SUMMARY AND EVALUATION OF 2018-2019 WINTER CLOUD SEEDING OPERATIONS IN CENTRAL AND SOUTHERN UTAH

Prepared for

State of Utah Division of Water Resources
Utah Water Resources Development Corporation

And

Lower Colorado River Basin States

by

David P. Yorty
Don A. Griffith

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Report No. WM 19-9
Project No. 18-418

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TABLE OF CONTENTS

Table of Contents
Continued

Table of Contents
Continued

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1.0 INTRODUCTION

Since the mid 1970s, operational cloud seeding has been routinely conducted throughout the winter and early spring seasons over many of the mountainous watersheds of central and southern Utah. Responsible water managers and others concerned about maintaining adequate water supplies have recognized that application of cloud seeding technology can be a viable method available to augment and help stabilize water supplies. By employing cloud seeding it could be possible to moderately increase the amount of precipitation and runoff beyond that which would have occurred naturally. Operations can be suspended in portions of or all of certain winter seasons that experience above to much above normal amounts of precipitation. Due to the program suspension criteria, cloud seeding operations were curtailed in the 1982, 1983, 1993, 1995, 2005, 2008, 2010, 2011, 2017 and 2019 water years. Operations were suspended entirely in the 1984 water year.

In many past winter seasons, cloud seeding has been conducted in several different regions within central and southern Utah. Since the mid-1970s seeding has been concentrated in the mountainous watersheds from Millard and Sanpete Counties southward to the Pine Valley Mountains and Washington County and the headwaters of the Sevier River in Iron and Garfield Counties. The mountainous portions of Tooele and Juab Counties have been included as seeding target areas since 1988. A map showing the current boundaries of these seeded target areas is provided in Figure 1.1. The target areas, generally the terrain above 7,000 feet MSL, were selected as high-yield areas with substantial snowpack accumulation. These areas are the primary contributors to spring and summer streamflow. Figure 1.2 depicts the average annual precipitation for the State of Utah. This figure graphically demonstrates these higher-yield areas.

Traditionally, the sponsoring participants (counties or water conservancy districts) have contracted the cloud seeding program in central and southern Utah with the Utah Water Resources Development Corporation (UWRDC). The UWRDC, a non-profit organization, was formed in the 1950s to act as a liaison between the agencies desiring cloud seeding and the company providing the actual cloud seeding equipment and operations. North American Weather Consultants (NAWC), a Utah firm, has been the contractor to the UWRDC in this capacity. During the current water year, the State of Utah, through the Division of Water Resources, was again a co-sponsor of this program through 50% cost sharing.

Cloud seeding in Utah is regulated by the Utah Department of Natural Resources through the Division of Water Resources. Utah law requires that operators conducting cloud seeding have both a license and a site-specific permit for the area(s) to be seeded. The law also requires that a notice of intent to conduct a cloud seeding project be published in the local area newspapers at least once per week for three weeks before commencing the cloud seeding. After complying with this requirement, NAWC was granted a license and permit to conduct cloud seeding for the mountainous watersheds in central and southern Utah. The core cloud seeding operations period was November 15, 2018 through March 15, 2019. The three Lower Colorado River Basin States (Arizona, California and Nevada), as in previous seasons, provided additional funding to extend the operational period in those areas of the southern target area, which contain tributaries to the Colorado River. The extension periods were November 1-15, 2018 and March 15-April 15, 2019.

