Cloud Seeding Annual Report and Evaluation

Six Creeks Program
2020-2021 Winter Season

Prepared For:

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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.

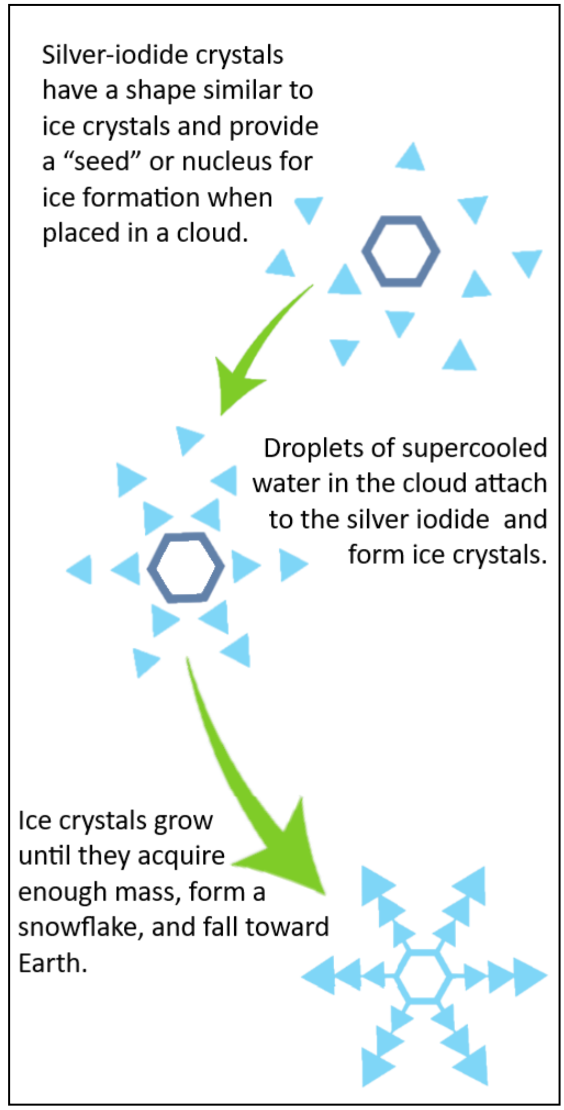
Silver iodide has been selected for its environmental safety and superior efficiency in producing ice in clouds. Silver iodide adds microscopic particles with a structural similarity to natural ice crystals. Ground-based and aircraft-borne technologies can be used to add the particles to the clouds.

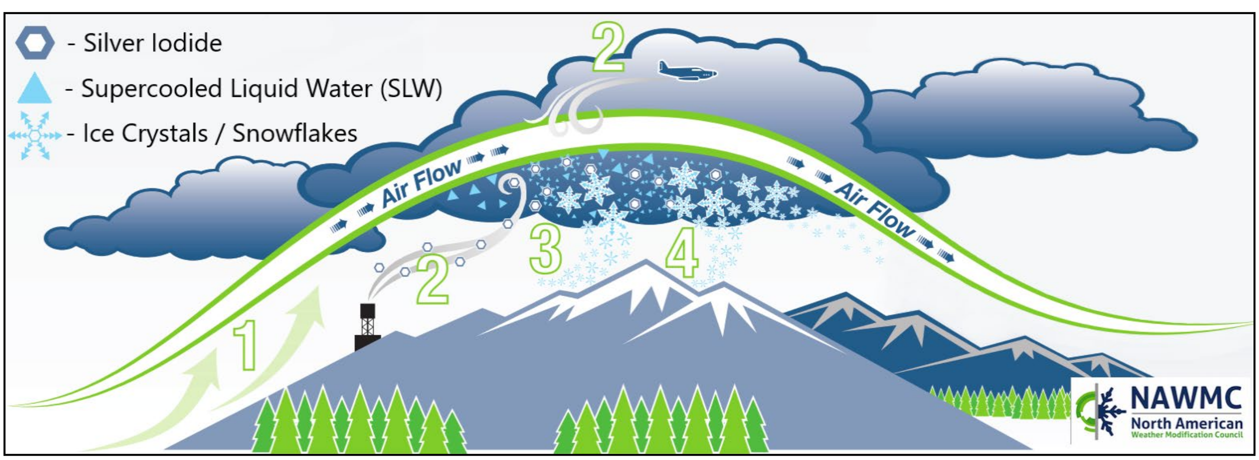
Safety

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.

