Cloud Seeding Annual Report and Evaluation

Program:

Six Creeks Program
2021-2022 Winter Season

Prepared For:

Salt Lake City Department of Public Utilities

And The

Utah Department 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.

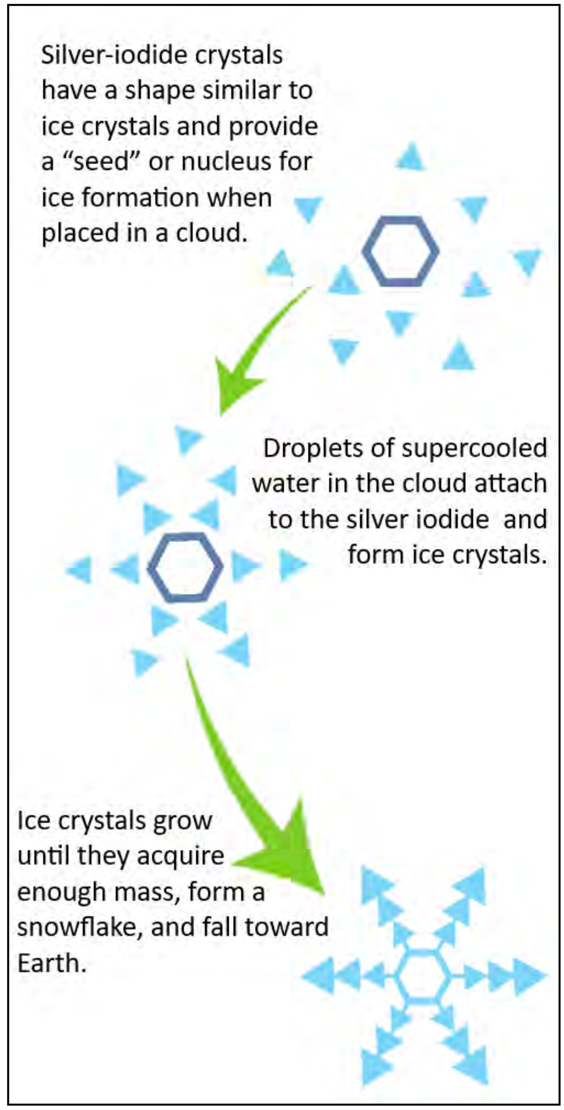
Silver iodide has been selected for its environmental safety and superior efficiency in producing ice in clouds. Silver iodide adds microscopic particles with a structural similarity to natural ice crystals. Ground-based and aircraft-borne technologies can be used to add the particles to the clouds.

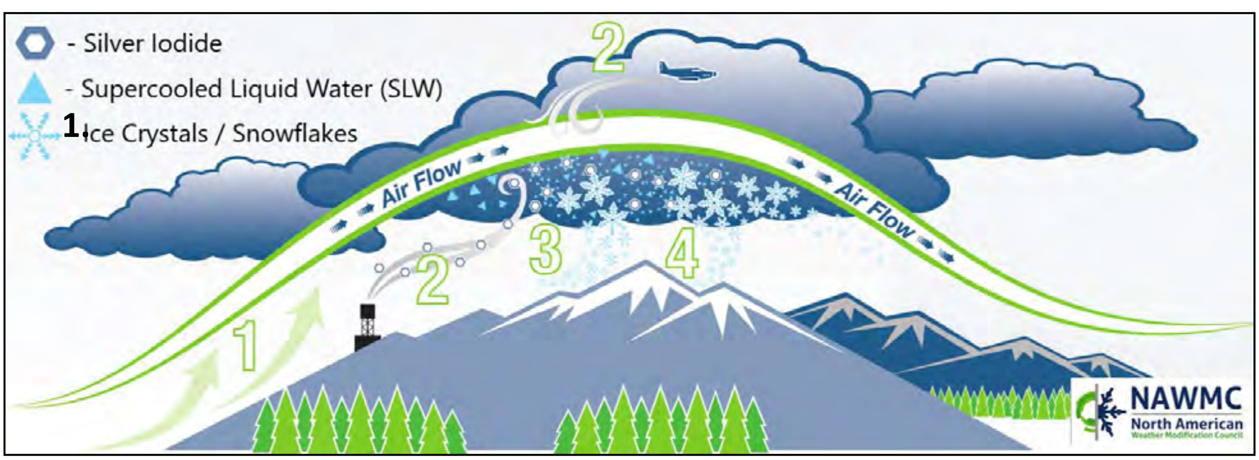
Safety

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.





STATE OF THE CLIMATE

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

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

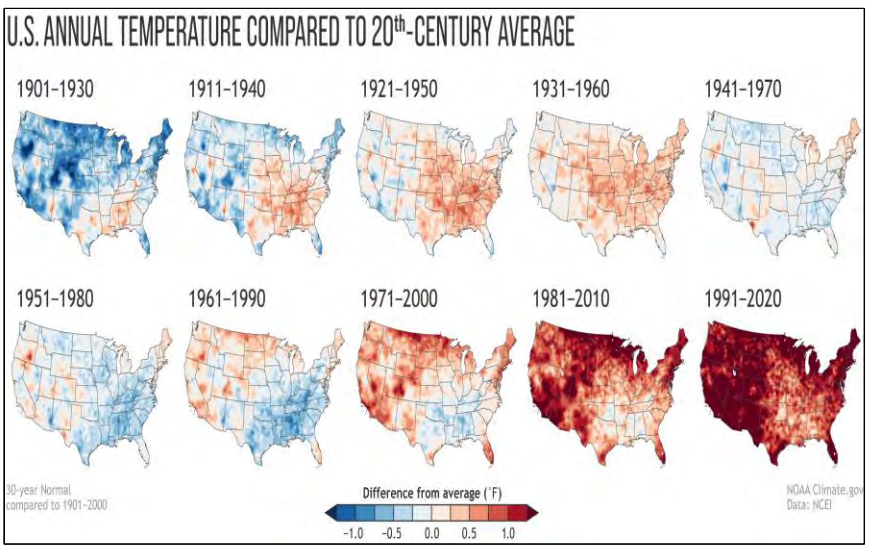


Figure 1 **U.S. Annual Temperature compared to 20th-Century Average**

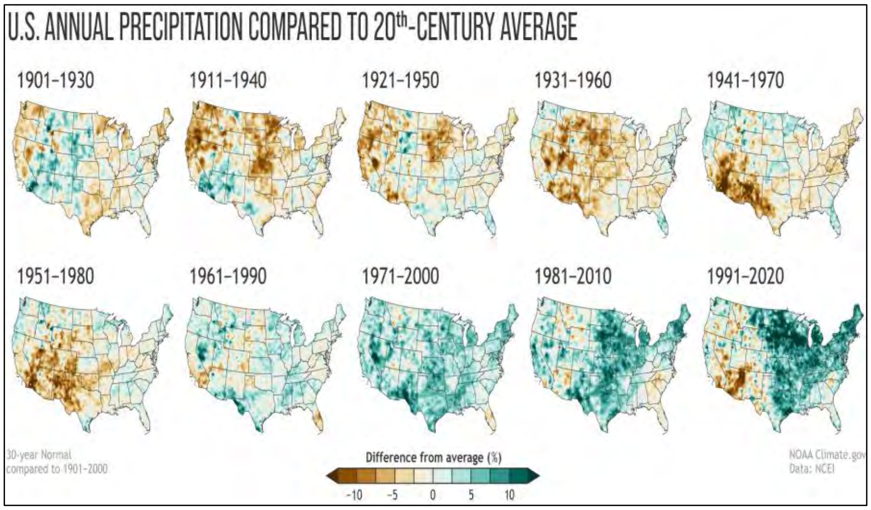


Figure 2 **U.S. Annual Precipitation compared to 20th-Century Average**

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1. EXECUTIVE SUMMARY

Salt Lake City Department of Public Works (SLCDPW) initially sponsored winter cloud seeding programs targeting the Six Creeks drainage basin in Water Years 1989 through 1996, with NAWC operating these programs. NAWC analysis of potential effects of the seeding indicated positive effects (~6% to 17% for water years 1989 and 1990, Thompson, et al., 1990). It was NAWC's understanding that this program was discontinued following water year (1996) due to budgetary considerations.

SLCDPW expressed an interest in the fall of 2018 in re-establishing a cloud seeding program to impact the Six Creeks drainage basins that provide runoff to the Salt Lake Valley. A proposal was drawn up by NAWC and accepted by SLCDPU in the fall of 2018, and the first season of operations for the current program began in December 2019.

The current season's cloud seeding program began on November 15, 2021 and ended on April 15, 2022. A total of 21 storm events were seeded during all or portions of 35 days during the 2021-2022 season, using a network of eight ground-based silver iodide generators. No seeded storm events occurred in November this season although there were seven seeded events in December, followed by two in January, two in February, seven in March and three additional seeded events in April. A total of 1060.75 cumulative hours of seeding generator operations were conducted during the season from the ground sites.

Snowpack and precipitation were again somewhat below normal in the Six Creeks project area during the 2021-2022 winter season, with a La Nina pattern in place similar to the previous season. As of April 15, 2022, sites in the Six Creeks target area reported snowpack water equivalent values ranging from roughly 60-80% of the median values for that date, with an overall basin value around 70% of the average (median).

There was only one seeding suspension that took place, specific to Little Cottonwood Canyon during the last week of December. Avalanche conditions became extremely high during that time, so that NAWC avoided using sites which would affect that canyon in particular. Seeding continued for the remainder of the program.

Target/control evaluations have been developed for the Six Creeks seeding program, utilizing NRCS SNOpack TELemetry (SNOTEL) precipitation and snow water content data. The precipitation evaluations include those utilizing both December – March and November – April period totals. For this report, consistent with last season's analysis, the December – March regressions were applied to the current season. The other evaluations were based on April 1 snow water content (SWE) values. The same set of target and control sites was utilized for the various evaluations, which includes five target and three control sites as detailed in Section 6.3 of the report. For each data type (December – March precipitation, November – April precipitation, and April 1 SWE), both linear and multiple linear regression equations were developed.

Results of the regression analyses for Water Year 2021 were in rather good agreement, with the precipitation evaluations (December – March, linear and multiple linear) yielding observed/predicted ratios of 1.02 and 1.05, respectively. Ratios above 1.0 are suggestive of an increase in target area precipitation due to seeding, while values near or below 1.0 are not. Given that these two values are both above 1.0, they suggest with relative confidence positive seeding effect in the 2% to 5% range.

The four-season mean of evaluation yielded ratios of 1.01 and 1.03 (precipitation linear and multiple linear), and 1.09 and 1.10 (snowpack linear and multiple linear). This four-year mean analysis suggests snowpack increases of up to 10% resulting from cloud seeding.

These results correspond to the results of longer running programs in nearby portions of the Rocky Mountain Corridor. This correspondence provides additional justification for the increase percentages predicted by the four-year evaluation. NAWC will continue to perform these evaluations as long as the program is operational. The statistical significance of the results of these evaluations will increase with each successive year of seeding and study.

Recommendations

NAWC sees tremendous opportunity for improving the program through the use of remotely operated equipment. Remote equipment allows generators to be placed in areas that would be inaccessible for manual operations. One such location is on the point of the mountain North of the Utah State Capital. This high elevation site, positioned north and west of the target area would prove ideal for seeding.

One remote generator would be sufficient to cover this area. The cost of the remote equipment can be discussed if there is adequate interest in its' adoption.