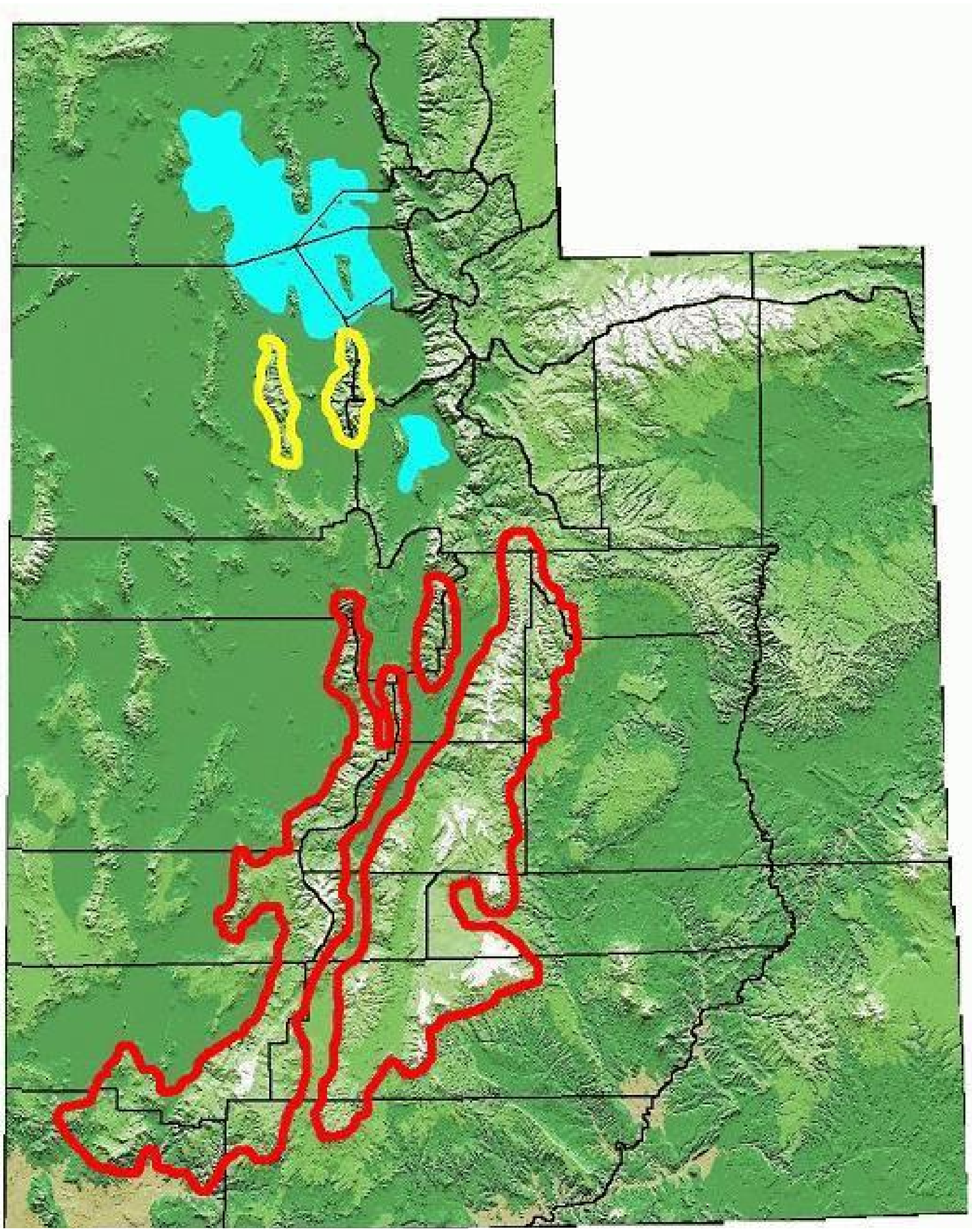

Figure 1.1 Seeded target areas in central and southwestern Utah; Eastern Tooele Target (yellow) and Primary Target (red)