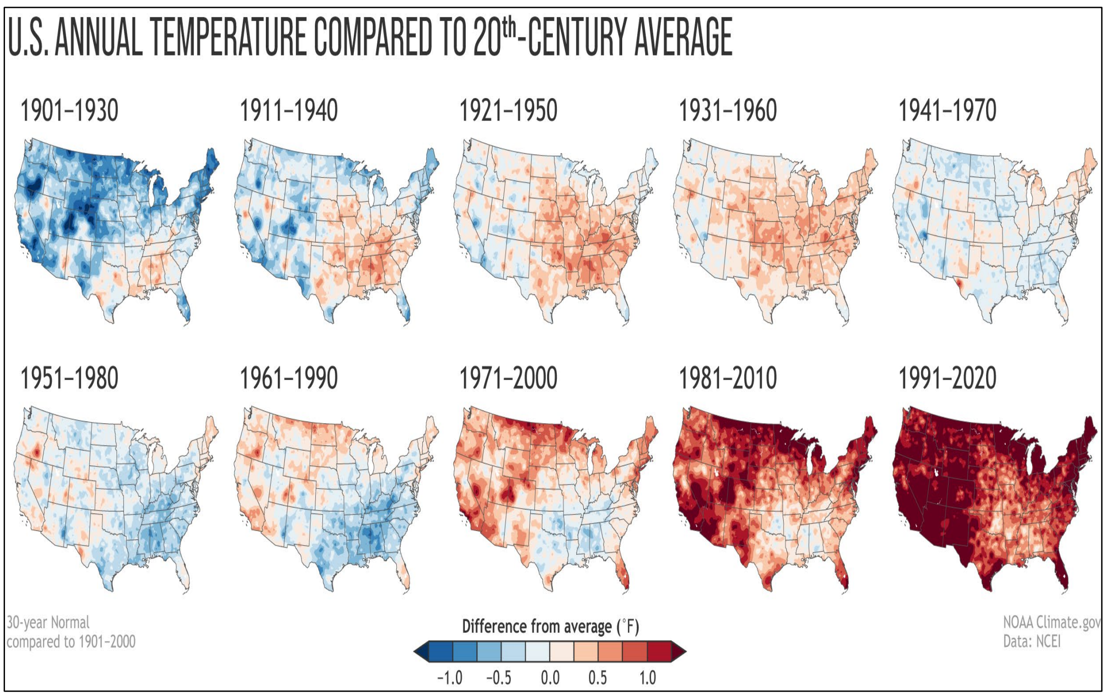


Figure 1 **U.S. Annual Temperature compared to 20th-Century Average**

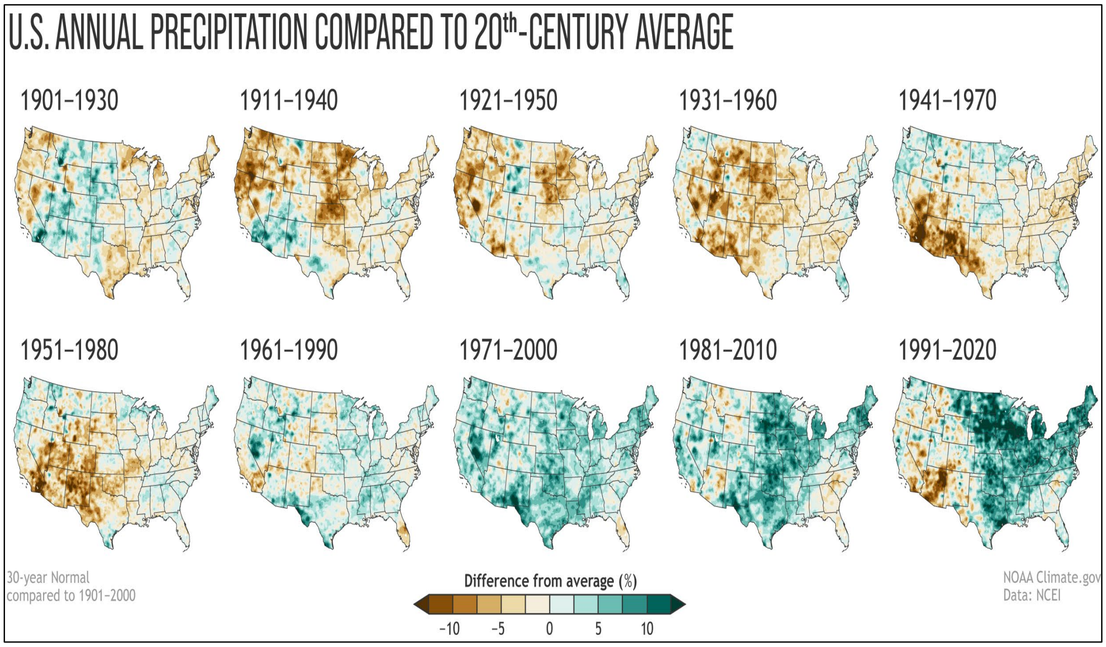


Figure 2 **U.S. Annual Precipitation compared to 20th-Century Average**

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EXECUTIVE SUMMARY

Cloud seeding for the Salt Lake City Public Utilities (SLCDPU) for the 2020-2021 winter season began on November 15, 2020 and ended on April 15, 2021. A total of 20 storm events were seeded during all or portions of 32 days during the 2020-2021 season. These storms were seeded using a network of eight ground-based silver iodide generators. Four seeding events occurred in December, four in January, five in February, four in March and three additional seeding events in April. A total of 825.75 cumulative hours of seeding generator operations were conducted during the season from the ground-seeding sites.

Snowpack and precipitation were significantly below normal in the Six Creeks project area during the 2020-2021 winter season. As of April 15, 2021, sites in the Six Creeks target area reported snowpack water equivalent values ranging from about 58% to 100% of the median, with an overall basin value of 66% of normal.

Due to unusual weather patterns snowpack conditions became very unstable in mid-February. NAWC carefully reviewed avalanche warnings and forecasts daily during this period. To avoid contributing to any avalanches in near-urban areas NAWC temporarily paused operations from certain ground seeding generators during this period. On February 14th, after careful consideration of the heightened avalanche risks, NAWC suspended all operations for the February 15-17 storm period. It was during this suspension period that heavy snowfall triggered an avalanche in Little Cottonwood Canyon (LCC). The canyon road was closed for almost two days as crews worked to clear the road from avalanche debris. Thanks to the insights of NAWC meteorologists, and internal guidance from Tamara Prue, cloud seeding did **not** contribute to the storm conditions that triggered the LCC avalanche.

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 0.99 and 1.03, respectively. Ratios above 1.0 would be suggestive of an increase in target area precipitation due to seeding. Averaging these values suggests a 2% increase in precipitation resulting from cloud seeding. The snowpack evaluations (April 1 SWE, linear and multiple linear) single season yielded ratios of 0.98 and 1.01, respectively.

As natural variabilities exist in the weather patterns for the target and control areas, long term averages, rather than single season results should be used to predict program effectiveness. **The overall three-season mean result is a ratio of 1.08, which indicates an 8% increase in precipitation/SWE. An 8% increase in SWE is equivalent to about 1.86 inches of additional SWE over the 6 Creeks Watershed.** NAWC prefers to quote seeding increase estimates based on roughly 10-year evaluation period. As this program continues to operate in future years, an even more statistically significant increase estimate will be determinable.

Recommendations

It is recommended that the winter seeding program for the Six Creeks Target area be continued. Routine application of weather modification technology each year can help stabilize and bolster water supplies (both surface and underground storage). Commitment to conduct a program each winter provides stability and acceptance by funding agencies and the general public. The program is designed so that it can be temporarily suspended or terminated during a given winter season, should snowpack accumulate to the point where additional water may not be beneficial.

1.0 INTRODUCTION

There exists a history of cloud seeding operations for the Six Creeks drainage basins dating 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 1.1 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 2018-2019 program ran from mid-December 2018 through April 18, 2019, ending before the agreed-upon date of April 30 due to high snow water content in the target basins. For the 2019-2020 seasons, the continuation of the same project area and sites from the 2018-2019 season.

An agreement was made over the summer of 2020, and a third season of cloud seeding operations was put into place, anticipated to operate from November 1, 2020 through April 15, 2021. This report focuses on the design, implementation, and operation of the program for the 2020-2021 winter season.

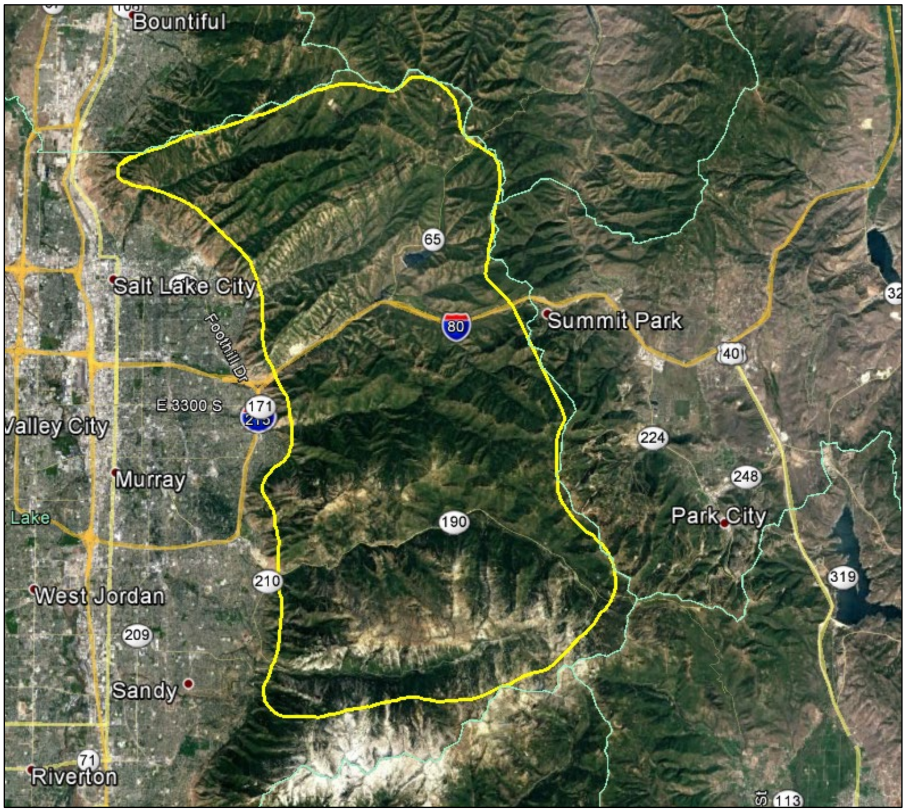

Figure 1.1 **Six Creeks Target Area**

2.0 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, which may be small particles like salts formed through evaporation off the oceans, 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 sometimes referred to as cold clouds. Cold clouds may have cloud bases that are warmer than freezing. Precipitation can occur naturally from both types of clouds.

In warm clouds, cloud droplets that survive long enough, especially when cloud drops are of different sizes, may collide and grow to raindrop sizes, subsequently falling 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; this is 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. Natural impurities in the atmosphere can cause cloud droplets that are colder than freezing, usually referred to as supercooled, to freeze. These supercooled cloud droplets are what causes icing to occur on aircraft. The natural impurities often consist of tiny soil particles or bacteria. These impurities are referred to as freezing nuclei. A supercooled cloud droplet can be frozen when it collides with one of these natural freezing nuclei thus forming an ice crystal. This process is known as contact nucleation. A water droplet may also be formed on a freezing nucleus, which has hygroscopic or water attracting characteristics. This same nucleus can then cause the water droplet to freeze at temperatures less than about -5°C, forming an ice crystal. This process is known as condensation/freezing. Once an ice crystal is formed within a cloud it will grow as cloud droplets around it evaporate and add their mass to the ice crystal, 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. They may reach the surface as raindrops if surface temperatures are warmer than freezing.

Research conducted in the late 1940's demonstrated that tiny particles of silver iodide could mimic natural impurities and serve as freezing nuclei at temperatures colder than -5°C. In fact, these silver iodide particles were shown to be much more active at temperatures between -5°C and -15°C than the natural freezing nuclei found in the atmosphere. Therefore, most modern day attempts to modify clouds to produce more precipitation (or reduce hail) have used silver iodide as a seeding agent. By definition, these programs are conducted to affect colder portions of clouds, typically cloud regions that are -5°C or colder. These programs are sometimes called cold cloud or glaciogenic seeding programs. Glaciogenic cloud seeding can be conducted in summer convective clouds whose tops pass through the -5°C level, and in winter stratiform clouds that reach at least the -5°C level.