2. INTRODUCTION

The history of cloud seeding operations for the Six Creeks drainage basins dates back to the late 1980s. Salt Lake City has sponsored winter cloud seeding programs targeting the area in water years 1989 through 1996. North American Weather Consultants (NAWC) operated these programs. NAWC analysis of potential effects of the seeding indicated positive effects (about 6% to 17% for water years 1989 and 1990, Thompson et al., 1990). It was NAWC's understanding that this program was discontinued following water year 1996 due to budgetary considerations.

The Salt Lake City Department of Public Utilities (SLCDPU) was contacted by the Utah Division of Water Resources regarding the cloud-seeding program. Following discussions, SLCDPU expressed an interest in re-establishing a cloud seeding program to impact the Six Creek's drainage basins that provide runoff to the Salt Lake Valley. This interest was expressed in a letter to Candice Hasenyager, coordinator of the Utah Division of Water Resources cloud seeding programs, that would enable cost sharing of this program with the Utah Division of Water Resources (e.g., up to 50% cost sharing state support).

NAWC contacted the SLCDPU and it was agreed that NAWC would prepare a proposal to conduct a program for the 2018-2019 winter season. The goal of the program would be to augment the flows of City Creek, Emigration Creek, Parleys Creek, Mill Creek, Big Cottonwood Creek and Little Cottonwood Creek. Figure 2.1 provides a map of the proposed target area (e.g., six creeks drainage areas above 6000 feet MSL). The SLCDPU accepted this proposal, and an agreement was signed effective November 19, 2018. The program has generally been conducted between about mid-November and mid-April in the subsequent seasons. This report focuses on the design, implementation, and operation of the program for the 2021-2022 season.

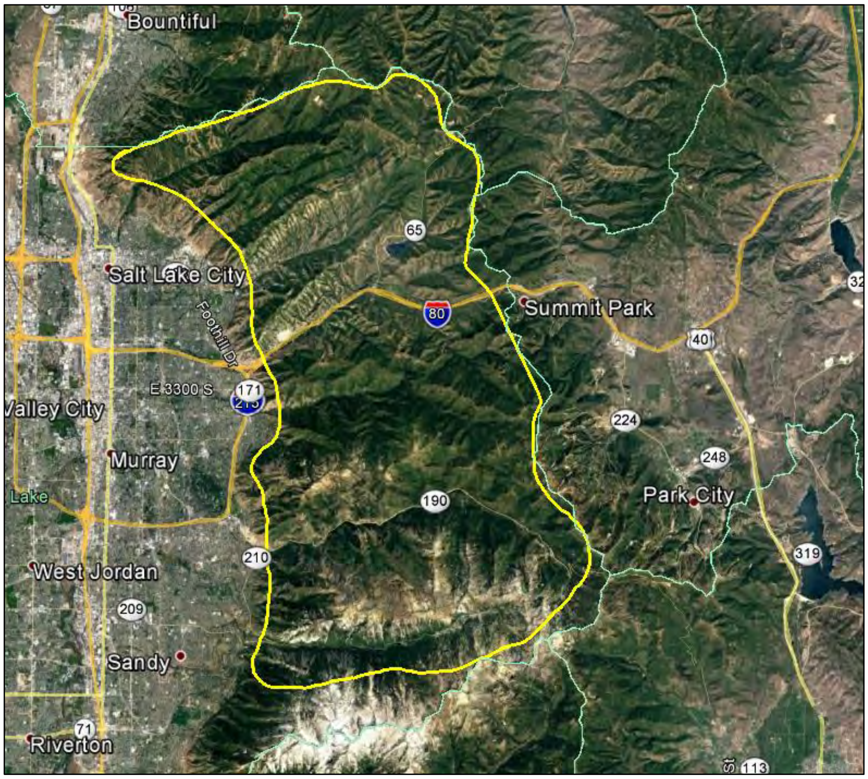

Figure 2.1 Six Creeks Target Area

3. CLOUD SEEDING THEORY

Clouds form when temperatures in the atmosphere reach saturation, that is, a relative humidity of 100%. This saturated condition causes water vapor to condense around a nucleus forming a cloud droplet. These nuclei, are known as cloud condensation nuclei. Clouds can be composed of water droplets, ice crystals or a combination of the two. Clouds that are entirely warmer than freezing are sometimes referred to as warm clouds. Likewise, clouds that are colder than freezing are referred to as cold clouds. Precipitation occurs naturally from both types of clouds, though this process is not always efficient.

In warm clouds, cloud droplets that survive long enough, collide and grow to raindrop sizes, at which point they can overcome updrafts within the cloud deck and fall to the ground as rain. This process is known as collision/coalescence. This process is especially important in tropical clouds but can also occur in more temperate climates.

In cold regions (< 0°C) of clouds, it is possible for cloud water droplets to remain in a liquid state while below the freezing point (supercooled), as a function of the purity of the cloud water droplets. In a laboratory environment, pure water droplets can remain unfrozen down to a temperature of -39°C. In natural settings temperatures as cold as -17°C are fairly common.

Supper cooled liquid water is the result of the energetic nudge that is required to instigate the freezing process. Without an energetic nudge the freezing of water is not spontaneous at 0°C. Impurities in the air can provide a surface for supercooled liquid water to congregate around and initiate the freezing process. These impurities are referred to as ice nuclei. Examples of ice nuclei include dust, salt and pollution particles, or in seeded areas silver iodide.

Once an ice crystal is formed within a cloud it can grow due to surrounding water vapor, eventually forming a snowflake (diffusional growth). Ice crystals can also gain mass as they fall and contact, then freeze, other supercooled cloud droplets, a process known as riming. These snowflakes may reach the ground as snow if temperatures at the surface are 0°C or colder, or as rain if surface temperatures are warmer than freezing.

Research conducted in the late 1940's demonstrated that tiny particles of silver iodide, under the right conditions, mimic natural particles and serve as freezing nuclei. Silver iodide is a particularly effective nucleating agent at temperatures colder than -5°C. Silver iodide particles were shown to be much more active at temperatures between -5°C and -15°C than other natural freezing nuclei found in the atmosphere.

The basis of this and other winter time cloud seeding programs, therefore relies on the intentional and calculated introduction of silver iodide into appropriate storm systems. When performed in accordance with industry best practices and historical research programs, silver iodide serves as a very effective nucleating agent. The efficiency of the natural storm system can thus be improved resulting in higher yielding snowfall events.

4. PROJECT DESIGN

4.1 Background

Operational procedures during the 2021-2022 Six Creeks cloud seeding program utilized the basic principles of applying cloud seeding technology that have been shown to be effective during more than 40 years of winter cloud seeding for some mountainous regions of Utah. Continued increases in availability of weather data and forecast products have led to improved seeding opportunity recognition capabilities, and continued analysis of the effectiveness of operational cloud seeding projects is leading to improved confidence in the accuracy of the long-term average effects of such programs. NAWC has incorporated observational, seeding method and evaluation enhancements into the project when they are believed to be of practical value.

4.2 Seedability Criteria

Project operations have utilized a selective seeding approach, which has proven to be the most efficient method, providing the most cost-effective results. Selective seeding means that seeding is conducted only during storms (or portions of storms) when seeding is likely to be effective. These decisions are based on several criteria, which determine the seedability of the storm and deal with meteorological characteristics (temperature, stability, wind flow and moisture content) associated with winter season cloud systems. The following points provide the seeding criteria, which NAWC has established for other Utah winter cloud seeding program:

- Cloud bases near or (ideally) 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 vertical movement 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 700 mb level (approximately 10,000 feet MSL) expected to be warmer than -15°C (5°F)

Seeding cannot be effective unless the seeding material reaches portions of clouds equal to or colder than the warmest activation temperature (near -5°C) for silver iodide. After combustion, the silver iodide solution produces ice-forming nuclei (crystals), which closely resemble natural ice crystals in structure. These crystals become active as ice-forming nuclei beginning at temperatures near -5°C (23°F) in-cloud. Since experience has indicated that seeding is most effective within a particular temperature seeding window (Griffith et al., 2013), the cloud seeding nuclei generators were operated only during those periods when the temperatures within the cloud mass were between about -5°C and -25°C (+23°F to -13°F). Seeding will generally be effective within this range, if the cloud base is at a lower elevation than the mountain crest and no temperature inversions or other stable layers exist between the elevation of the cloud seeding generator and the cloud base. The existence of low-level inversions, or any significant stable layers, can inhibit the effects of seeding by trapping silver iodide particles released from ground-based sources and preventing them from traveling to portions of the cloud where they can aid in nucleation and eventual precipitation production. For the seeding to be effective, the AgI crystals must become active in the cloud region which contains supercooled liquid water droplets, with sufficient downwind distance for the growth and precipitation process to affect the targeted areas. If the AgI crystals take too long to become active, or if the temperature upwind of the crest is too warm, the plume will pass from the generator through the precipitation formation zone and over the mountain crest without freezing the cloud drops in time to affect precipitation in the desired area.

Most storms that affect Utah's mountains are associated with synoptic (large-scale) weather systems that move into Utah from the southwest, west, or northwest. Usually, they consist of a frontal system and/or an upper trough, with the air preceding the front or trough flowing from the south or southwest. As the front/trough passes through the area, the wind flow changes to the west, northwest, or north and the atmosphere cools. Clouds and precipitation may precede the front/trough passage, or they may mostly occur along the boundary of the colder air mass that moves into the region, and in some cases, continuing in the airmass behind the front or trough. For that reason, the seeding generators were situated to enable effective targeting in varying wind flow regimes, primarily ranging from southwesterly to northwesterly. As a clarification of this, winds in meteorology are reported as the direction from which the winds are blowing. For example, a southwest wind means the winds are blowing from the southwest towards the northeast.

4.3 Equipment and Project Set-Up

The locations of the eight seeding generators are shown in Figure 4.1, with site information in Table 4-1. The sites were located to maximize their potential use during typical storm periods.

The cloud seeding equipment at each site includes a cloud seeding nuclei generator and a propane gas supply tank. Figure 4.2 shows the White Reservoir site. The seeding solution consists of 2% (by weight) silver iodide (AgI), complexed with small portions of sodium iodide and para-dichlorobenzene, in solution with acetone. This particular formula is designed specifically to be a fast acting, nucleation agent via the condensation-freezing mechanism, rather than via the slower contact nucleation mechanism. This is an important characteristic, given the relatively narrow mountain barriers within the cloud seeding target areas in Utah.

When a site is in operation, the propane gas pressurizes the solution tank, which forces the solution into the burn chamber. The regulated seeding solution is sprayed into the propane flame, where microscopic silver iodide crystals are formed through the combustion process. The silver iodide is released at a rate of roughly eight grams per hour.

NAWC has a standing policy of operating within guidelines adopted to ensure public safety. Accordingly, NAWC, working in conjunction with the Utah Division of Water Resources, has developed criteria and procedures for the suspension of cloud seeding operations. Appendix A provides the resulting suspension criteria.