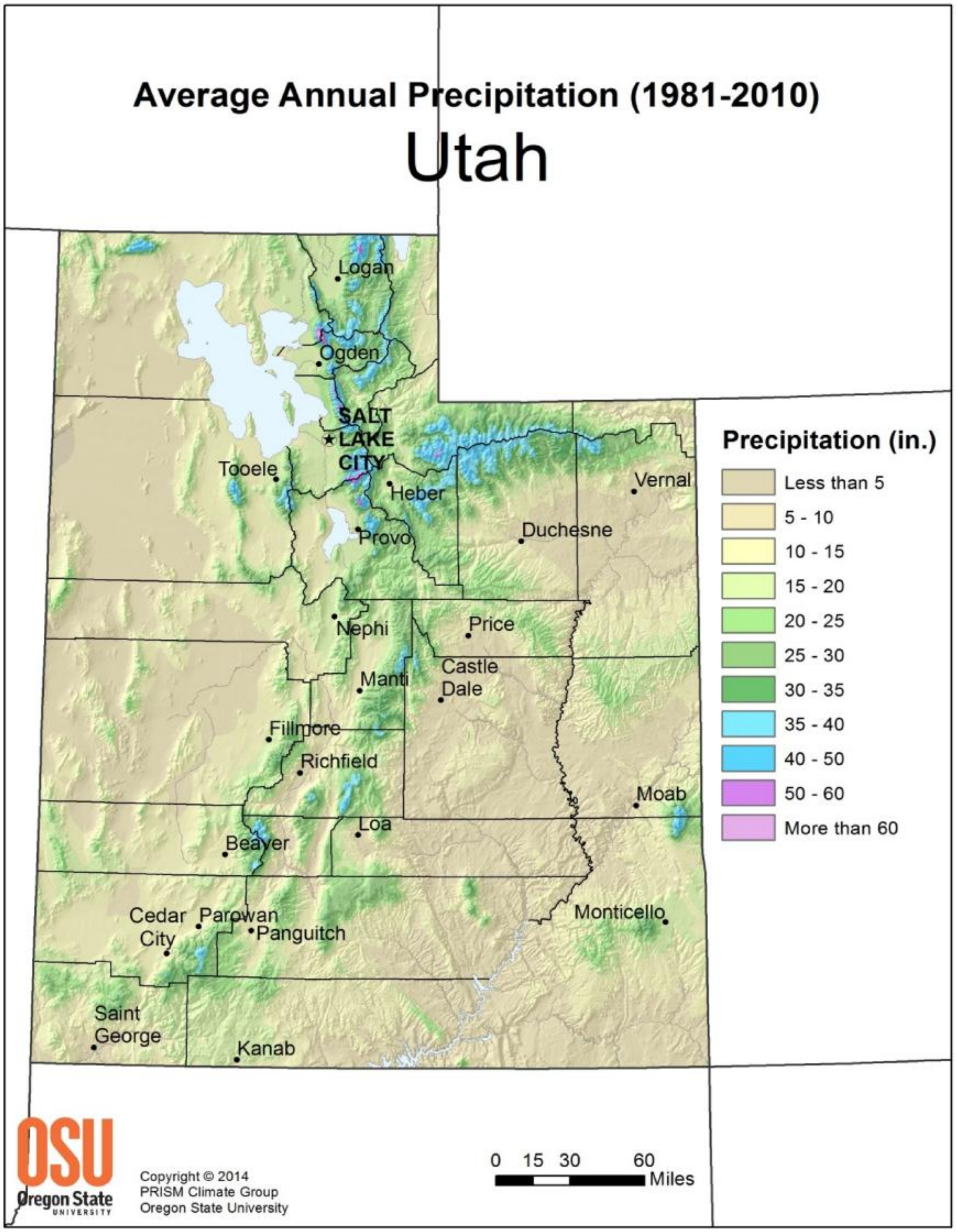

Figure 1.2 Utah average annual precipitation

1.1 Project Extension Period

The demand for fresh water continues to grow in the southwest, and the Colorado River is an extremely important component of the surface water supply in the region. Colorado River water interests have worked together in recent years to develop new or improved strategies aimed at enhancing the flow of the river better managing the water resources. One of the most promising strategies is increasing the use of cloud seeding for precipitation augmentation where and when viable seeding opportunities occur.

The Central/Southern Utah Project was one of two Utah projects selected to receive supplemental Lower Basin funding. Via an agreement between the Lower Basin States and Utah's Division of Water Resources, supplemental funds for extension of the operational seeding period for a portion of the Central/Southern Project have also been provided. The extension periods funded by Lower Basin States were from November 1-15 and March 16 – April 15 this past winter season. Thus, additional benefit was realized by some of the primary target area sponsors at no additional cost to them.

1.2 Installation and Operation of Icing Rate Meters

An earlier agreement with the three Lower Basin States had provided funds to purchase some hardware for three remote icing rate meters. The Lower Basin States provided funds in the 2009 agreement to install and operate two of these sites beginning during the 2009-2010 winter season. One site was installed in central Utah in conjunction with a Utah Department of Transportation site (Skyline), a second site was established at the Brain Head ski area in southern Utah. Beginning with the 2012-13 winter season, a third icing meter site has been active at Dry Ridge in the Uintas (this is within the High Uintas seeding program target area). The icing rate meters detect the presence of supercooled liquid water (SLW) cloud droplets embedded in naturally occurring winter storms. These SLW droplets are the targets of the cloud seeding activities. Funds from the Lower Basin States are also provided for analysis of the ice detector data to help improve understanding of when/where SLW occurs in cold-season storm events. A separate report will once again cover the analyses of data collected from these sites during this past season.

2.0 PROJECT DESIGN

2.1 Background

Evaluations of this long-standing operational seeding project have consistently indicated increases in wintertime precipitation during the periods in which cloud seeding was conducted. Statistical analyses have suggested seasonal increases in precipitation that may be attributed to the cloud seeding program, averaging between 5% and 15% (Griffith, et al, 2009). Operational procedures during the 2018-2019 Central/Southern Utah 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 the 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 the Central/Southern Utah Program. NAWC has incorporated observational, seeding method and evaluation enhancements into the project when they are believed to be of practical value to the project.

2.2 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. The criteria deal with meteorological characteristics (temperature, stability, wind flow and moisture content) associated with winter cloud systems. Table 2-1 provides the seeding criteria which NAWC has established for the southern/central Utah winter cloud seeding program.

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. This will generally be accomplished if the cloud base is at a lower elevation than the mountain crest and no temperature inversions or stable layers exist between the elevation of the cloud seeding generator and the cloud base. There were some storm events during the season where the cloud temperatures were too warm for seeding to be effective according to NAWC's operational criteria (see Table 2-1, item 4) and were therefore not seeded. The existence of low-level stability 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. Griffith, et al, 2013 provides additional information on the seedability of winter storms.

Table 2-1

NAWC Winter Cloud Seeding Criteria

1) CLOUD BASES ARE BELOW THE MOUNTAIN BARRIER CREST.

2) LOW-LEVEL WIND DIRECTIONS AND SPEEDS WOULD FAVOR THE MOVEMENT OF THE SILVER IODIDE PARTICLES FROM THEIR RELEASE POINTS INTO THE INTENDED TARGET AREA.

3) 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.

4) TEMPERATURE AT MOUNTAIN BARRIER CREST HEIGHT EXPECTED TO BE -5°C (23°F) OR COLDER.

5) TEMPERATURE AT THE 700 MB LEVEL (APPROXIMATELY 10,000 FEET) EXPECTED TO BE WARMER THAN -15°C (5°F).

2.3 Equipment and Project Set-Up

During the autumn of 2018, following a period of off-season maintenance, NAWC technicians re-installed the ground-based cloud seeding generators at sites selected to produce seeding plumes over the target areas in various wind situations. The target areas are discussed in more detail in Section 4.0. The seeding generator site locations, approximately 70 in all, are shown in Figure 2.1. Information on these locations is provided in Table 2-2.

Eleven ground-based seeding sites were available in eastern Tooele County (ET) during the season, located throughout the Tooele Valley from Erda and Grantsville southward to Faust, with additional sites to the west of the Stansbury Range, in Skull Valley. These locations allow for targeting of this portion of the seeding target area (Oquirrh and Stansbury Mountains) during a variety of wind flow situations.