There has been some research and operational programs designed to increase precipitation from warm clouds. The seeding agents used in these programs are hygroscopic (water attracting) particles, typically some kind of salt (e.g., calcium chloride). These salt particles can form additional cloud droplets, which may add to the rainfall reaching the ground. This seeding technique, which is sometimes referred to as warm cloud or hygroscopic seeding, can also modify the warm portion of clouds that then grow vertically to reach temperatures colder than freezing. A research program conducted in South Africa targeting these types of clouds indicated that such seeding did increase the amount of rainfall from the seeded clouds.

In summary, most present-day winter cloud seeding programs introduce a seeding agent, such as microscopic sized silver iodide particles, into clouds whose temperatures are colder than freezing. These silver iodide particles can cause cloud droplets to freeze, forming ice crystals. These ice crystals can grow to snowflake sizes, falling to the ground as snow or as rain depending on the surface temperature.

3.0 PROJECT DESIGN

3.1 Background

Operational procedures during the 2020-2021 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 wintertime 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.

3.2 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 cloud systems. The following points provide the seeding criteria, which NAWC has established for other Utah winter cloud seeding program:

- Cloud bases are 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 seeding 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 sufficiently far upwind of the mountain crest so that the available supercooled liquid water can be effectively converted to ice crystals which will then grow to snowflake sizes and fall out of the cloud onto the mountain barrier. 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 Pacific Ocean 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. Winds in meteorology are reported from which the winds are blowing. For example, a southwest wind means the winds are blowing from the southwest towards the northeast.

3.3 Equipment and Project Set-Up

The locations of the eight seeding generators are shown in Figure 3.1, with site information in Table 3-1. It should be noted that winds during winter storms in Utah typically blow in a general west to east fashion, usually from the southwest before frontal passages and from the northwest following frontal passages. The sites were located to maximize their potential use during typical storm periods.

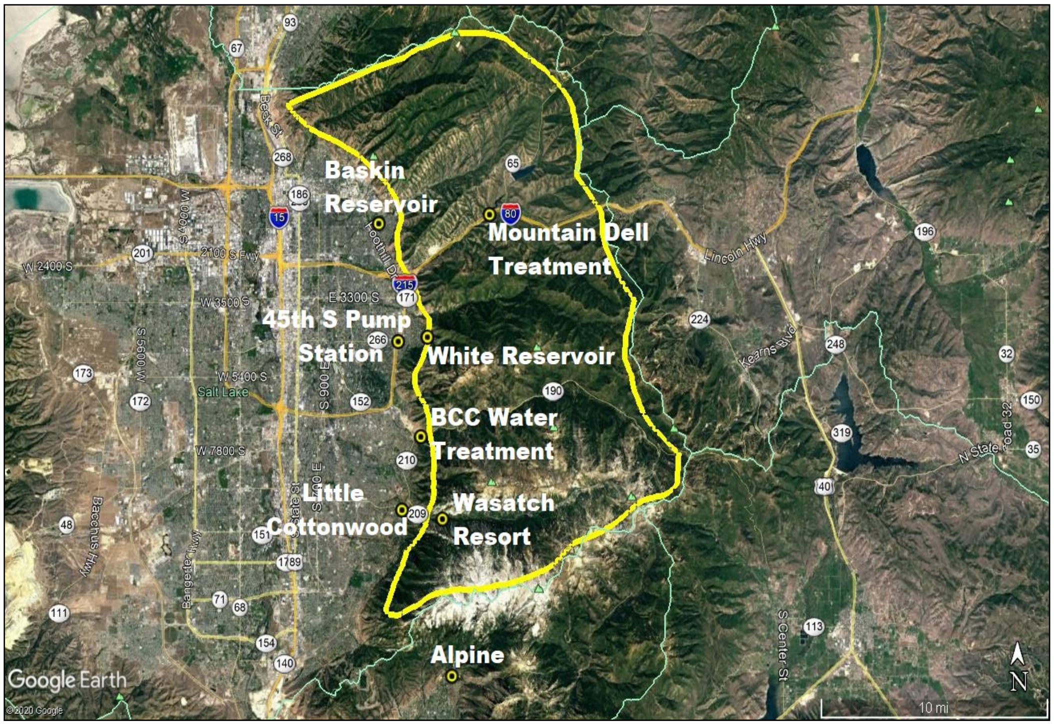

Figure 3.1 **Target Area and Seeding Site Locations**

Table 3-1
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

The cloud seeding equipment at each site includes a cloud seeding nuclei generator and a propane gas supply tank. Figure 3.2 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 was in operation, the propane gas pressurized 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 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 3.2 **White Reservoir Cloud Seeding Site**

4.0 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 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 4.1 – 4.3 show examples of some of the available weather information that was used in this decision-making process during the 2020-2021 winter season.

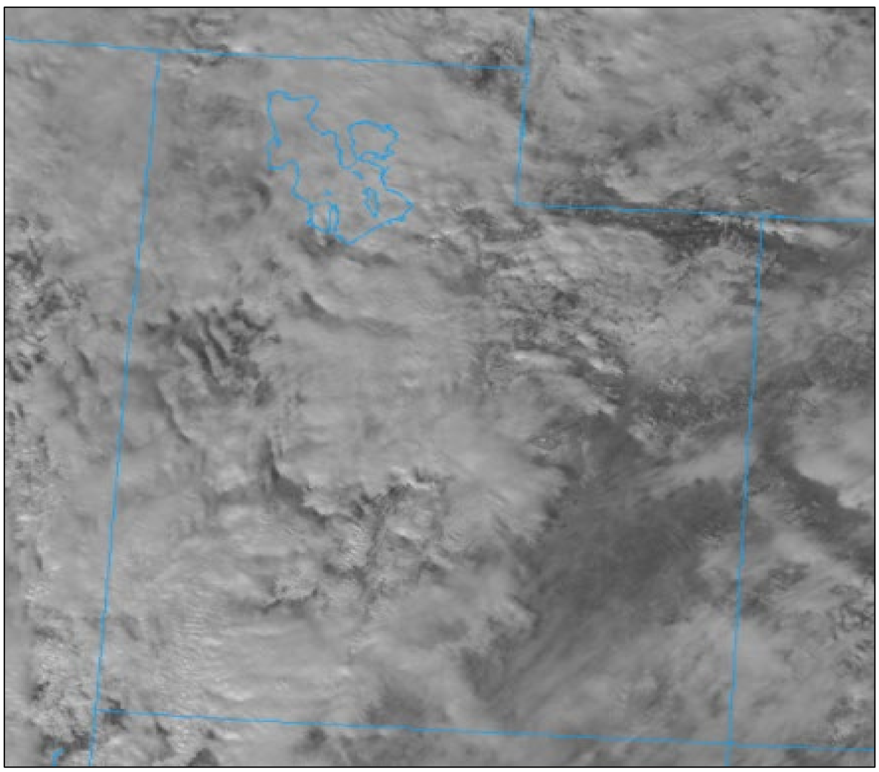

Figure 4.1 Visible satellite image at 1326 MDT on March 24, 2021.

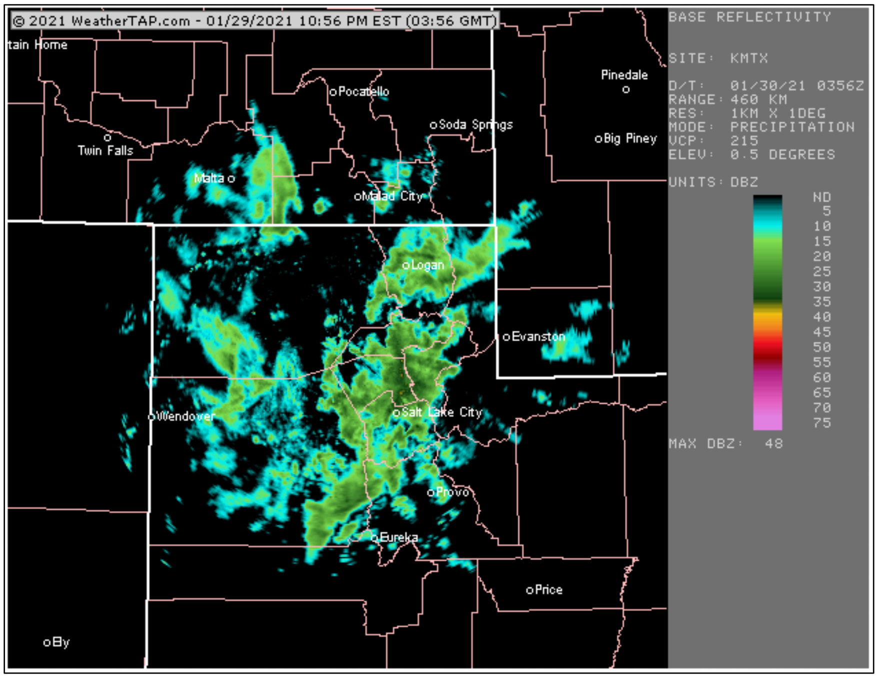

Figure 4.2 **Composite Reflectivity radar image from the Salt Lake City at 2056 MDT on Jaunary 29, 2021.**