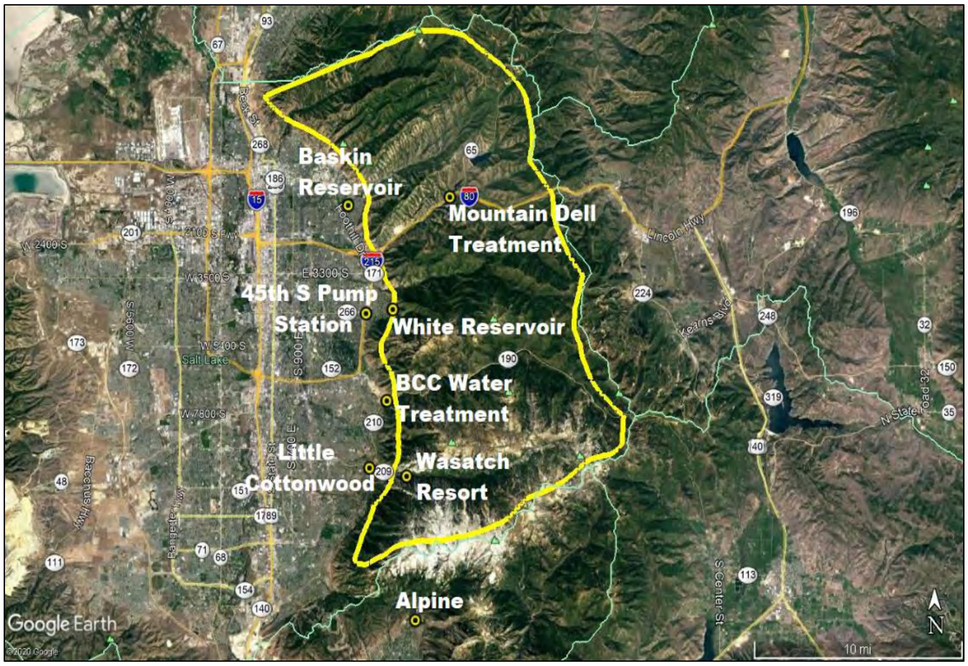

Figure 4.1 **Target Area and Seeding Site Locations**

Table 4-1
Seeding Site Locations

Site Number	Name	Latitude (°N)	Longitude (°W)	Elevation (feet)
1	Baskin Reservoir	40.7438	111.8183	4835
2	Mountain Dell Treatment	40.7488	111.7227	5380
3	45th South Pump Station	40.6747	111.8014	4950
4	White Reservoir	40.6772	111.7760	5620
5	Big Cottonwood Canyon Water Treatment	40.6189	111.7818	4993
6	Little Cottonwood	40.576	111.798	5170
7	Wasatch Resort	40.571	111.763	5650
8	Alpine	40.479	111.755	5440

Figure 4.2 **White Reservoir Cloud Seeding Site**

5. WEATHER DATA AND MODELS USED IN SEEDING OPERATIONS

NAWC maintains a fully equipped project 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, NEXRAD radar information, and weather/highway cameras. This information helps NAWC meteorologists to determine when conditions are appropriate for cloud seeding. Each of NAWC's meteorologists also has access to these same products at home, to allow continued monitoring and conduct of seeding operations outside of regular business hours. Figures 5.1 – 5.4 show examples of some of the available weather information that is used in this decision-making process for operational cloud seeding programs.

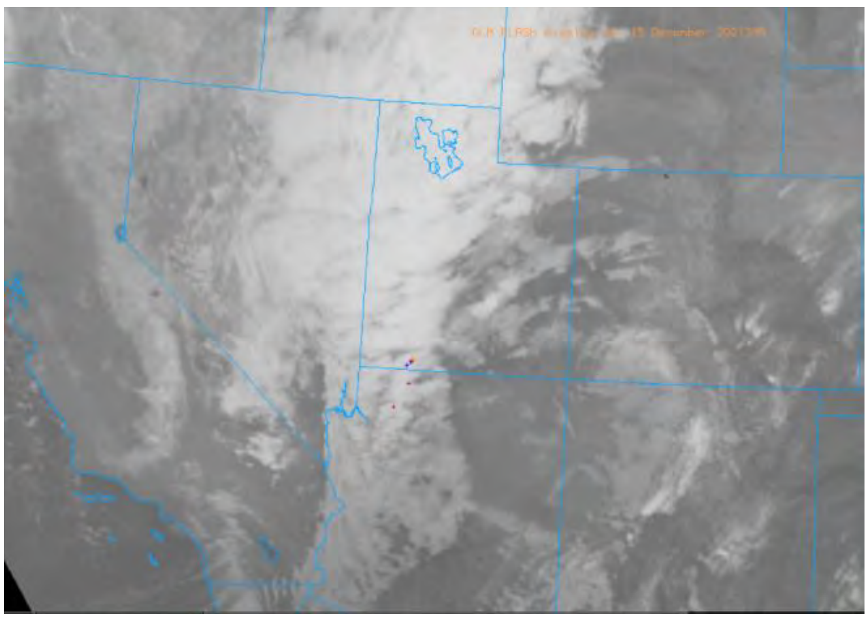

Figure 5.1 **Infrared satellite image at 2050 MDT on December 14, 2021 as a major frontal system affected the state**

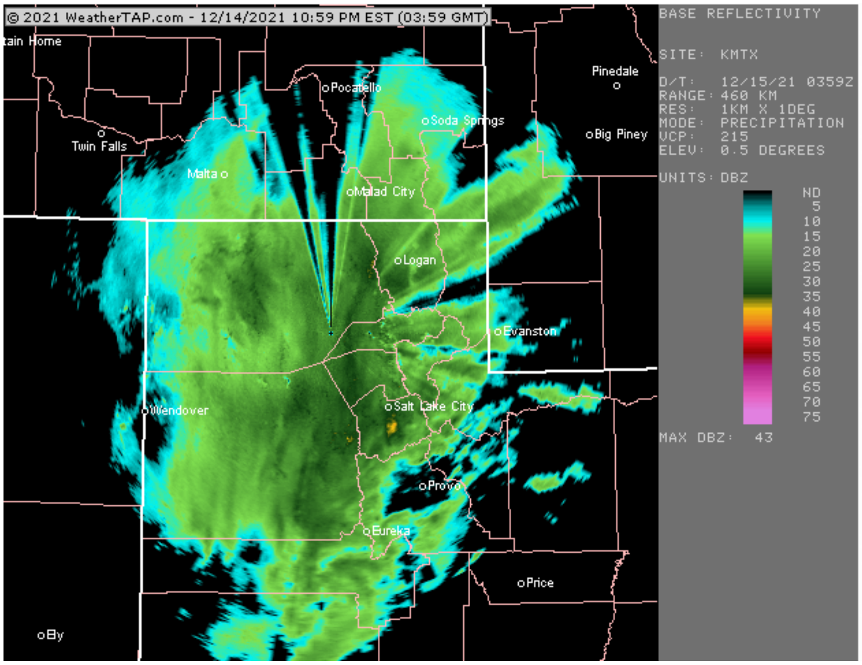

Figure 5.2 **Radar reflectivity radar image over northern Utah at 2059 MDT on December 14, 2021.**

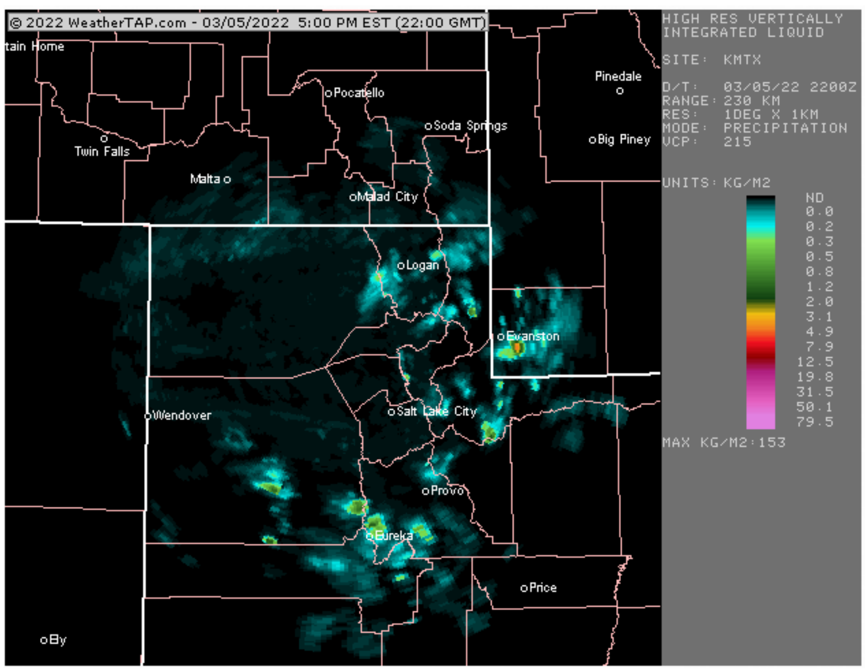

Figure 5.3 **Radar depiction of vertically integrated water values in some showers on the afternoon of March 5, 2022.**

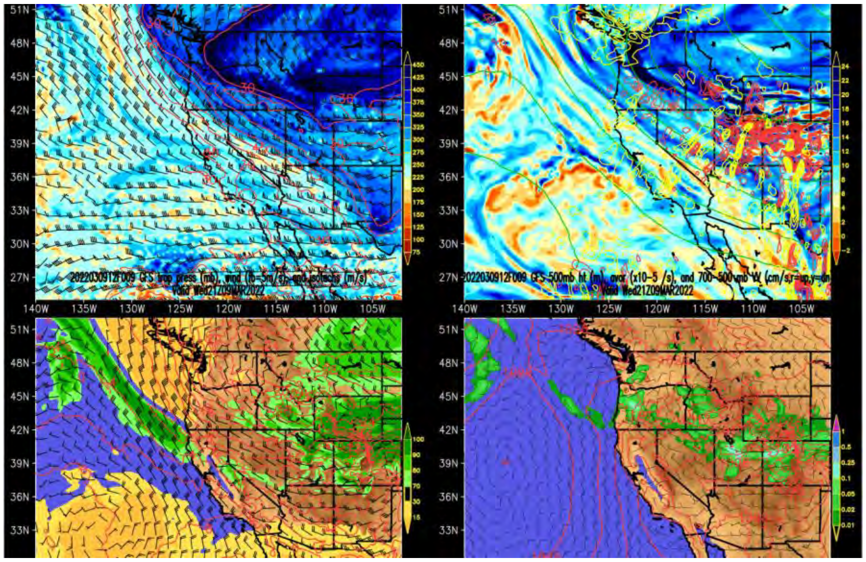

Figure 5.4 Example of GFS (Global Forecast System) model output for a storm event over the western U.S. on March 9. Forecast model data is widely used by program meteorologists in the analysis and forecast of conditions favorable to seeding operations.

6. OPERATIONS

6.1 Overview

This season's cloud seeding program for Six Creeks target area became active on November 15, 2021 and ended on April 15, 2022. A total of 21 storm events were seeded during all or portions of 35 days. There were seven seeded events in December, two each in the months of January and February, seven in March, and three additional seeding events in April. A total of 1060.75 cumulative hours of seeding generator operations were conducted during the season from the ground sites. Table 6-1 provides the dates and ground generator usage for the season. Tables 6-2 a and b provides the hours of generator operations by generator site location.