The second seeded target group is referred to as the Primary Target (PT). This target area covers a large portion of central and southwestern Utah, including the principle mountain ranges listed below.

- Wasatch Range - northeast of Nephi
- Wasatch Plateau - east of Mt. Pleasant to east of Manti
- San Pitch Mountains - east of Levan to Gunnison
- Fish Lake Hightop Plateau - east of Koosharem
- Pavant Range - east of Fillmore to Cove Fort
- Tushar Mountains - east of Beaver
- Sevier Plateau - east of Salina to Panguitch
- Valley Mountains - east of Scipio
- Paunsaugunt Plateau - east of Panguitch and Hatch
- Markagunt Plateau - east of Paragonah to Brian Head
- Pine Valley/Harmony Mountains - southwest of Cedar City to St. George
- Kolob Terrace - south of Cedar City to Springdale

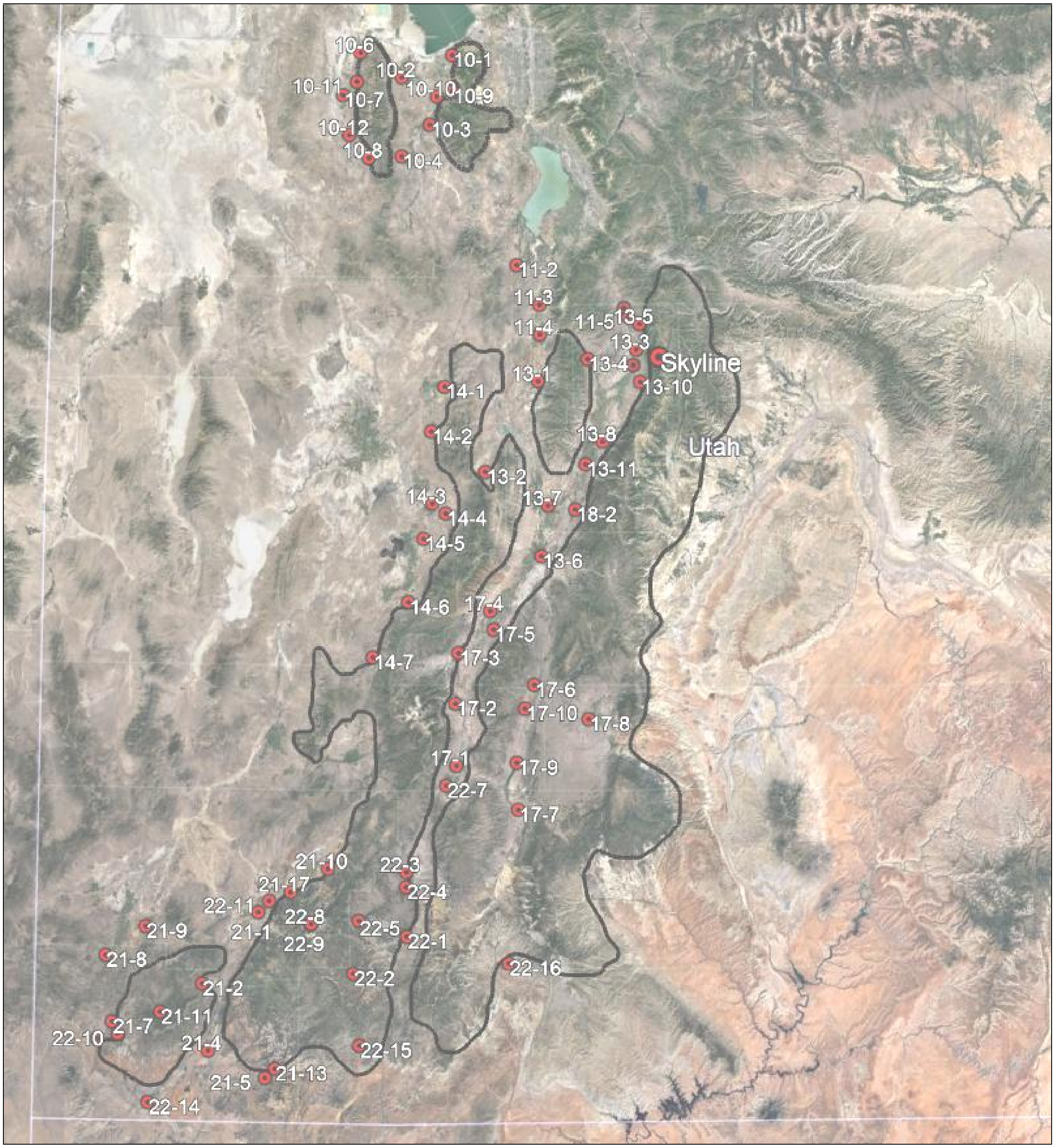

Figure 2.1 Target areas and seeding site locations (not all sites may be seen on map due to proximity to others)