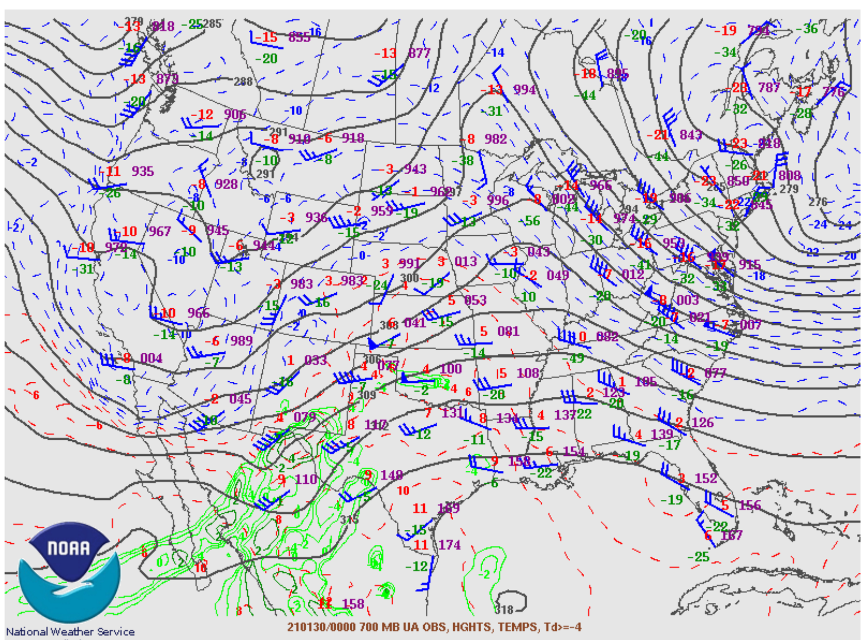

Figure 4.3 **Map of temperatures/dewpoints/winds at 700 mb (approximately 10,000 feet MSL) valid at 0600 MDT on January 30, 2021**

5.0 OPERATIONS

This season's cloud seeding program for Six Creeks target area began on November 15, 2020 and ended on April 15, 2021. A total of 20 storm events were seeded during all or portions of 32 days. There were no seeded events in November, four in December, four in January, five in February, four in March and three additional seeding events in April. A total of 825.75 cumulative hours of seeding generator operations were conducted during the season from the ground sites. Table 5-1 provides the dates and ground generator usage for the season. Tables 5-2 a and b provides the hours of generator operations by generator site location.

Table 5-1
Storm Dates and Generator Usage, 2020-2021 Winter Season

Storm Number	Storm Period	Number of CNGs Operated	Generator Hours
1	December 12, 2020	2	7.75
2	December 14, 2020	3	11.5
3	December 17-18, 2020	5	78.75
4	December 22-23, 2020	5	89
5	January 4-5, 2021	6	64.25
6	January 18, 2021	2	5
7	January 22-23, 2021	4	52.25
8	January 29-30, 2021	6	63.5
9	February 3-4, 2021	3	32.25
10	February 5, 2021	2	16.75
11	February 13-14, 2021	4	61
12	February 15-17, 2021	4	54
13	February 26-27, 2021	5	92.25
14	March 11, 2021	2	6.5
15	March 20, 2021	6	45.75
16	March 21, 2021	2	6.5
17	March 25-26, 2021	2	33.75
18	April 5-6, 2021	6	75.25
19	April 14, 2021	1	7.25
20	April 15, 2021	3	23
Total	---	---	825.75

Table 5-2a
Generator Hours for 2019-2020, Storms 1-12

Storm	1	2	3	4	5	6	7	8	9	10	11	12
Date	**12-12**	**12-14**	**12/17-18**	**12/22-23**	**1/4-5**	**1/18**	**1/22-23**	**1/29-30**	**2/3-4**	**2/5**	**2/13-14**	**2/15-17**
SITE												
Baskin Reservoir			17.5	19.75	12				12		20	18.5
Mountain Dell Treatment	5.25	3.75		19.75		2.5	5	12.5			19.75	17.75
4500 S Pump House			17.5	19.75	11			17.75	11.75		20.25	18.25
White Reservoir			17.5	19.75	11						20	18.5
Big Cottonwood Treatment	2.5		7.75	10	12.75	2.5	5		8.5	8.25		
Little Cottonwood Canyon		4			11.5							
Wasatch Resort		3.75	18.5		6		22.25	16.5		8.5		
Alpine							20	16.75				
Total	**7.75**	**11.5**	**78.75**	**89**	**64.25**	**5**	**52.25**	**63.5**	**32.25**	**16.75**	**61**	**54**

Table 5-2b
Generator Hours for 2019-2020, Storms 13-24

Storm	13	14	15	16	17	18	19	20
Date	2/26-27	3/11	3/21	3/22	3/25-26	4/5-6	4/14	4/15
SITE								
Baskin Reservoir			8			4.5		8.5
Mountain Dell Treatment	24	3.25	9	4		10		
4500 S Pump House	22.25		7.25			17		
White Reservoir			7.25			20.5		
Big Cottonwood Treatment	24		7.5	2.5	16.75	5		8.5
Little Cottonwood Canyon	20					18.25		
Wasatch Resort	21		8.75					
Alpine				6.5	17		7.25	
Total	**92.25**	**6.5**	**45.75**	**6.5**	**33.75**	**55.75**	**7.25**	**23**

Snowfall for the 2020-2021 winter season was well below normal 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 58% to 100% of the median, with an overall basin value of 66% of the median snowpack. Water Year precipitation, similarly, was below normal, ranging from 69% to 85% of the mean with a basin average of 71%. The breakdown for each SNOTEL site is provided in Table 5-3. The reason for the differences between median snow water equivalent (SWE) percentage and precipitation percent of average values is partially explained by the differences between the median values used for snowpack and mean values used for precipitation.

Table 5-3
Snowpack and Precipitation Data from SNOTEL sites – April 15, 2021

Measurement Site	Snow Water Equivalent (in)			Water Year Precipitation (in)		
	4-15-21	Median	%	4-15-21	Mean	%
Louis Meadow	8.6	14.4	60	21.3	28.3	75
Lookout Peak	23.9	24.9	96	26.0	33.0	79
Parleys Summit	11.2	11.2	100	19.8	23.4	85
Mill-D North	18.7	22.8	82	21.1	28.4	74
Brighton	13.4	23.3	58	19.7	28.5	69
Snowbird	31.1	40.5	77	30.0	39.5	76
Basin Index %			66			71

Figures 5.1 to 5.3 show plots of data from three SNOTEL sites located in the target area during the 2020-2021 winter season. Figure 5.4 shows the seasonal snow water equivalent time series data for the Provo-Utah-Jordan Basin compared to average values and some recent winter seasons.

