5	2		7.75	5			**119.5**
CV-3										**51.75**

Storm	21	22	23	24	25	26	27	28	29	Season Total
Dates	**Mar. 4**	**Mar. 12**	**Mar. 23**	**Mar. 24**	**Mar. 25**	**Mar. 26**	**Mar. 28**	**Mar. 30**	**Mar. 31**	
CV-5		6	4.5			8.5	3.5			**122.5**
CV-6		6.5	5	6.25		8.5	4.25			**85.5**
CV-7		1.75	5	6			4.75			**124.25**
CV-9										**0**
CV-10										**0**
CV-11		7	5		4	7.75	4			**139**
CV-12	3.5	7	3		4	8.75	4.75			**174.25**
CV-13	3		5		4.25	8.5	5.75			**152**
CV-14	3.75	5.5								**28.5**
CV-15	4	7	4.25		3.5	7.5	5.25			**199.25**
CV-16		4.5				7.5	3.25			**104**
CV-17	4									**107.75**
CV-18		6.25		7.5						**75.25**
CV-19		4	4.5							**49.25**
CV-20		7.25	4.5							**95**
CV-21			5.5				5.25	11.25	9	**100.25**
CV-22			5.75					11.25	8	**62**
CV-23			5					12	8	**30.25**
Storm Total	**18.25**	**81**	**66.25**	**59**	**15.75**	**76.5**	**48.75**	**34.5**	**25**	**2060**

APPENDIX C: GLOSSARY OF RELEVANT 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: 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.

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.

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

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 Nino: 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 has an effect on 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).

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 indicated 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.

Inversion: Refers to a layer of the atmosphere in which the temperature increase with elevation

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 Nina: 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 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 (counter-clockwise) 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

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.

Pressure Heights:
(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 pattern): 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.

Storm Track (sometimes reference 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

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 (counter-clockwise) circulation pattern in the Northern Hemisphere.

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

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.

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 site