Table 2-2
Seeding Site Locations

Site Number	Name	Lat. (N)	Long. (W)	Elev. (ft.)
10-1	Lakepoint	40°40.65’	112°15.22’	4430
10-2	Grantsville	40°35.99'	112°28.88'	4342
10-3	Stockton	40°26.12'	112°21.18'	5234
10-4	Clover	40°19.50'	112°28.75'	5342
10-6	Skull Valley North	40°41.11'	112°40.10'	4289
10-7	Skull Valley Central	40°32.20'	112°44.74'	4390
10-8	Terra	40°19.12'	112°37.60'	5166
10-9	Pine Canyon	40°33.09'	112°15.15'	5095
10-10	Settlement Canyon	40°31.14’	112°18.16’	5140
10-11	Skull Valley #3	40°35.00’	112°41.00’	4300
10-12	Skull Valley #4	40°23.87’	112°42.92’	4890
11-5	Indianola	39°48.20'	111°29.07'	5986
11-2	Elberta	39°57.12'	111°57.72'	4732
11-3	Mona	39°48.93’	111°51.61’	4943
11-4	Nephi West	39°42.78'	111°51.56'	5042
11-5	Hideaway Valley	39°46.32'	111°27.90'	6300
13-1	Levan	39°33.17'	111°52.06'	5286
13-2	Scipio	39°14.50'	112°06.06'	5322
13-3	Fairview	39°39.61’	111°25.87’	6125
13-4	Fountain Green	39°37.69'	111°38.88'	5985
13-5	Milburn	39°44.88'	111°24.96'	6787
13-6	Salina	38°57.22'	111°51.21'	5190
13-7	Centerfield	39°07.60'	111°49.43'	5100
13-8	Ephraim	39°20.73'	111°34.95'	5626
13-10	Mt. Pleasant	39°32.46'	111°27.03'	5981
13-11	Manti	39°16.08'	111°39.51'	5505

Site Number	Name	Lat. (N)	Long. (W)	Elev. (ft.)
13-12	Fairview South	39°36.44'	111°26.71	5855
14-1	Leamington	39°31.99'	112°16.92'	4721
14-2	Oak City	39°22.76'	112°20.43'	5059
14-3	McCornick	39°07.95'	112°20.01'	4848
14-4	Holden	39°05.92'	112°16.49'	5077
14-5	Fillmore	39°00.71’	112°22.30’	4879
14-6	Kanosh	38°47.71'	112°26.20'	5048
14-7	Cove Fort	38°36.35'	112°35.44'	5942
17-1	Junction	38°14.28'	112°13.42'	6018
17-2	Marysvale	38°26.98'	112°13.72'	5870
17-3	Joseph	38°37.34'	112°13.00'	5435
17-4	Richfield	38°45.96’	112°04.68’	5296
17-5	Annabella	38°42.17'	112°03.77'	5316
17-6	Koosharem	38°30.87'	111°53.13'	6973
17-7	Antimony	38°05.29'	111°57.25'	6661
17-8	Loa	38°23.83'	111°38.89'	7052
17-9	Angle	38°14.91'	111°57.65'	6415
17-10	Greenwich	38°26.00’	111°55.54’	6882
18-2	Mayfield	39°06.97'	111°42.52'	5550
21-1	Cedar City West	37°43.84'	113°04.53'	5525
21-2	New Harmony	37°29.05'	113°18.85'	5355
21-4	Toquerville	37°15.16'	113°17.12'	3377
21-5	Rockville	37°09.70'	113°02.35'	3737
21-7	Veyo	37°20.79'	113°42.04'	4544
21-8	Enterprise	37°34.50'	113°43.99'	5345
21-9	Newcastle	37°40.61'	113°33.73'	5242
21-10	Paragonah	37°52.98’	112°46.56’	5880
21-11	Pine Valley	37°23.05'	113°29.57'	6579

Site Number	Name	Lat. (N)	Long. (W)	Elev. (ft.)
21-12	Gunlock	37°17.16'	113°45.88'	3638
21-13	Springdale	37°11.65'	112°59.83'	3987
21-17	Summit	37°48.04'	112°55.96'	6009
22-1	Hatch	37°39.20'	112°26.00'	6922
22-2	Duck Creek	37°31.50’	112°39.80’	8451
22-3	Spry	37°52.43'	112°26.24'	6564
22-4	Panguitch	37°49.33'	112°26.30'	6619
22-5	Panguitch Lake	37°42.39’	112°38.47’	8255
22-7	Circleville	38°10.27'	112°16.03'	6082
22-8	Brian Head Summit	37°41.64'	112°50.76'	9591
22-9	Brian Head	37°41.58'	112°51.00'	9700
22-10	Dammeron Valley	37°18.26'	113°40.56'	4546
22-11	Enoch	37°46.44'	113°01.55'	5566
22-14	St. George	37°04.16'	113°32.56'	2709
22-15	Orderville	37°16.62’	112°38.10’	5470
22-16	Henrieville	37°33.72’	112°59.64’	6000

The primary target area reaches from eastern Juab County, in central Utah, southward to the northern portions of Washington and Kane Counties in southwestern Utah.

There are approximately 60 seeding generator sites available for the primary target areas. These generators extended roughly in north to south lines west of the target areas in eastern Juab, Millard and Beaver Counties as well as throughout Sanpete, Sevier and Piute Counties. Further south, generators were located in Iron, Garfield, Kane, and Washington Counties. This equipment array, by design, provided for generator operations regardless of wind direction, as some generators were always upwind of a portion of the target area during storms. It should be noted that winds during winter storms in Utah typically blow from the west toward the east;

usually from the southwest before frontal passages and from the northwest following frontal passages.