Table 6-1
Storm Dates and Generator Usage, 2021-2022 Winter Season

Storm Number	Storm Period	Number of CNGs Operated	Generator Hours
1	December 8-9	4	22
2	December 10	4	28.5
3	December 14-15	3	30
4	December 16-17	3	66
5	December 24-25	3	54
6	December 26	4	31
7	December 30-31	6	111.75
8	January 7-8	1	11.5
9	January 20-21	5	61.5
10	February 15-16	5	57.5
11	February 21	5	30.5
12	March 5-6	7	106.75
13	March 8-9	8	159.5
14	March 13	2	4
15	March 16	6	25.25
16	March 20	4	30.75
17	March 29	4	32.5
18	March 31	5	24.75
19	April 4-5	5	47.75
20	April 11-13	6	93
21	April 14-15	4	57
Total	**---**	**---**	**1060.75**

Table 6-2a

Generator Hours for 2021-22, Storms 1-12

Storm	1	2	3	4	5	6	7	8	9	10	11	12
Date	Dec 8-9	Dec 10	Dec 14-15	Dec 16-17	Dec 24-25	Dec 26	Dec 30-31	Jan 7-8	Jan 20-21	Feb 15-16	Feb 21	Mar 5-6
SITE												
Baskin Reservoir	5.5	7		22		8	18.75		11.5			5.75
Mountain Dell Treatment	5.5	7.5	13.25				18.25			4		20
4500 S Pump House	5.5	7	8.25	22	18	8	19.25		11.5	12	4.25	4
White Reservoir	5.5	7	8.5	22	18	8	19		11.75	12	5	
Big Cottonwood Treatment					18	7	18	11.5	12		4.75	20
Little Cottonwood Canyon							18.5		14.75	24.5	8	21
Wasatch Resort										5	8.5	21
Alpine												15
Storm Total	**22**	**28.5**	**30**	**66**	**54**	**31**	**111.75**	**11.5**	**61.5**	**57.5**	**30.5**	**106.75**

Table 6-2b
Generator Hours for 2021-22, Storms 13-21

Storm	13	14	15	16	17	18	19	20	21
Date	Mar **8-9**	Mar **13**	Mar **16**	Mar **20**	Mar **29**	Mar **31**	Apr **4-5**	Apr **11-13**	Apr **14-15**
SITE									
Baskin Reservoir	23		4	7.75	8	5		2	
Mountain Dell Treatment	23.75	1	5		8.5			5	
4500 S Pump House	18.75		4	8		5	2.5		
White Reservoir	18.75		4	7.5	8	5	2.25	27.5	
Big Cottonwood Treatment	22.5	3	5.25		8	5.5	14	6	14.5
Little Cottonwood Canyon	22.5		3	7.5			14.5	24.5	15
Wasatch Resort	24					4.25	14.5	28	14.5
Alpine	6.25								13
Storm Total	**159.5**	**4**	**25.25**	**30.75**	**32.5**	**24.75**	**47.75**	**93**	**57**

Snowfall for the 2021-2022 winter season was below normal (median) values for all of the target area and most of northern Utah. As of April 15, 2021, SNOTEL sites in the Six Creeks target area reported snowpack water content ranging from about 60% to 80% of the median, with an overall basin value of 70% of the median snowpack. Water Year precipitation, due in large part to a very wet October, was much closer to the median value at 97%. Data for each SNOTEL site is provided in Table 6-3.

Table 6-3
Snowpack and Precipitation Data from SNOTEL sites – April 15, 2022

Measurement Site	Snow Water Equivalent (in)			Water Year Precipitation (in)		
	4-15-22	**Median**	**%**	**4-15-22**	**Median**	**%**
Louis Meadow	5.5	6.5	85%	23.1	22.5	103%
Lookout Peak	19.0	25.8	74%	28.4	30.8	92%
Parleys Summit	9.1	10.8	84%	23.2	22.7	102%
Mill-D North	13.8	22.2	62%	25.9	25.8	100%
Brighton	13.7	22.2	62%	26.4	26.2	101%
Snowbird	31.6	38.8	81%	34.1	35.5	96%
Basin Index %			70%			97%

Figures 6.1 to 6.3 show plots of data from three SNOTEL sites located in the target area during the 2021-2022 winter season. Figure 6.4 shows the seasonal snow water equivalent time series data for the Provo-Utah-Jordan Basin as a whole compared to average values and some recent winter seasons.

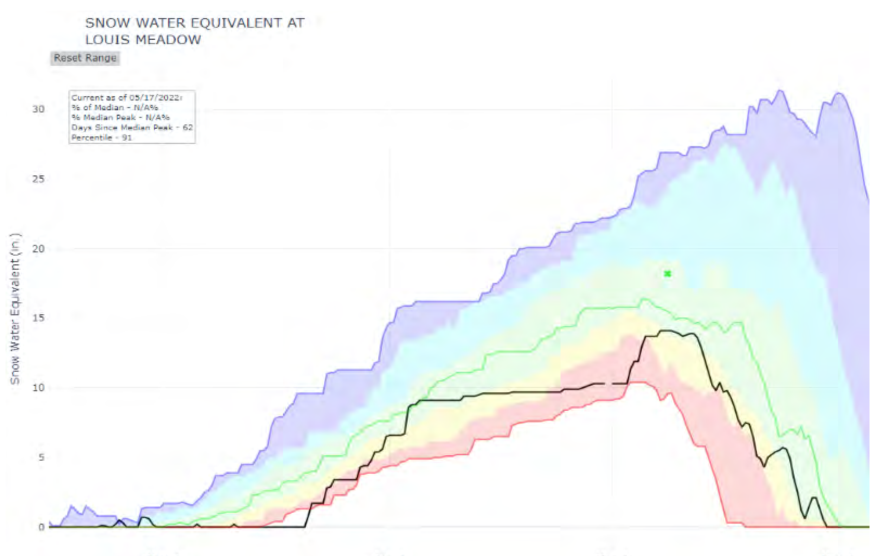

Figure 6.1. **NRCS SNOTEL snow and precipitation plot for Louis Meadow. Historical max/min values shown as purple and red lines; median as green; current season as black.**

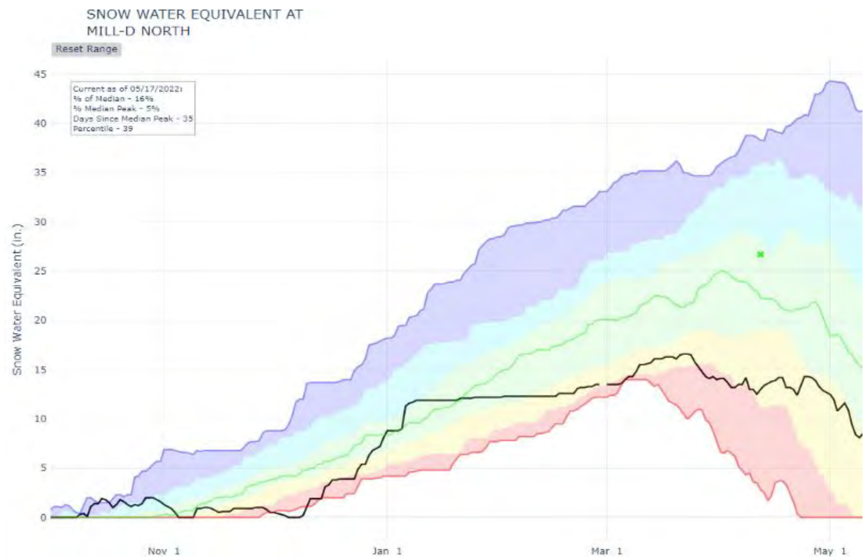

Figure 6.2. **NRCS SNOTEL snow and precipitation plot for Mill D – North. Historical max/min values shown as purple and red lines; median as green; current season as black.**

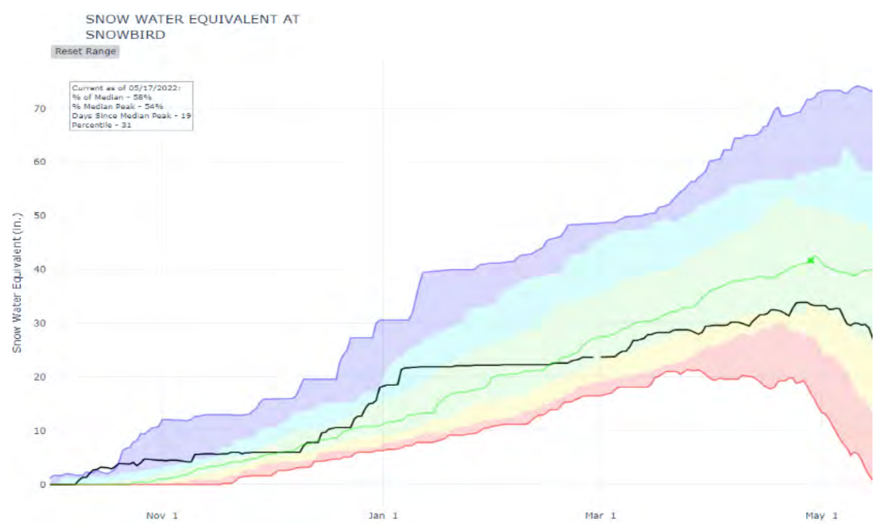

Figure 6.3. **NRCS SNOTEL snow and precipitation plot for Snowbird. Historical max/min values shown as purple and red lines; median as green; current season as black.**

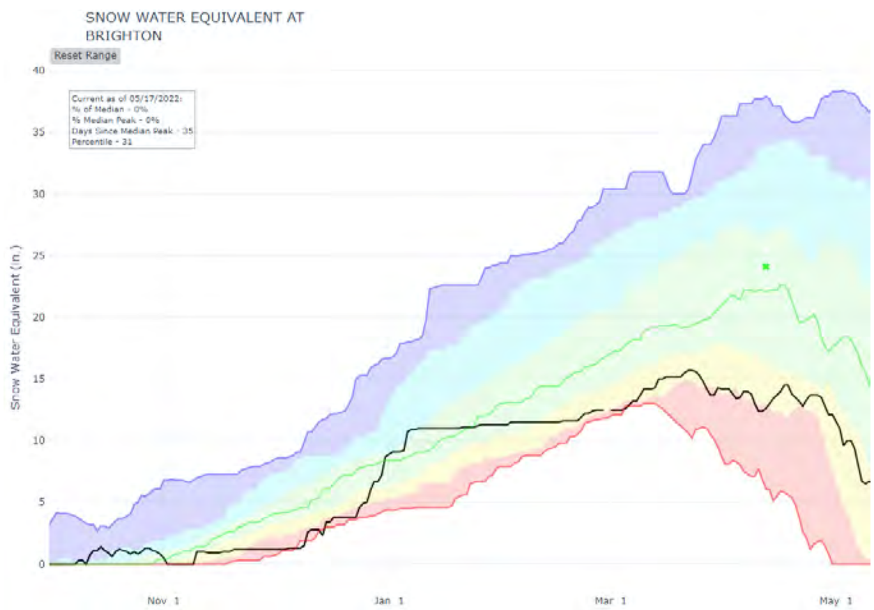

Figure 6.4 **NRCS SNOTEL snow and precipitation plot for Brighton. Historical max/min values shown as purple and red lines; median as green; current season as black.**

6.2 Operational Procedures

In operational practice, approaching storms were monitored at the NAWC operations center at NAWC's corporate offices located in Sandy, Utah utilizing online weather information. If the storm met the seedability criteria presented in Table 3-1, and if no seeding curtailments or suspensions were in effect, an appropriate array of seeding generators were activated and adjusted as conditions required. Seeding continued as long as conditions were favorable and seedable clouds remained over the target area. In a normal sequence of events, certain generators would be used in the early period of storm passage, some of which might be turned off as the wind direction changed, with other generators then used to target the area in response to the evolving wind pattern. The wind directions during productive storm periods in the Six Creeks target area usually favor a northwesterly or southwesterly direction. In meteorology wind direction is reported in terms of the direction from which the wind is blowing; for example, a northwesterly wind would be blowing from the northwest toward the southeast.