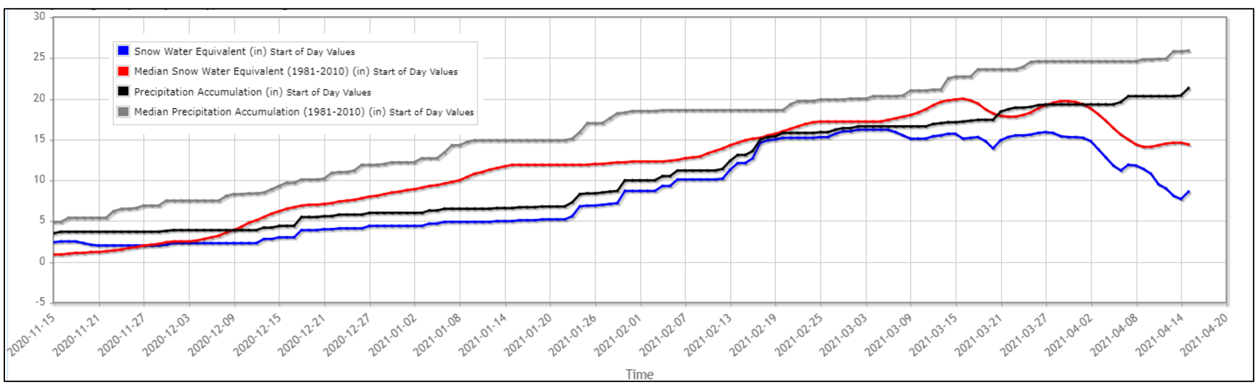

Figure 5.1. **NRCS SNOTEL snow and precipitation plot for November 15, 2020 through April 16, 2021 for Louis Meadow.**

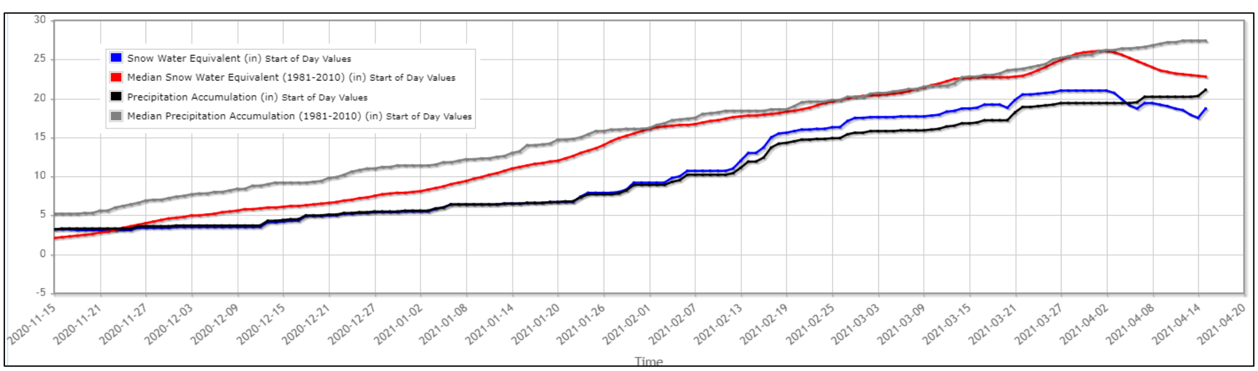

Figure 5.2. **NRCS SNOTEL snow and precipitation plot for November 15, 2020 through April 16, 2021 for Mill D – North.**

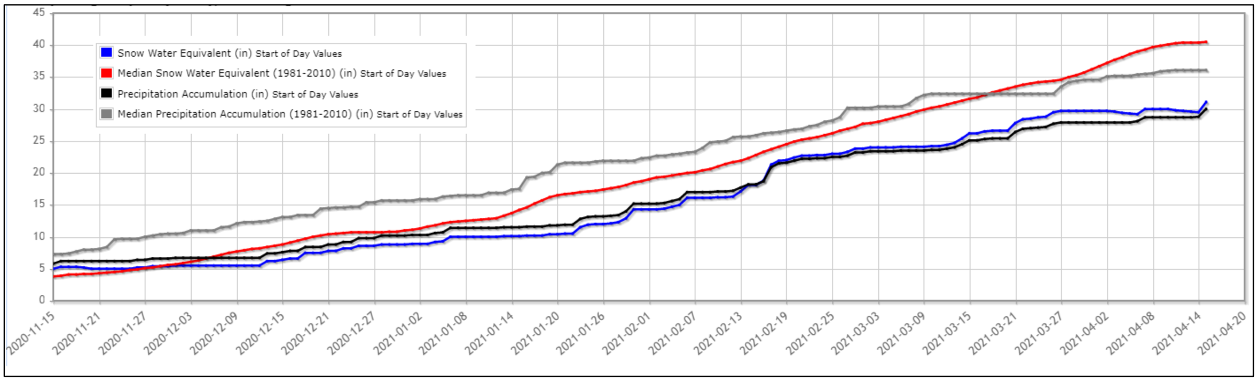

Figure 5.3. **NRCS SNOTEL snow and precipitation plot for November 15, 2020 through April 16, 2021 for Snowbird.**

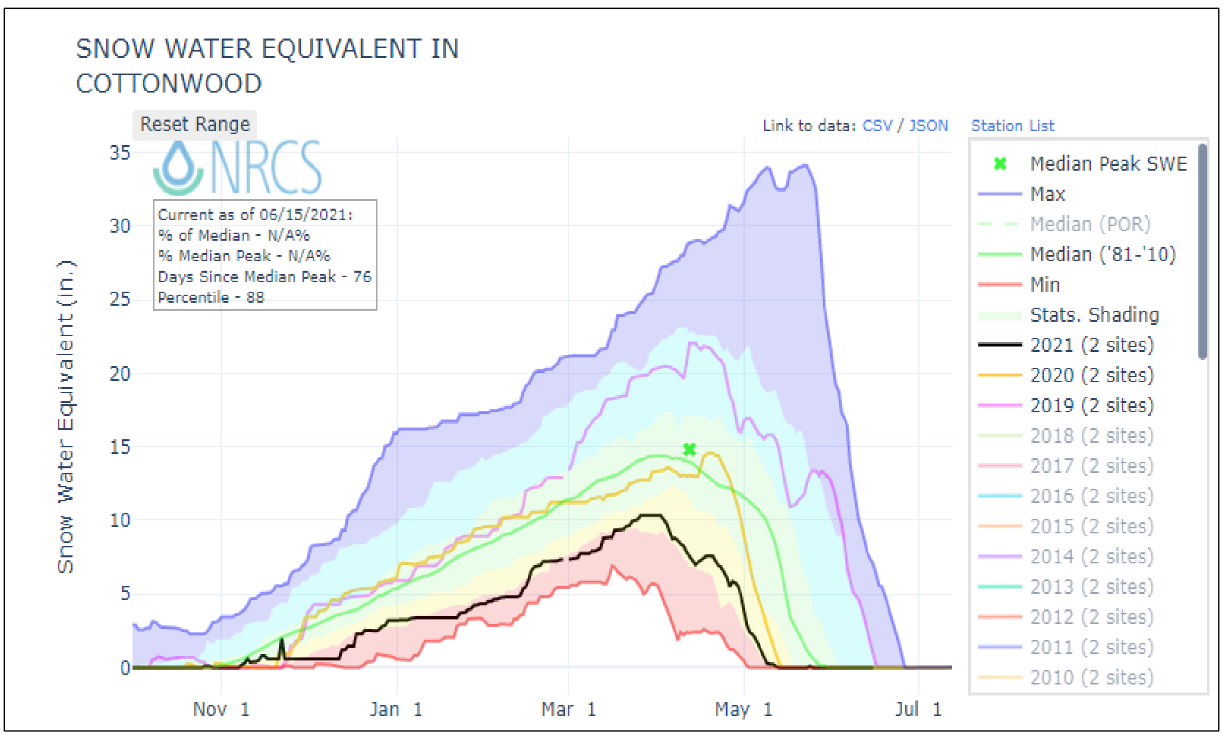

Figure 5.4 **Cottonwood Creeks Snow Water Equivalent values 2019-2021 with Median SWE values.**

5.1 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.

5.2 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 2020

November was relatively quiet and dry for the Wasatch Range, with no seeding operations taking place during the month.

December 2020

On the 12th, an area of low pressure to the west allowed for snow showers to develop along foothill and high elevations. Cameras during the start of the event showed heavy snowfall occurring in the canyons as well as cumulus clouds, visually, developing over the higher terrain. Cloud seeding operations began around 1330 MDT with additional sites added throughout the day, as 700 mb temperatures continued to drop with cold air advection moving into the Wasatch, around -12°C by 1630 MDT. Seeding operations continued until around 1930 MDT, when precipitation started to wane in intensity with the loss of daytime heating and drier air moving into the area. In addition, temperatures at 700 mb had cooled further, to around -15°C, which is the coldest at which seeding material would likely be effective.

Some light snowfall occurred during the early morning hours of the 14th, but stability was too strong for seeding operations to occur. By 1400 MDT, stability dissipated, and snowfall became heavier. Temperatures were around -9°C at 1400 MDT, with west/northwesterly flow in place at the surface and aloft. Conditions were marginal for seeding to occur, mainly due to light winds, but operations did begin at 1400 MDT. Seeding continued throughout the day until around 2000 MDT, when snowfall on radar and visually, began to decline. All seeding operations ended at this time, with only a few scattered, light snow showers occurring overnight and into the 15th.