The cloud seeding equipment at each site includes a cloud seeding generator unit and a propane gas supply tank. The seeding solution consists of two percent (by weight) silver iodide (AgI), complexed with small portions of sodium iodide and para-dichlorobenzene, in solution with acetone. This particular solution is used because it is formulated 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. The 2% silver iodide solution has been used throughout most of the history of the program, although a 3% solution was used during some past seasons.

The seeding units are manually operated by a local operator igniting propane in a burn chamber, and then adjusting the flow of the seeding solution into the burn chamber through a flow rate meter. The propane gas pressurizes the solution tank, which allows the solution to be forced 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, and after combustion it produces these 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 and -25°C (+23 to –13°F). 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 towards the northeast.

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. Due to a large number of wildfires during the past couple of years, NAWC's suspension criteria included situations that might impact several burn areas located with the central/southern Utah target areas during periods that might be conducive to debris flows. Appendix A provides the resulting suspension criteria. There was a seeding suspension during the 2018-2019 season, beginning in February for portions of southwestern Utah due to high snowpack. This suspension continued intermittently for the remainder of the season. There was also a minor suspension for a portion of Sanpete County in April due to construction at a nearby reservoir. Details on these suspensions are provided in Section 4.

3.0 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 a fully capable computer system with internet access at home, to allow continued monitoring and conduct of seeding operations outside of regular business hours. Figures 3.1 – 3.3 show examples of some of the available weather information that was used in this decision-making process during the 2018-2019 winter season. Figure 3.4 provides predictions of ground-based seeding plume dispersion for a discrete storm period in central and southern Utah using the National Oceanic and Atmospheric Administration's HYSPLIT model (Appendix B). This model helps to estimate the horizontal and vertical spread of a plume from potential ground-based seeding sites in real-time, based on wind fields contained in the weather forecast models.

An agreement between the three Lower Colorado River Basin States and the Utah Division of Water Resources has provided funding to acquire and install icing rate meters and special precipitation detectors at three sites in Utah. These sites were re-established for the 2018-2019 winter season, with two of them located in the Central/Southern Utah project area. The two in the project area were located at Brian Head (east of Cedar City) and at Skyline (east of Fairview). The icing meters are designed to measure supercooled (colder than freezing) cloud droplets. As described in the introduction section of this report, supercooled cloud droplets are the targets of the seeding activities. The ice detectors are used to measure the occurrence of supercooled liquid cloud droplets, useful in making real-time seeding decisions as well as for later analysis. The icing meter "cycles" when a certain amount of icing accumulates on a small probe. The probe is then heated briefly to de-ice the probe. Multiple cycles are indicative of likely favorable seeding situations, assuming that the other seeding criteria (especially temperature) are met. Figure 3.5 provides a photograph of an installation at Brian Head. Figure 3.6 provides a close-up of this suite with labels assigned to the various components, which is similar to the site at Skyline as well.

Global and regional forecast models are a cornerstone of modern weather forecasting, and an important tool for operational meteorologists. These models forecast a variety of parameters at different levels of the atmosphere, including winds, temperatures, moisture, and surface parameters such as accumulated precipitation. An example of a display from the global GFS forecast model is shown in Figure 3.7.

A more recent product to which NAWC obtained access provides the ability to display a special High-Resolution Rapid Refresh (HRRR) model meteorological data in support of operations. The software used by NAWC was developed by Idaho Power Company in support of their cloud seeding operations primarily by providing analyses and forecasts of supercooled liquid water, temperature, moisture, and other parameters relevant to operations. The HRRR model does not forecast seeding effects, or the dispersion of seeding material such as the HYSPLIT model does, but it contains important atmospheric parameters in much higher time and space resolution than other (e.g. global) weather forecast models. An example of HRRR products is shown in Figure 3.8, for an April 10 seeded storm period in central Utah.