6.3 Operational Summary

This section summarizes the weather conditions and seeding operations during the season's storm events. All times are local (MST/MDT) unless otherwise noted.

November 2021

Following a wet October, November was generally a dry and mild month. There were some limited operations for a separate program targeting the Snowbird resort within the Six Creeks area, but otherwise conditions were not favorable for targeting the Six Creeks program after it became active on November

15. Figure 6.5 shows November precipitation around the state as a percentage of normal. The Six Creeks area is in an area which received about 30% of the normal monthly precipitation.

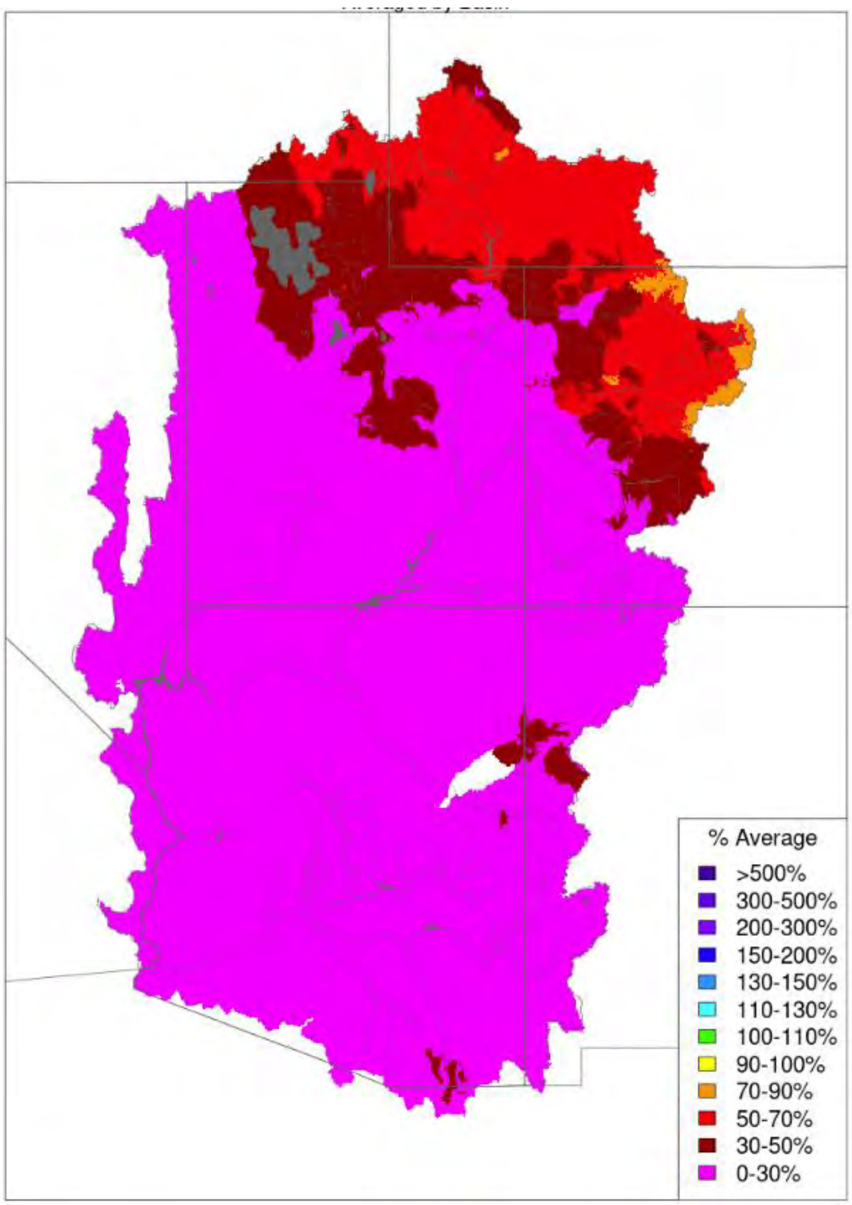

Figure 6.5 November 2021 precipitation percent of normal

December 2021

Dry and mild conditions persisted across the area through the first week of December. A long wave trough pattern then developed across the western U.S. starting around December 8. This resulted in an extended period of cold and wet weather with numerous storm events during the remainder of the month. There were seven seeded storm periods during the month of December. Avalanche conditions were carefully monitored before and during each event to ensure that all regulations were honored. December 23-31 saw avalanche danger increase and become high across the area which prompted the suspension of seeding operations for Little Cottonwood Canyon in particular. Seeding did continue for most of the Six Creeks target area.

The first seeded storm event of the season occurred during the morning to midday hours of December 9, with widespread precipitation over the area. Temperatures cooled to below -6 C at 700 mb in northwesterly flow. By early afternoon precipitation and seeding ended. By the morning of December 10, temperatures had become quite cold (near -15 C at 700 mb) and northwesterly flow led to lake effect snow showers. Seeding was conducted again during the morning through midday hours of the 10th to target this activity. Although only portions of this storm event (which began on December 8) were seeded for the Six Creeks program, the storm as a whole produced over an inch of water content for most of the target area from December 8-10.

A strong frontal system moved into northern Utah on the evening of December 14, with widespread moderate to heavy precipitation and some strong winds. As temperatures cooled overnight, conditions became favorable for seeding in the post-frontal environment and snow showers continued over the Wasatch Range. Seeding was conducted from late in the evening on the 14th until about mid-morning on the 15th when snowfall activity ended. Although much of the precipitation occurred in the warm portion of this storm before seeding operations began, storm totals exceeded an inch of water content across most of the Six Creeks target area. Most ski areas reported 10-20 inches of snowfall.

Seeding began in the late afternoon of December 16 as temperatures cooled in northwesterly flow and a trough brought snow showers to the area. Low-level stability in the Salt Lake Valley was a potential issue at times in this event, although seeding sites ran overnight and conditions appeared at least marginally good for mixing of the material. Some convective type snow showers occurred with temperatures cooling to below -13 C at 700 mb on the morning of December 17. Seeding operations continued in through midday and much of the afternoon on December 17 with nice looking convective clouds as well as orographic snow showers and some lake enhancement in northwesterly flow. By late afternoon moisture decreased and operations ended. Precipitation totals with this system were around 0.5 – 0.8" of water content in the target area.

Another significant snowfall event affected the area from December 23-25. Initially, the main snow band was producing snowfall from a higher cloud deck and appeared naturally efficient so that no seeding was conducted on the 23rd. Latter portions of the event, beginning on the evening of the 24th, contained orographic and somewhat convective type showers that appeared good for seeding. Precipitation ended mid-morning on the 25th along with seeding ops. The seeded portion of this event produced about a quarter inch of water equivalent with heavier amounts in the initial portion. Seeding was suspended for Little Cottonwood Canyon due to avalanche conditions there.

A strong cold front, with some significant wind activity and snow squalls, affected the area on December 26. Seeding was conducted during the daytime hours, although temperatures were fairly cold and dropped to below -15 C at 700 mb following the frontal passage. Precipitation totals ranged from about 0.20 – 0.60" of water equivalent.

Some additional storm periods late in December featured mostly light snowfall and clouds composed of mostly ice, generally not favorable for seeding operations. However, a significant snowfall event on December 30-31 produced good conditions for seeding beginning in westerly flow on the afternoon of the 30th. Seeding continued in northwesterly flow until late morning on the 31st, with temperatures becoming quite cold (well below -15 C at 700 mb) by later in the day so that clouds were composed mainly of ice and conditions were no longer favorable. Precipitation totals with this storm event as a whole were greater than expected, with well over 1.5" of water content in most of the Six Creeks area.

December precipitation was about 150-200% of the monthly average, as shown in Figure 6.6.

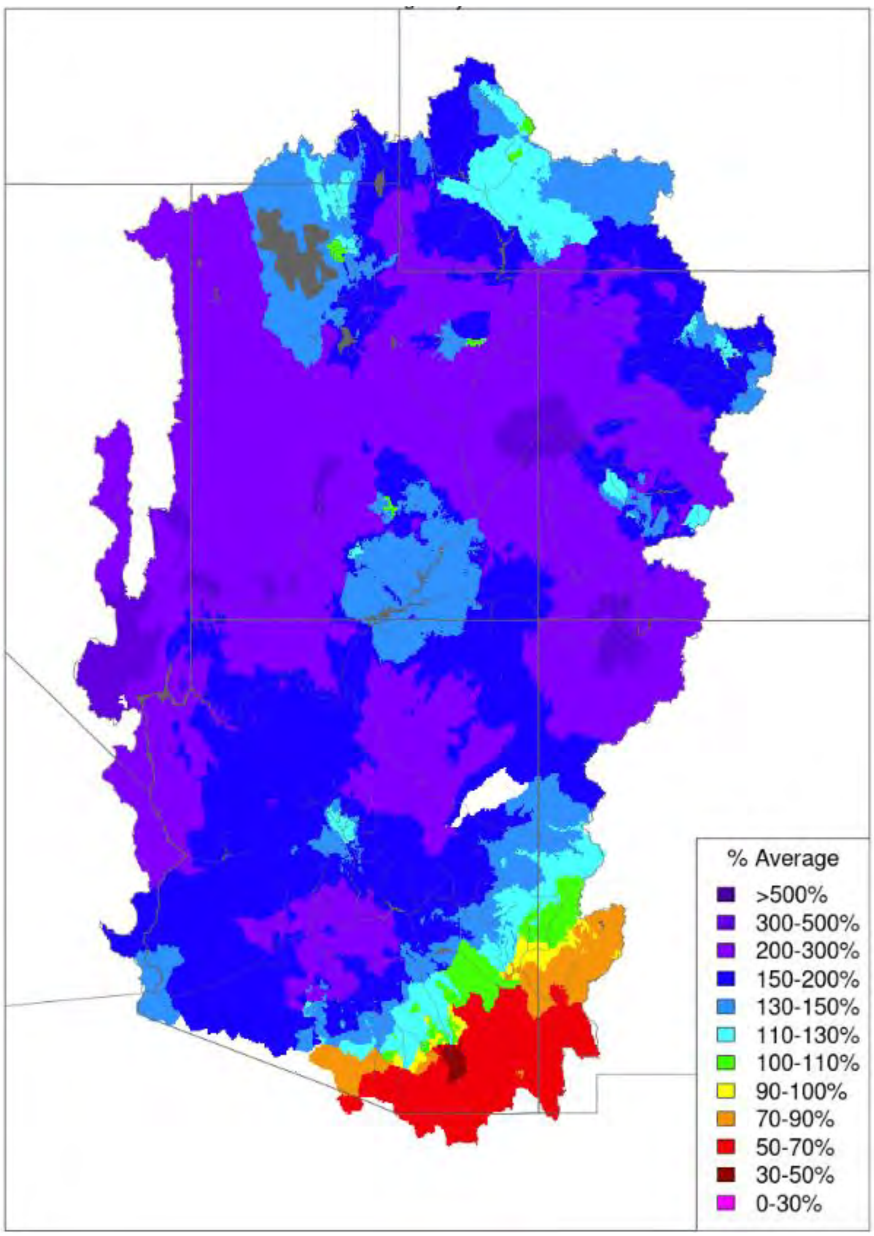

Figure 6.6 December 2021 precipitation, percent of average

January 2022

Aside from a wet period from approximately January 4-7 that brought significant snowfall to portions of northern Utah, January was a generally dry month. Some of the storm events that did make their way into the area were very lacking in moisture and contained arctic air. A temperature inversion during portions of the month also inhibited operations. In all, there were only two seedable storm period in January.