During the period of December 17th-18th, a trough that moved into the western U.S. from the Pacific allowed for instability, moisture and precipitation to occur over most of Utah. Seeding operations were slow to start on the 17th, due to some lingering stability issues. However, by midday on the 17th, an area of precipitation moved into the Wasatch, with temperatures cooling to around -8°C. This allowed for seeding operations to begin, but only from a single site. By late on the 17th, conditions became more favorable for the activation of additional sites that continued to operate into the morning hours of the 18th. Temperatures by 0830 MDT on the 18th were rather cold and drying of the atmosphere was occurring as the trough axis had moved through the area and into eastern Colorado. Storm totals were substantial, with resorts in the Cottonwoods 24-hour totals observing 10 to 18 inches.

A large scale trough was poised just to the west from Idaho, across western Utah and into Nevada on the 22nd. Pre-trough conditions were dry to start, but strong cold air advection behind a strong cold front changed things dramatically by 1200 MDT. A number of sites were activated at this time, with moderate to heavy precipitation indicated by area cameras. Temperatures dropped to around -10°C at this time as well. The initial band of precipitation moved through the area with additional snow showers developing behind the front with the onset of daytime heating. Northwesterly flow also aided in the development of precipitation that moved into the Wasatch. There was a brief lull in precipitation during the latter part of the day, but additional disturbances moved through the area overnight on the 22nd into the 23rd. Seeding continued throughout this period, with operations ending early on the 23rd, as drier and cold conditions built into the area. Figure 5.5 shows the SWE for Utah through the end of December.

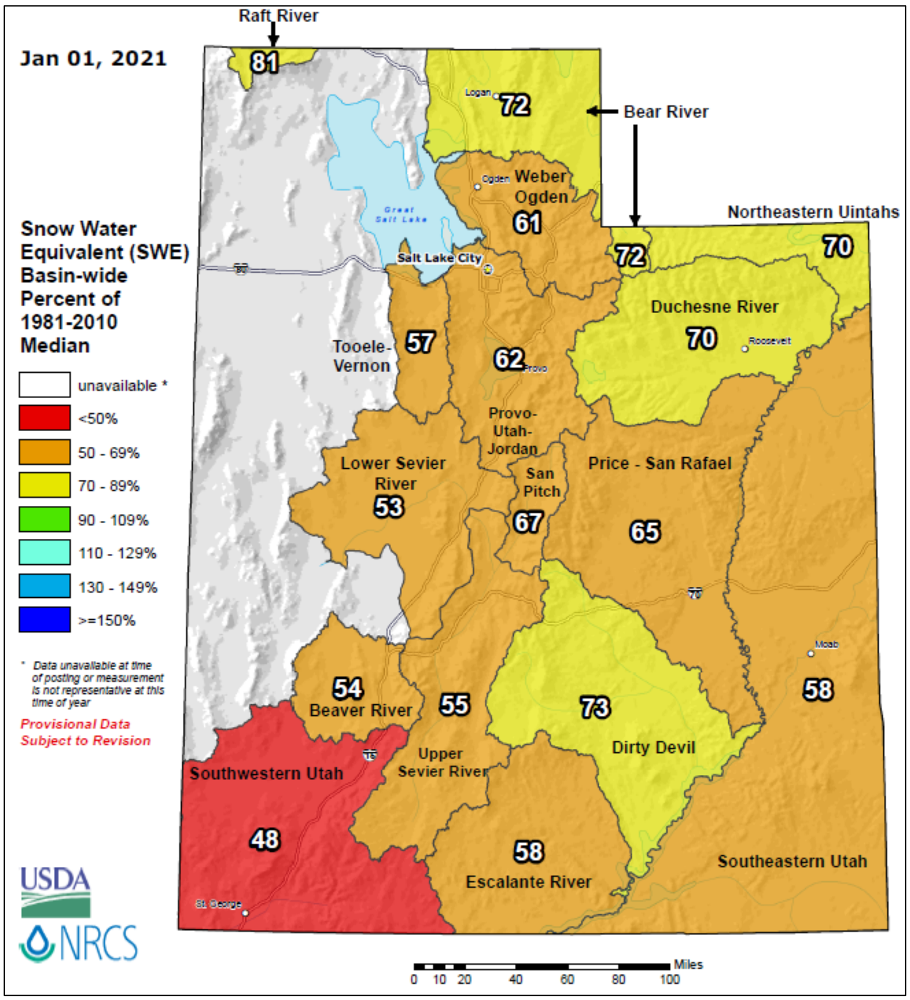

Figure 5.5. **January 1, 2021 SWE, expressed as a percent of 1981-2010 median value.**

January 2021

The month of January offered several seeding opportunities to the Six Creeks target area, with a total of four operations days. SWE percentages did improve slightly during the month of January, but still remained below normal.

On the 4th, a fast moving, vigorous mid-level trough and its associated cold front moved across the area starting around 1900 MDT. Warm temperatures in the mid-levels dropped to around -8°C and cooled further during the evening hours. Seeding operations began shortly after the frontal passage, with due westerly flow and cold temperatures expected to accompany the precipitation over the area. Operations continued until around 1000 MDT, when snow showers seemed to taper off. SWE values for the system ranged between 0.50 to 0.70 inches during the evening for the target area.

A weak system traversed northern Utah during the daytime hours of the 18th. The trough contained very limited moisture and only scattered snow showers occurred early on during the day. By midday, a favorable wind regime of a north/northwesterly direction, combined with some enhanced localized snow shower activity led to start of seeding operations. Seeding continued through the evening hours but ended when precipitation shifted eastward, away from the Wasatch Range.

An area of low pressure affected the area beginning on the 22nd, with an increase of precipitation occurring later in the day. By 1300 MDT, radar showed an increase of activity on radar with cameras showing favorable conditions developing as well. The most southern site was activity in response to this, as winds were still south/southwesterly throughout the afternoon. Winds remained as such on the 22nd, with only a few additional sites activated to target the range in south/southwesterly flow. On the 23rd, moderate to heavy snowfall continued, with the onset of northwesterly flow, and additional sites were added with the changing wind direction. Precipitation began to wane by 1500 MDT, and thus seeding operations were concluded. Light snowfall continued through the evening hours but was scattered in nature and only light additional accumulations resulted. Little and Big Cottonwood Canyons observed snow totals were between 20 and 30 inches during this event.

The last event of the month occurred during the period of the 29th – 30th. A large area of low pressure that was over California split around the Sierra Nevada Mountains, which allowed residual moisture to move into Utah. Precipitation began before seeding operations, as temperatures were slightly too warm for seeding initially. By 1500 MDT, temperatures aloft decreased and precipitation began to increase. Seeding operations began, mostly from sites that would favor a south/southwesterly wind regime. The colder part of the storm moved into the area during the overnight hours of the 29th and into the 30th, with additional sites being added during the evening hours. By the morning hours of the 30th, activity began to wane, with northwesterly flow in place. Seeding operations ended by mid-morning. Snowfall totals from the ski resorts ranged between 15 to 20 inches of new snowfall, with SWE values of 0.60 to 1 inch.

Figure 5.6 shows cumulative SWE values for the state of Utah through the end of January.