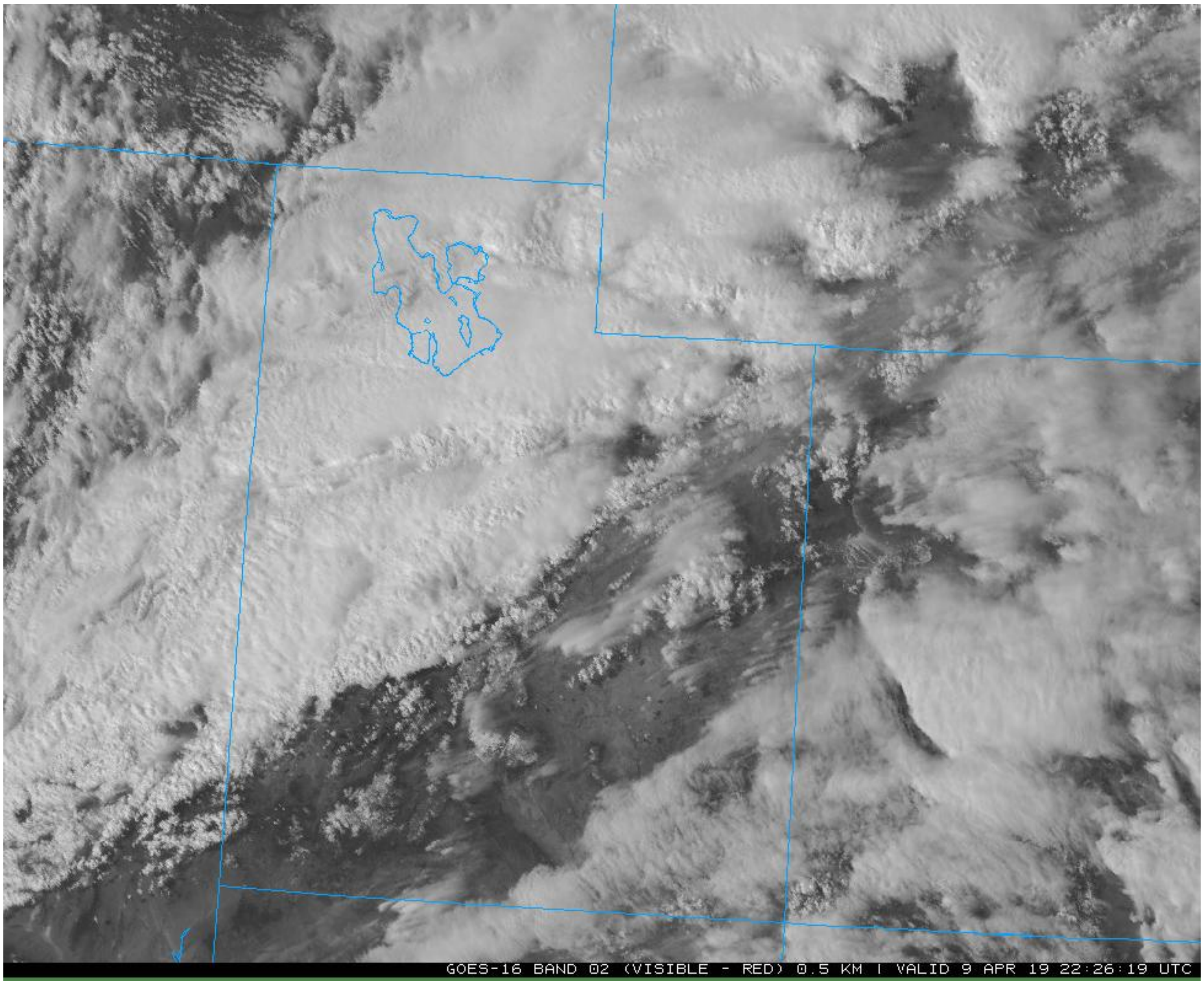

Figure 3.1 Visible spectrum satellite image at 1626 MDT April 9 as a strong cold frontal boundary moved across the state