A strong zonal flow pattern brought precipitation focused north of the area during the January 4-7 period. Some light precipitation occurred at times but with warm temperatures and lower level stability being an issue. The Six Creeks program was near the southern edge of the main precipitation activity during this period, although orographics were good and the target area generally picked up over 2 inches of water content during this time period as a whole. There was only some minimal seeding conducted (from one site) on the night of January 7-8 as temperatures cooled somewhat on the tail end of this stormy period. However, conditions became quite dry by the morning of the 8^{th}.

A fairly weak and splitting system did provide a seeding opportunity on the night of January 20-21. The 700 mb temperature fell from near -5 C on the 20^{th} to near -12 C by the morning of the 21^{st}. Precipitation totals of around a quarter inch were measured, with seeding ending on the morning of the 21^{st}.

Portions of the Wasatch around the Six Creeks area received anywhere from about 30-70% of the January average (Figure 6.7), basically all occurring with the event early in the month. There was a strong north-south gradient observed due to the location of this event affecting mainly far northern portions of the state.

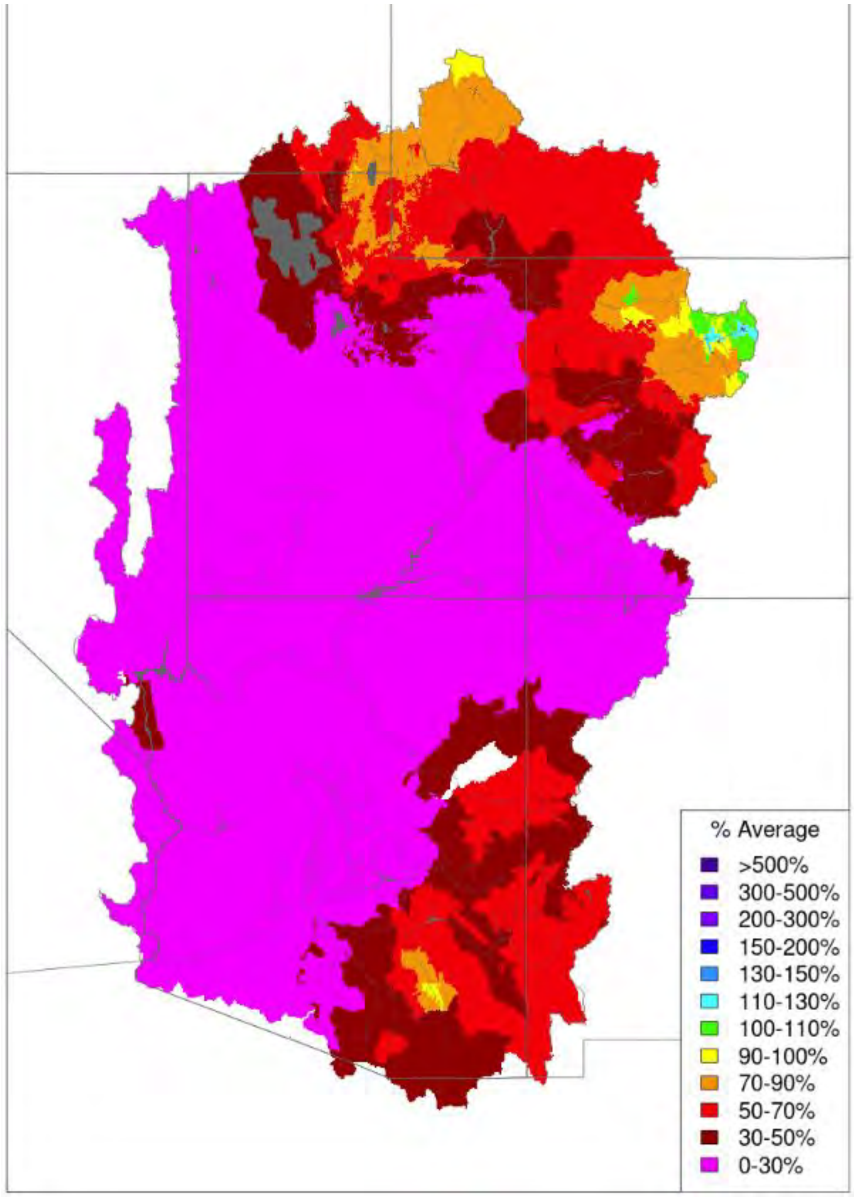

Figure 6.7 January 2022 precipitation, percent of average

February 2022

An unfavorable weather pattern remained locked in place during February, with only a few weak systems that generally arrived from the north and lacked any significant moisture. Temperatures inversions became fairly widespread over portions of northern Utah during much of the month and these also minimized any seeding potential. There were two seeded storm periods in February.

A trough moving into the area from the north brought some snow showers beginning the night of February 15 but mainly during the day on the 16th. The 700 mb temperature cooled to around -12 C with improved mixing during the daytime hours and some nice orographic and convective type snow showers developed that looked pretty favorable for seeding per visual and other observations. Seeding was conducted mainly on the 16th at several sites favorable to northwesterly flow. Precipitation totals of 0.2 to 0.4" were observed.

A frontal band with light snowfall moved southward across the area on the morning of February 21. Although most clouds were relatively high and moisture with this system was lacking, there were a few lower clouds and seeding was conducted during the morning to midday hours from several sites. Precipitation totals were limited, around 0.1 to 0.3".

February precipitation was under 30% of the normal monthly amount, as shown in Figure 6.8.

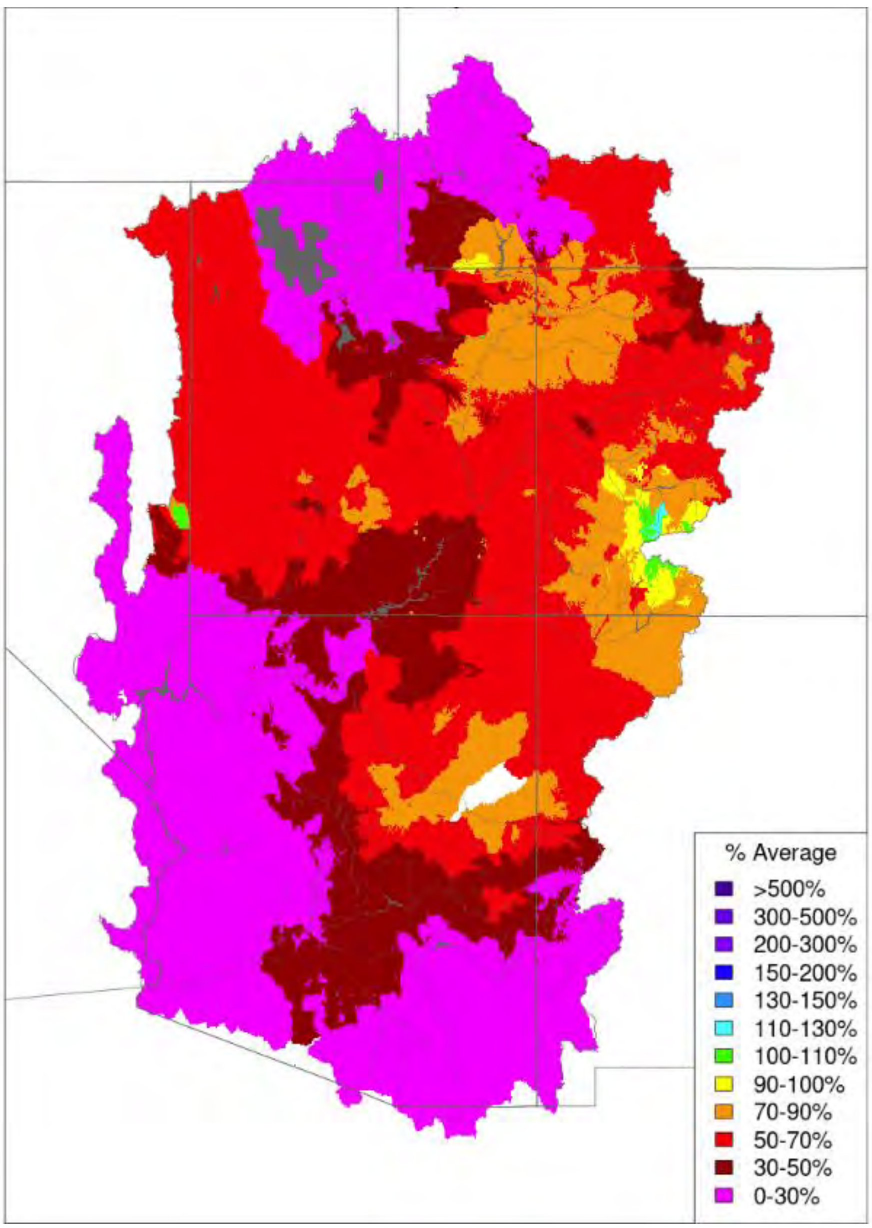

Figure 6.8 **February 2022 precipitation percent of average**

March 2022

The weather pattern became somewhat more active during March, although precipitation amounts around the region were highly variable and generally on the low side. Many of the storm events that affected the area continued to lack low level moisture, which was very characteristic of the season as a whole.

A storm event on March 5-6 brought a complex wind pattern to the area as a partially closed low developed over the southern Great Basin with several smaller scale circulation centers. A surface frontal boundary over northern Utah merged with a mid-level feature arriving from the southwest late in the afternoon, setting off widespread showers and some locally heavy thunderstorms near the southern Salt Lake Valley. This was followed by widespread precipitation which turned to snow in the valley as 700 mb temperatures dropped below -8 C overnight. Seeding began on the afternoon/evening of March 5 and continued overnight during this widespread moderate snowfall event (locally heavy in some lower elevation areas around the Salt Lake Valley). By early afternoon on the 6th, snowfall and seeding operations ended. Precipitation totals ranged between about 0.5 – 1.0” in the Six Creeks area with this event.

A trough embedded in a strong west-northwest flow pattern brought snowfall into the area beginning on the afternoon of March 8 in southwesterly flow. A frontal zone moved through in the evening with winds shifting to the northwest overnight. The 700 mb temperature was around -10 to -12 C. A band of heavier snowfall moved over the area during the early morning hours of March 9 followed by scattered convective snow showers during the day with some cold advection in northwesterly flow. Snow showers and seeding ended during the evening of the 9th. Overall, this was one of the most seeded events and utilized all of the available seeding sites at least during some time period. It was also one of the biggest events with about 1-2” of snow water content in most of the target area.

A weak, fast-moving system on March 13 produced a brief seeding opportunity as some convective showers and thundershowers developed during the late afternoon. Low-level moisture was generally lacking, with fairly high-based clouds. Some brief seeding was conducted from a couple of sites. Despite the lack of lower-level moisture, the target area received up to over a half inch of snow water content in places.

A weak system on March 16, combined with some lower-level moisture plus daytime heating resulted in convective snow shower development. Temperatures were good, near -8 C at 700 mb with light northwesterly winds. Seeding was conducted for these showers during the midday and afternoon hours. Precipitation amounts were fairly light and scattered, mostly under a quarter inch.

A cold frontal passage during the day on March 20 resulted in a seeding opportunity, using several sites, from the late morning through the afternoon hours. The 700 mb temperature dropped to around -10 C behind the front and some weakly convective snow showers developed during the afternoon hours. This activity ended by about sunset with clearing skies. Precipitation amounts approaching a half inch were common at SNOTEL sites in the target area for this event.