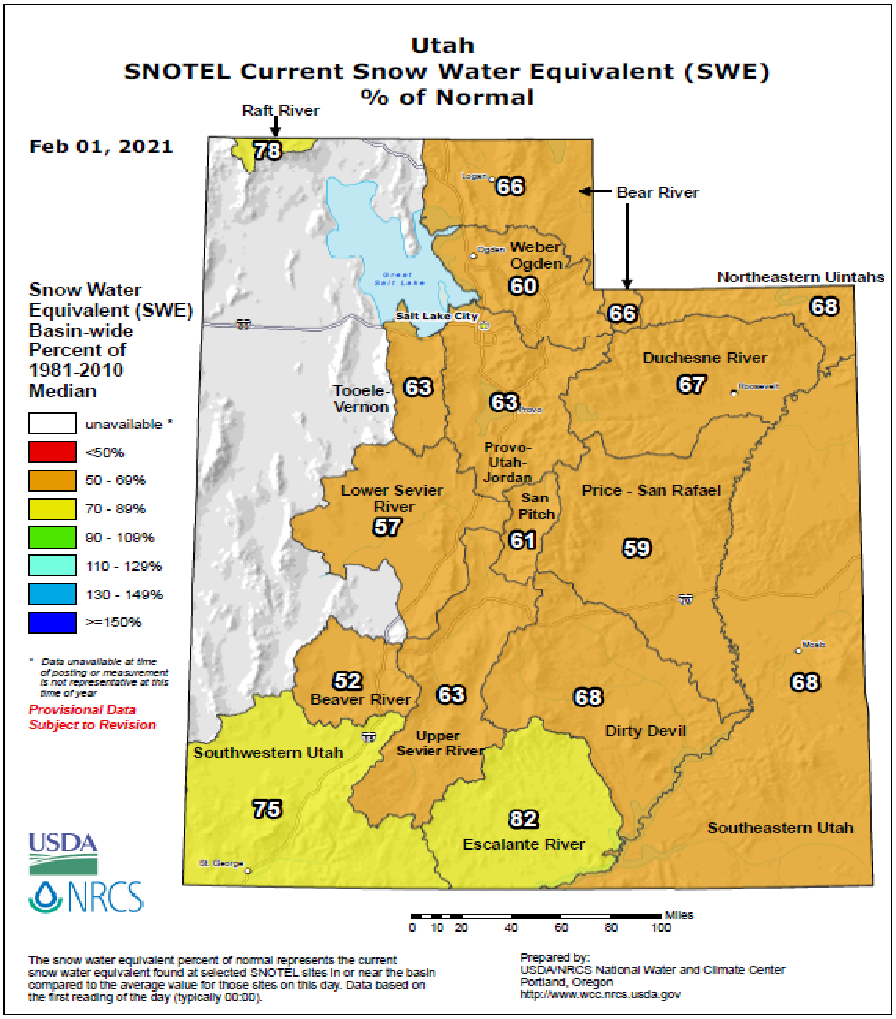

Figure 5.6 **February 1, 2021 SWE, expressed as a percent of 1981-2010 median value.**

February 2021

February brought a mix of weaker and stronger storms, but overall, an active pattern continued from the last part of January into February. Water conditions dramatically improved from February 1st to March 1st, as a progressive pattern near the end of the month impacted most of the state.

On the 3rd, a moderately strong and fast moving trough moved through the Salt Lake Valley early this morning. The front moved through very quick, but operations did occur, mostly in the post frontal storm regime. Northwest flow allowed for the use of a number seeding sites as the front moved through. There was some post-frontal precipitation over the area, which is generally a very favorable synoptic pattern for seeding operations to occur. Cold air moved into the behind the front and some residual snow showers as well as orographics allowed for seeding operations to continue overnight into the 4th. An additional 3-4 inches of snowfall occurred during the overnight hours, with lake effect producing some of this additional snowfall. Snow and seeding operations ended during the morning hours.

A trough dropped into eastern Utah on the 5th, with an embedded weather system affecting the Wasatch Range. Northwesterly flow was in place in the mid-levels, with surface winds exhibiting a more southerly direction. Temperatures throughout the event ranged between -8 and -10°C at 700 mb, an ideal range for seeding operations. By midday, activity on radar and cameras warranted seeding operations to begin from a number of sites. Moderate snowfall occurred throughout most of the day, as a weak system moved across the Salt Lake Valley. By late in the day, activity began to dissipate and thus seeding operations were concluded.

A large-scale upper level trough of low pressure moved through the Pacific Northwest and into Utah later on the 13th. Ahead of the trough, conditions were too stable and warm for seeding and these conditions continued through midday. However, by 1330 MDT, conditions became more favorable with northwesterly flow building into the area with the passage of the trough axis over Utah. Colder air continued to filter into the area in the evening, allowing for ideal conditions for seeding to occur overnight and into the following morning. An important operational note for this event is that seeding was not conducted for Big and Little Cottonwood Canyons, as the avalanche risk was rising and would likely yield a historic avalanche cycle in the next few days. Operations elsewhere continued until the early morning hours, when precipitation had waned, and conditions became unfavorable for seeding to continue. Observed 24-hour snowfall totals ranged from 25-35 inches for the Wasatch.

A largescale trough continued to be the dominate weather factor for the next seeded period of February 15th – 17th. This storm period was the most active of the 2020-2021 winter season. Upwards of 50 inches of new snowfall occurred during this three-day event, which yielded historic avalanche conditions and a 60 hour interlodge at ski resorts in Big and Little Cottonwood Canyon ski resorts. Due to the nature of the event, and the closure of Little Cottonwood Canyon for almost two full days through an historic avalanche cycle that occurred, seeding operations were modified and suspended throughout most the event, to ensure the protection of life and property.

Northwest flow was nearly persistent during this three day period, with temperatures and moisture ideal for the heavy snowfall event that occurred. Seeding did occur early on the 15th but was only for sites that would not affect Big and Little Cottonwood Canyons and only for a short period of time. Close coordination occurred between NAWC staff and personnel at Salt Lake City Department of Public Works (SLCDPW) during this event, to ensure that conditions were closely monitored. Ultimately, by the 15th, the Utah Avalanche Center issued an extreme avalanche risk for the Wasatch and operations were suspended between 1200 and 1600 MDT on the 15th.

A trough moved into the upper Great Basin on the 26th, which allow for light snowfall to beginning during the morning hours. The cold front associated with this trough moved through the project area by later in the day, which allowed for the start of seeding operations. Storm attributes became very favorable as the trough passed through the area and as northwesterly flow occurred, post frontal. Seeding operations continued into the morning of the 27th, when lake effect snow showers continued to target the project area. Temperatures were quite cold by midday, but with convective snow showers, which are typically excellent for seeding operations. Operations were concluded around 2000 MDT, with the decline in snowfall activity, with very cold temperatures and low liquid water content expected overnight. Snow water contents for this storm ranged between 0.5-1.5 inches.

Figure 5.7 shows cumulative SWE values for the state of Utah through the end of February, with improvement noted in most watersheds of Utah.

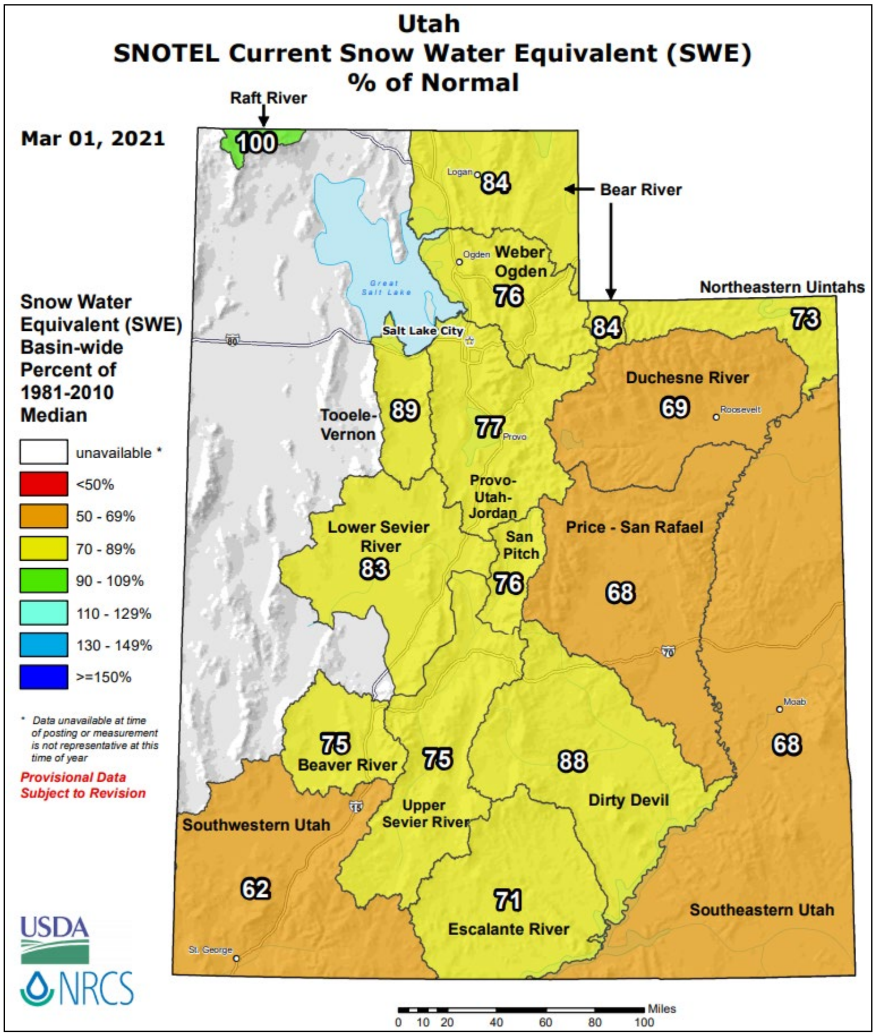

Figure 5.7. **March 1, 2021 SWE, expressed as a percent of 1981-2010 median value.**

March 2021

March provided another month of a progressive pattern that brought much needed snowfall to the state. Most of the storms this month were on the weaker side, but still allowed for a number of seeding operations to occur.