A surprisingly good situation developed on March 29 with a weak trough over the area. The lower levels were fairly moist with dew point values well above freezing. Daytime heating combined with strong orographic effects to produce a persistent area of convection (including lightning activity) aligned with the Wasatch Range and the eastern portion of the Salt Lake Valley. This activity persisted through the afternoon and early evening and included some graupel and small hail, an indication of significant amounts of supercooled water. Winds had a fairly strong northerly component, so essentially the northern half of the seeding site array was active from midday through the early evening hours. Precipitation amounts were locally much higher than forecast, ranging up to an inch or more of water content in some parts of the target area.

A weak system crossed the area on March 31 with light northwesterly winds, and a 700 mb temperature around -5 C. Light precipitation was mostly falling from higher clouds initially, but lower-level moisture increased by midday and some scattered convective showers developed in the afternoon. Seeding was conducted from the late morning until late afternoon, when showers ended. Precipitation was pretty minimal with this system, generally 0.1" or less.

Figure 6.9 shows March precipitation as a percentage of normal, which was quite variable geographically but generally in the vicinity of 70% for the Six Creeks area.

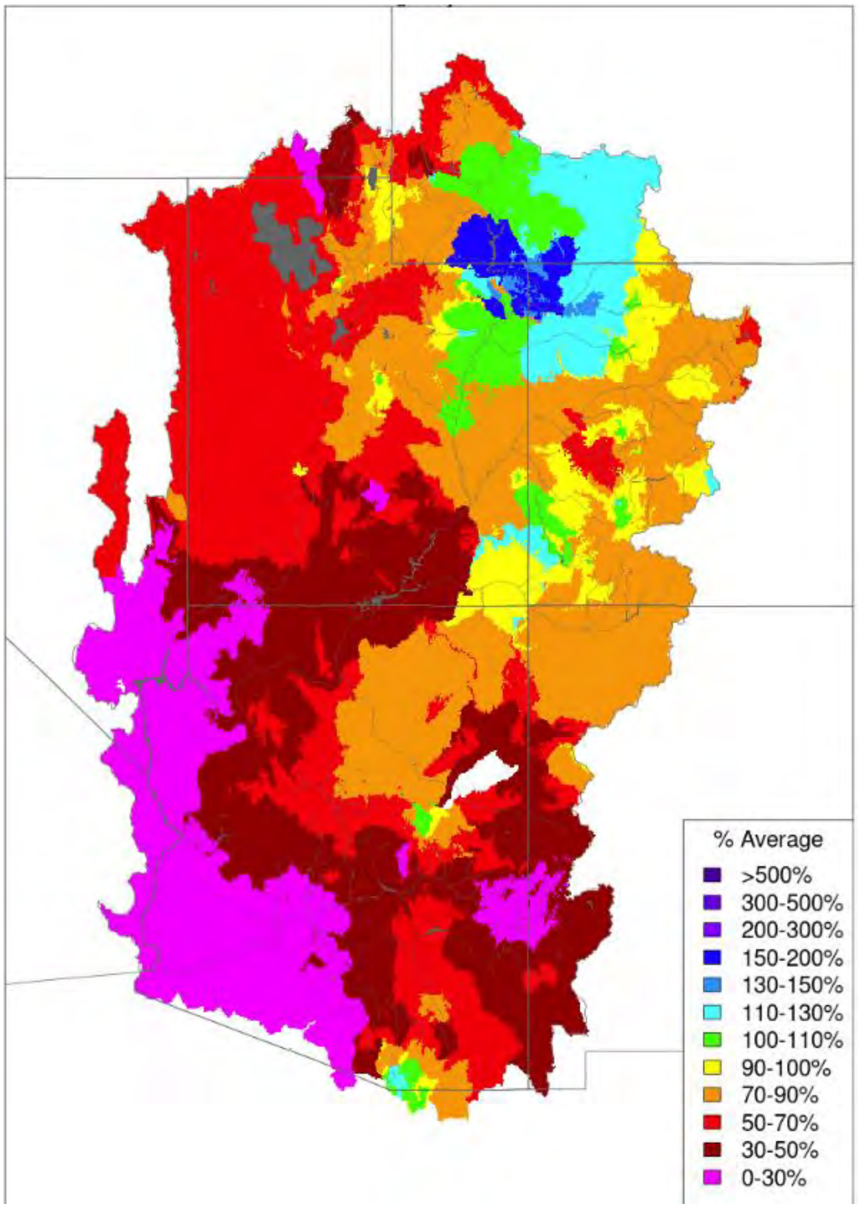

Figure 6.9 March 2022 precipitation, percent of average

April 2021

April precipitation was again quite variable over the area, with a strong north-south gradient near the Six Creeks watershed. The storm track was somewhat active and strongly favored northern portions of the state. This produced three seeding opportunities in April, prior to the program ending for the season on April 15.

Somewhat favorable seeding conditions developed on the night of April 4-5, as a frontal system affected northern Utah. Temperatures were quite warm initially but conditions improved into the early morning hours of April 5. Seeding was conducted from a few sites overnight with a couple additional sites added on the morning of the 5th. However, conditions became unfavorable by late morning with only some higher clouds over the area, and operations ended. This system brought variable amounts of precipitation, mainly focused on higher elevations of the target area where locally over a half inch of water content was received.

An unseasonably large and cold trough affected the area during the April 11-13 period, with a strong cold front arriving on the evening of the 11th. The 700 mb temperature dropped from about 0 C ahead of the front to as cold as -15 C by the morning of the 12th. A band of heavy snowfall affected the area on the evening of the 11th in the frontal zone, followed by convective type snow showers on the 12th in cold northwesterly flow. There was some lake enhancement of the snow showers locally as well. However, on the 12th lower-level moisture was notably lacking with dew points becoming quite low. Much of the seeding ended on the 12th for this reason, although seeding was continued at a couple of the more favorable sites again overnight (April 12-13) and into the 13th as a similar situation persisted, with some lake enhanced snow showers. Seeding finally ended by the afternoon of the 13th. Precipitation totals from this event were generally between 1.0 – 1.6” of water content in the target area, with fairly impressive amounts of low-density snowfall accumulating.

As a cold trough lingered over the Pacific Northwest on April 14-15, a band of light snowfall developed in a southwesterly flow pattern and seeding began from some favorable sites on the evening of the 14th. Some weak convective snow showers persisted in westerly flow on the morning of the 15th, and seeding continued until almost midday for higher portions of the watershed. Seeding operations ended before noon, and this was the final seeded event of the season.

Figure 6.10 shows precipitation percentages of normal in April, which were near normal in portions of northern Utah down to about the Six Creeks area and generally well below normal elsewhere.

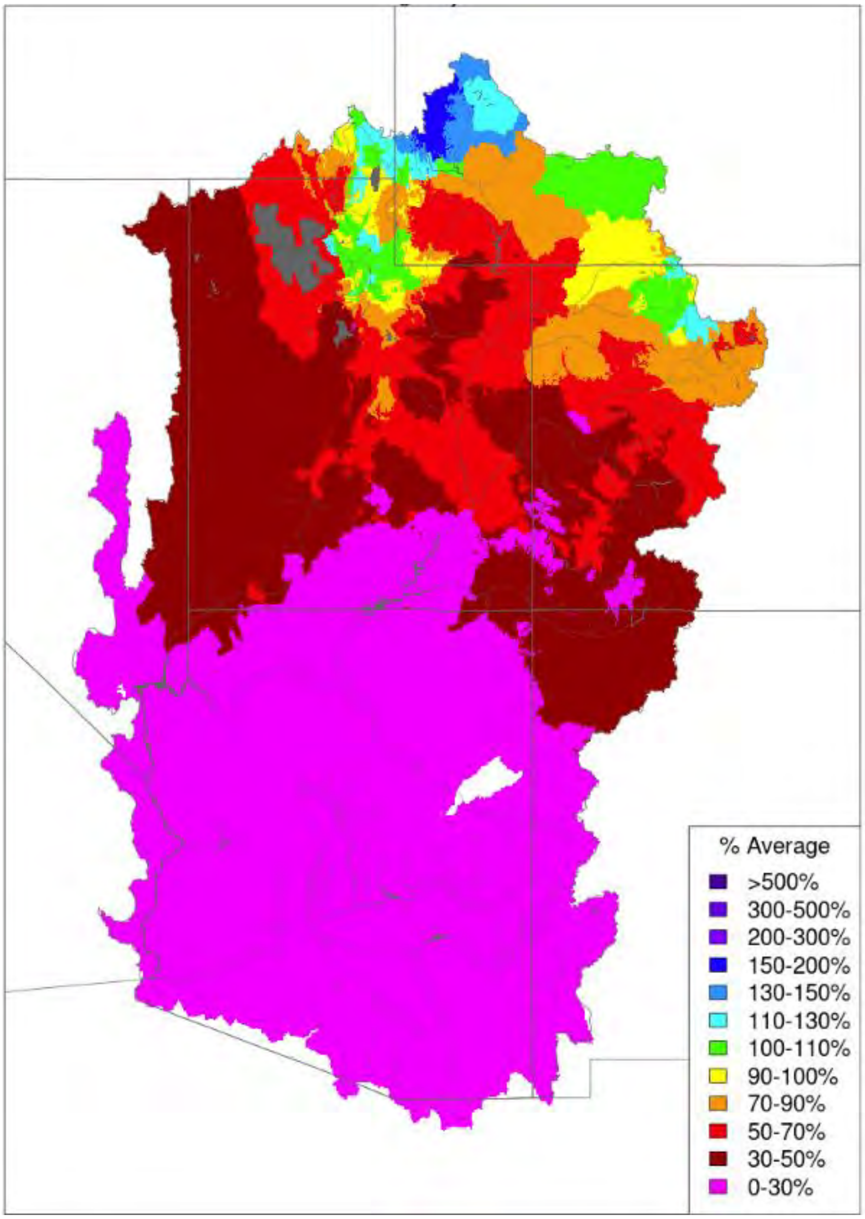

Figure 6.10 April 2022 precipitation, percent of average

7. ASSESSMENT OF SEEDING EFFECTS

7.1 Background

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 for the Six Creeks program. 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 is significant.

NAWC has used a commonly employed evaluation technique referred to as the target and control comparison, based on evaluating the effects of seeding on a variable that would be affected by seeding (such as precipitation or snow water content). Records of the variable to be evaluated are acquired for an historical (non-seeded) period of sufficient duration, ideally 20 years or more. These records are partitioned into those that lie within the designated seeded target area of the project and those in appropriate control areas. Ideally the control area consists of sites well correlated with the target area sites, but which would be unaffected by any seeding programs. All the historical data, 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 (calculates) the most probable 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 occurred during the seeded seasonal periods.

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 seeding impacts, which would result in an underestimate of the seeding effect. 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% of the variance (random variability) in the historical data set is explained by the regression equation. Correlations less than about 0.80 are still acceptable, but it would likely take much longer (many more years of comparison) to attach any statistical significance to the apparent seeding results.