On the 11th, an area of low pressure yielded mostly south/southeasterly flow over the project area. The storm provided limited moisture and snowfall, but did provide a seeding opportunity from a few sites. A southeasterly flow regime is somewhat rare with storms that affect the project, so there were limited sites to use to target it appropriately. Some of the snow showers were slightly convective, so this helped to aid seeding operations. Seeding concluded by the evening, as activity waned.

After a week of no seedable storms over the project area, a strong system impacted the area on the 20th, which provided a seeding opportunity. Strong cold air advection moved into the area behind a cold frontal passage in the morning, which allowed for seeding operations to start. Operations occurred throughout the day, as a band of precipitation affected the Salt Lake Valley and Wasatch. This band was east of the area by the evening hours and seeding operations were then concluded. Snowfall totals from around the project area ranged from 12 to 18 inches of new snowfall in the higher elevation locations.

On the 25th, an upper level low was digging into Nevada and began to affect Utah during the evening hours. Most of the day was characterized by some light precipitation but most of it was elevated and evaporating before it reached the surface. By 1600 MDT, increased southerly flow and moisture allowed for the moistening of the lower levels and precipitation began. Operations began shortly after, with a few sites to target the project area in southwesterly flow. Seeding continued into the 26th, with light snow showers continuing but not much more in the way of accumulations occurring. Operations ended around 1000 MDT. The storm snowfall totals ranged from 6-10 inches across the target area.

Figure 5.8 shows the SWE for Utah through the end of March.

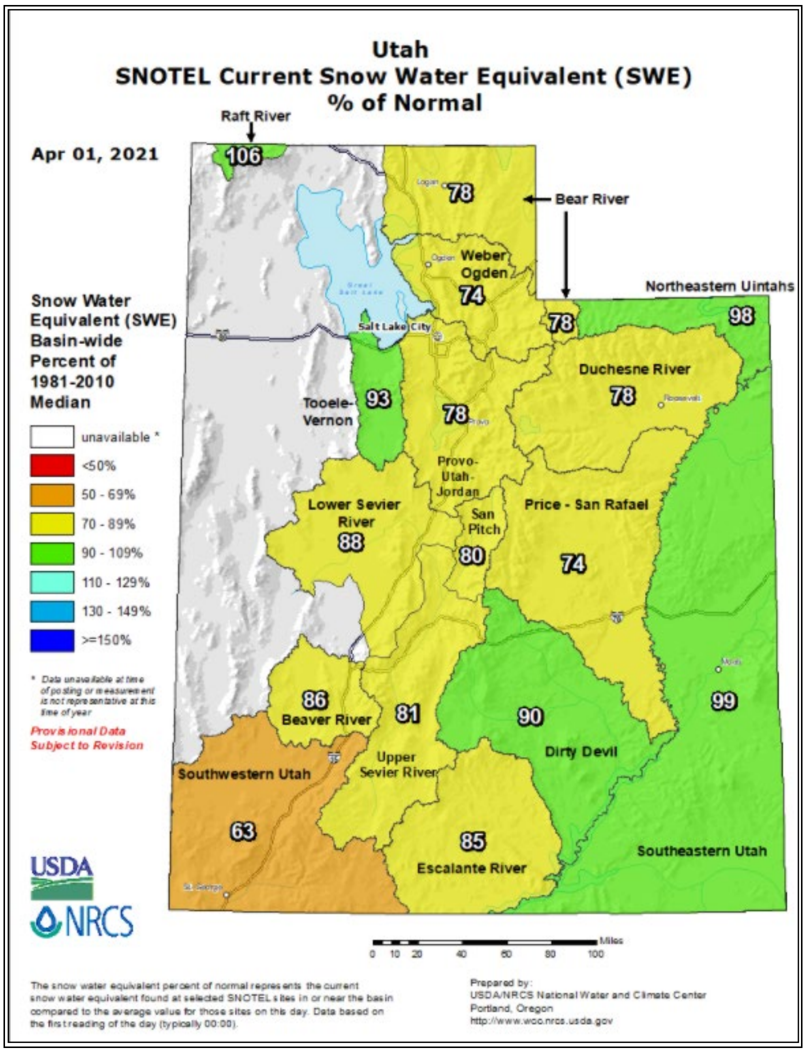

Figure 5.8. April 1, 2021 SWE, expressed as a percent of 1981-2010 median value.

April 2021

April brought a few additional seeding opportunities, with the project ending on April 15th. The three storm events that occurred were a mix of weak to moderately strong events, in which seeding could occur.

A compact and cold trough was centered over eastern Oregon and Idaho today and moved into northern Utah by the evening hours of the 5th. Snowfall began along the Wasatch by around 1700 MDT, with a strong cold frontal passage and a strong burst of precipitation initially. A secondary boundary produced locally heavy snow shows over the area, which included embedded convection. Most sites for this event were activated in westerly flow for the overnight hours. Widespread convective snow showers continued into the morning of the 6th and allowed for operations to continue through midday. Light snowfall began to taper off by 1500 MDT and thus operations were concluded. Ski areas generally reported 24-hour totals for 6-12 inches, with SWE values of 0.5-1 inch.

A large scale trough was draped across the western U.S on the 14th, with Utah on the favored easterly side for precipitation. South/southwesterly flow occurred throughout most of the day, so only one site that favors this wind regime was used for most of the day. By later in the day, precipitation waned with some light snow showers still ongoing after sunset.

The trough from the previous day shifted further eastward and was located over northern Utah on the morning of the 15th. Temperatures were around -7°C at 700 mb and winds were somewhat light and variable with the core of the trough very close to the target area. Valley sites were not used today, due to weak wind fields but other, higher elevation sites being utilized. Radar returns were indicating moderate precipitation throughout the day, with convective cells developing in the afternoon hours. By 1900 MDT, a few showers were left over but for the most part, precipitation and operations ended at this hour.

6.0 ASSESSMENT OF SEEDING EFFECTS

6.1 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 used as an external data set for these new evaluations, which can be used for some statistical measures that help to gauge the usefulness of a particular equation.

6.2 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 to receive substantial seeding effects in northwesterly wind patterns. Due to these factors, a decision was made to exclude it as a control site.

6.3 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 SWE equations have slightly lower correlations (r values) and the results may be inferior to those produced by the corresponding precipitation analyses.

Figure 6.1 shows a map of the target area and the five target SNOTEL sites, while Figure 6.2 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 Upper 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, 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 6.2 should be ideal for producing a realistic forecast of "natural" target area precipitation for comparison to the observed values during the seeded seasons. For the Six Creeks target area, sites that were inside the target area were utilized.

Figure 6.1 **Six Creeks SNOTEL Target Site Locations (target area denoted in red)**

Figure 6.2 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

6.4 Results for the 2021 Water Year

Evaluation results for the 2021 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 0.99 and 1.03 for this season linear and multiple linear equations, respectively, which is marginally suggestive of a positive seeding effect. The snowpack evaluations yielded similar ratios of 0.98 and 1.01 for the linear and multiple linear equations, respectively.

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 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 2021 season's results, while the bottom row summarizes the overall mean for the last three consecutive seeded seasons. As natural variabilities exist in the weather patterns of the target and control areas, long term averages, rather than single season results should be used to predict program effectiveness. The overall three-season mean result is a ratio of 1.08, which indicates an 8% increase in precipitation/SWE. This ratio is equivalent to about 1.86 inches of additional precipitation/SWE for each season. 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 this seeded period. Precipitation evaluations for this period indicated an average increase ratio of 1.01 (linear) and 1.02 (multiple linear) while SWE evaluations demonstrated an average increase ratio of 1.14 (linear) and 1.16 (multiple linear).

Table 6-3
Evaluation Results for the 2021 Water Year

Evaluation Type	Observed/Predicted Ratio	Observed – Predicted Difference (inches of precipitation or SWE)
Precipitation December-March Linear	0.99	-0.16
Precipitation December - March Multiple Linear	1.03	0.53
Snow April 1 Linear	0.98	-0.40
Snow April 1 Multiple Linear	1.01	0.11
2021 Mean of Results	1.00	0.02
2019-2021 Mean	1.08	1.86