For the Six Creeks program, which was originally active in the late 1980s through mid-1990s, a target/control evaluation was developed in the early 1990s and used to estimate the seeding effects. The regression equation developed at that time utilized precipitation data from various sources. This was before a significant SNOTEL data climatology was available, as most of the SNOTEL sites were installed in the late 1980s in this area, with the earliest sites being installed in the late 1970s. Most of the other types of precipitation gauges used in the early analysis are no longer consistently active or have poor data availability (e.g., data gaps) compared to SNOTEL data which normally has no missing data. Additionally, lower elevation precipitation sites have poorer correlation to the higher elevations of the seeding target area than do similar high-elevation (i.e., SNOTEL) control sites. Therefore, the various recently developed target/control analyses for this program, which can be applied to the past and current seeded seasons (and to any future seeded seasons), are based solely on SNOTEL data. The historical regression period of 22 years consists of the non-seeded water years of 1997-2018, which is considered an adequate base period. The earlier seeded seasons of 1988-1996 can be considered an external data set for these more recent evaluations, and considered separately from the recent seeded season data during the current program.

7.2 Evaluation Approach

The state of Utah (as well as many other westerns states) has an excellent SNOTEL data collection system. These automated sites collect both cumulative precipitation and snow water content data. Precipitation and snowpack data used in these analyses were obtained from Natural Resources Conservation Service (NRCS) SNOTEL sites and are publicly available online. For evaluation of a seeding program, the precipitation data are typically summed over a representative season (for example, November – April or December – March) which can be used consistently in the evaluation, even though the seasonal period of seeding operations may potentially vary somewhat from one season to another. April 1 snow water equivalent (SWE) measurements are hydrologically strategic and have typically been used for the snowpack portion of the seeding evaluations, since at high elevation sites the April 1 SWE frequently represents the approximate maximum snow accumulation for the winter season. Most streamflow and reservoir storage forecasts are also made by state water agencies based on the April 1 snowpack data.

Some potential pitfalls with snowpack measurements must be recognized when using snow water content to evaluate seeding effectiveness. One potential problem is that not all winter storms are cold, and sometimes rain falls in the mountains. At some lower elevation mountain sites this can lead to a disparity between precipitation totals (which include all precipitation that falls) and snowpack water content (which includes only the water content of the snowpack at a particular time). In addition, warm periods can cause some melting of the snowpack prior to April 1. If the melting is sufficient, the water content in the snow can be lower than the total amount which actually fell. Additionally, not all storms that produce snow in the higher elevation areas of Utah are seeded. Since the April 1st snow water content usually represents total seasonal snowpack accumulation, the apparent results of a seeding program conducted for a portion of the accumulation season will be less (in terms of the percentage increase) than if only the seeded period was evaluated.

In evaluating the SNOTEL site data, double-mass plots were produced as a quality control measure. These are a special type of scatterplot of cumulative data over a specified time period, allowing a chronological comparison of two sites, or a site vs. a group data mean, etc. The purpose is to test for outliers in the data or long-term changes in the relationships between sites, which would negatively affect a target/control evaluation. In some cases, sites, which appear to be outliers in this way, may be excluded from the analyses. For these equations, potential target and control sites were compared in this way for the non-seeded seasons. In general, the data were in good agreement for both precipitation and snowpack during these seasons. However, one potential control site (Timpanogos Divide), which is just south of the Six Creeks target area, had data that varied somewhat from that of most other sites during certain time periods. The location of this particular site also suggests that, although technically outside of the target area, it is likely subject to some seeding effects in northwesterly wind patterns. Due to these factors, a decision was made to exclude it as a control site.

7.3 Target and Control Data Resulting Equations

The precipitation evaluation equations utilize SNOTEL data summed over both the November – April and December – March seasonal periods. This allows some flexibility in focusing the precipitation analysis on the seasonal periods when seeding actually takes place, if the program is active in future seasons. The snowpack (SWE) equations utilize April 1 data, although data from other dates could be selected (which would require the development of new regression equations). April 1 SWE may include snow that accumulated before seeding began in a particular season, and would exclude the effects of any seeding after April 1, etc. In some seasons, snowmelt prior to April 1 may also affect the SWE analyses to an extent. For these reasons, the snowpack (SWE) equations have slightly lower correlations and the results may be less reliable than those produced by the corresponding precipitation analyses.

Figure 7.1 shows a map of the target area and the five target SNOTEL sites, while Figure 7.2 shows the locations of the three control sites in relation to the target area. Location and elevation information for these sites is provided in Table 6-1. The five SNOTEL sites selected within the seeding target area should represent this area well in terms of their geographic locations and the potential to quantify seeding effects. The three control sites were selected based on the desire to bracket the target area geographically, especially in the north-south dimension. This helps to account for storm track variations and to avoid cross seeding effects on other seeding programs at the control sites. This is a challenging task, due to the number of seeding programs in Utah. A site north of the target area (Farmington SNOTEL) and a couple of sites in eastern/northern Nevada, Berry Creek and Pole Creek, were selected as controls. The two Nevada sites are also utilized as controls for other Utah seeding programs. A SNOTEL site (Cascade) located to the south of Timpanogos was analyzed as a potential control; however, that site had a shorter period of record, which begins in 2003. It also did not compare well to other sites in the area on a double-mass plot, with many seasonal and multi-seasonal variations in comparison to the other sites. The final selection of the three control sites shown in Figure 7.2 should be ideal for producing a realistic forecast of "natural" target area precipitation for comparison to the observed values during the seeded seasons. SNOTEL sites located inside the Six Creeks target area are utilized as the set of target sites.

Figure 7.1 Six Creeks SNOTEL Target Site Locations (target area denoted in red)

Figure 7.2 **Six Creeks SNOTEL Control Site Locations**

Table 6-1
Target and Control SNOTEL Sites for Precipitation and Snowpack Evaluations

Site Name	Latitude	Longitude	Elevation (feet)
Target Sites			
Snowbird	40°34' N	111°40' W	9177
Brighton	40°36' N	111°35' W	8766
Mill-D North	40°40' N	111°38' W	8963
Parley's Summit	40°46' N	111°38' W	7585
Lookout Peak	40°50' N	111°43' W	8161
Control sites			
Farmington (Upper)	40°58' N	111°49' W	7902
Berry Creek, NV	39°19' N	114°37' W	9377
Pole Creek, NV	41°52' N	115°15' W	8360

The linear regression equation developed from the historical relationship between the control and target groups is of the following form:

$$Y_C = A(X_O) + B$$

where Y_C is the calculated average target area precipitation (inches) for a specific period (e.g., December-March), and X_O is the control average observed precipitation for the same period. The coefficients A and B, the slope and y intercept values from the historic regression equation are constants. The seeding effect

(SE) can be expressed as the ratio (R) of the average observed target precipitation to the average calculated (estimated) natural target precipitation, such that:

$SE = R = (Y_O)/(Y_C)$

where Y_O is the target area average observed precipitation (inches) and Y_C is the target area average calculated precipitation (inches). The seeding effect can also be expressed as a percent excess (or deficit) of the expected precipitation in the form:

$SE = (Y_O – Y_C) / (Y_C \times 100)$

The regression equations and the historical correlation coefficients for the two target areas are presented in Table 6-2. The stations, which constitute each control/target group, are listed in Appendix C.

Table 6-2
Regression Equations and Coefficient/Variance for Precipitation and Snowpack Evaluations

Evaluation Type	Equation	Correlation Coefficient (r)	Variance (r^2)
Precipitation November-April Linear	$Y = 1.267(X) + 1.76$	0.932	0.868
Precipitation November-April Multiple Linear	$Y = 0.623(X_1) + 0.003 (X_2) + 0.366(X_3) + 2.24$	0.959	0.920
Precipitation December-March - Linear	$Y = 1.339(X) +0.37$	0.943	0.889
Precipitation December-March- Multiple Linear	$Y = 0.588(X_1) + 0.014 (X_2) + 0.546(X_3) +1.02$	0.958	0.917
Snow April 1 Linear	$Y = 1.131(X) – 2.35$	0.943	0.889
Snow April 1 Multiple Linear	$Y = 0.406(X_1) + 0.411 (X_2) + 0.205 (X_3) – 0.56$	0.946	0.895

where Y = Calculated average target precipitation (November – April) or April 1st snow water content, and X = control 3-site average, X_1 = Farmington, X_2 = Berry Creek, NV and X_3 = Pole Creek, NV

7.4 Results for the 2022 Water Year

Evaluation results for the 2022 Water Year were mixed when using these equations to predict the natural precipitation or snow for the target area in the absence of seeding, in comparison to the observed values. Results of the December – March precipitation and the April 1 snowpack evaluations are shown in Table 6-3. It is worth keeping in mind that single-season results have very little statistical significance, and multiple seasons are required to yield a stable result in these types of evaluations. This is due to a high natural variability in precipitation and snowfall patterns between control and target sites, compared to the effects of the seeding program. The precipitation evaluations yielded observed/predicted ratios of 1.02 and 1.05 for this season linear and multiple linear equations, respectively, which is suggestive of a positive seeding effect. The snowpack evaluations yielded single-season ratios of 0.87 for both the linear and multiple linear equations. It is not clear why the snowpack results are significantly lower this season than for precipitation, although it is possibly that a warm spell in late March affected the control vs. target sites unequally in regards to early season melt. However, this variable can work in either direction and is simply one factor (specific to snowpack analysis) that makes the target/control equations imperfect.

There are several extraneous factors that can affect the outcome of these evaluations, particularly on a single-season basis. The efficiency of precipitation gauges in catching snowfall is known to decrease (perhaps substantially) with increasing wind speed. The SWE measurements can also be affected by various factors, such as blowing snow or variations in snowmelt patterns during the season prior to April 1. The effect of any of these factors may vary from site to site and from season to season, which may affect the relationship between target and control data and thus the evaluation results.

In addition to the ratio of the observed to predicted values discussed above, the predicted values obtained in the regression equations can be subtracted from the corresponding observed values, to examine the difference in observed minus predicted values based on the target area average. When the observed/predicted ratio for a particular evaluation is less than 1.0, this value will be negative, and when the ratio is greater than 1.0 the value will be positive. When data from several or more seeded seasons are available, the composite observed minus predicted values based on multiple seasons of data can begin to indicate the magnitude of precipitation (or snow water content) increases that are likely being generated by the cloud seeding operations.

The second-to-bottom row in Table 6-3 summarizes the overall mean of the 2022 season's results, while the bottom row summarizes the overall mean for the period of 2019 through 2022 seasons. The data are not typically averaged in this way, but these mean values may aid in the interpretation of the mixed results from the different evaluation techniques. The overall three-season mean result is a ratio of 1.06, which could be taken to suggest an 8% increase in precipitation/SWE. This ratio is equivalent to just about 1.20 inches of additional precipitation/SWE for the seasons. A similar program was conducted for this Six Creeks target area for water years 1989 through 1996. The linear and multiple linear regression equations developed for the analysis were also applied to the historically seeded period of 1989-1996 water years (one or more of these SNOTEL sites did not have data available yet in 1988). For this set of years as a whole, December – March precipitation evaluation results averaged 1.01 (linear) and 1.02 (multiple linear). For April 1 SWE, results averaged 1.14 (linear) and 1.16 (multiple linear).

Table 6-3
Evaluation Results Summary

Evaluation Type	Observed/Predicted Ratio	Observed – Predicted Difference (Inches of precipitation or SWE)
Precipitation December-March Linear (single season only)	1.02	0.37
Precipitation December - March Multiple Linear (Single season only)	1.05	0.84
Snow April 1 Linear (Single season only)	0.87	-2.24
Snow April 1 Multiple Linear (Single season only)	0.87	-2.16
2022 Mean of Results	0.95	-0.80
2019-2022 Mean	1.06	1.20