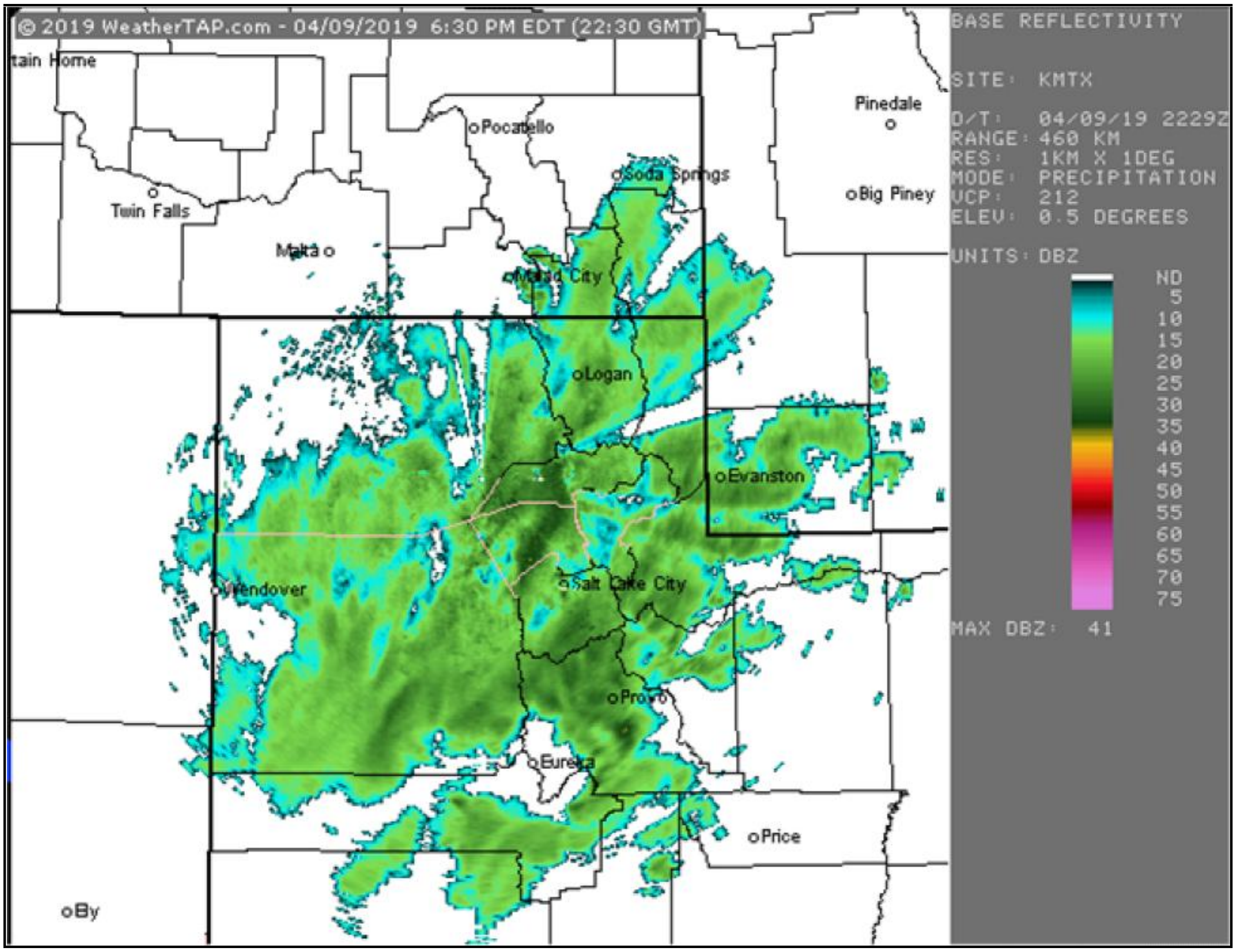

Figure 3.2 Weather radar image, Salt Lake City area, at 1630 MDT April 9

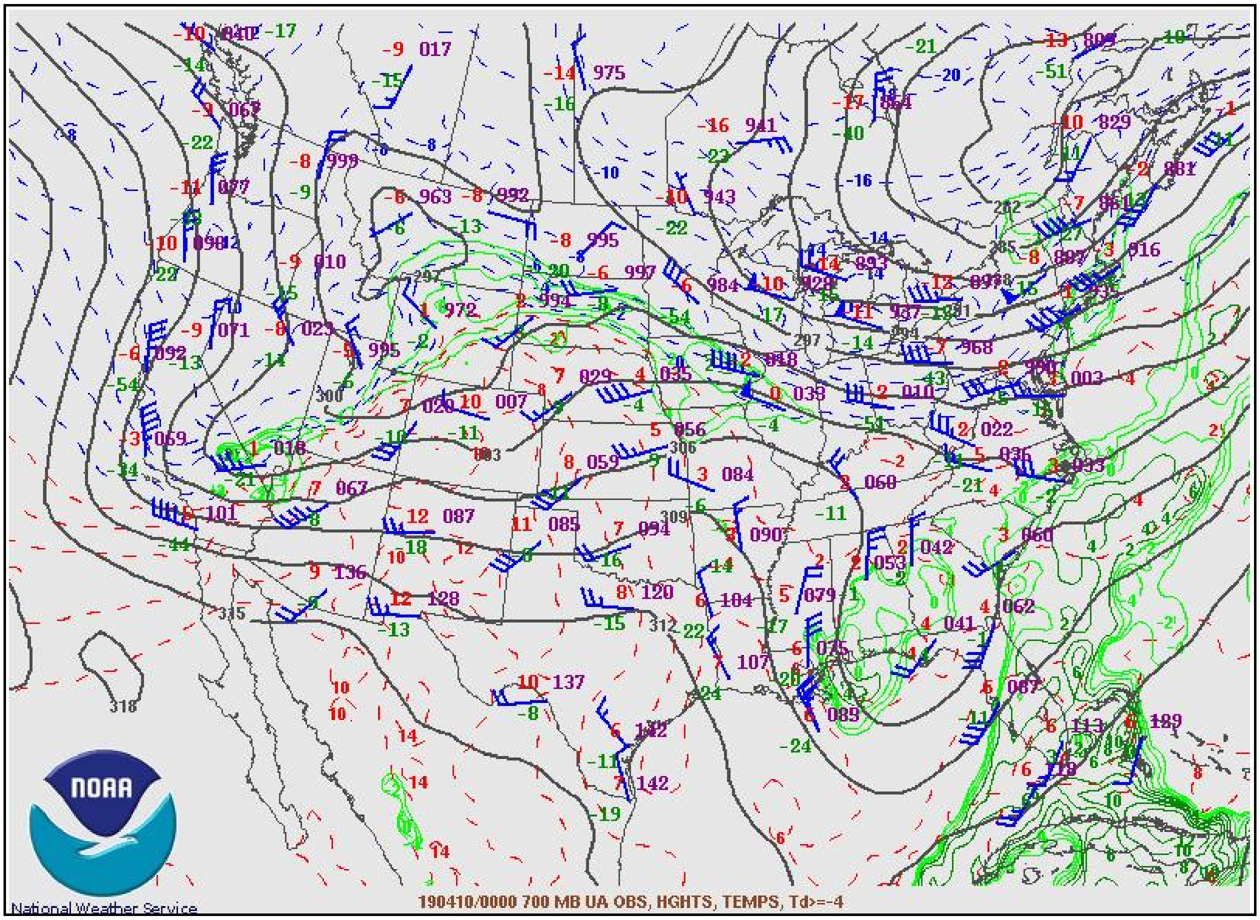

Figure 3.3   700 mb map at 1600 MDT 4-9-19

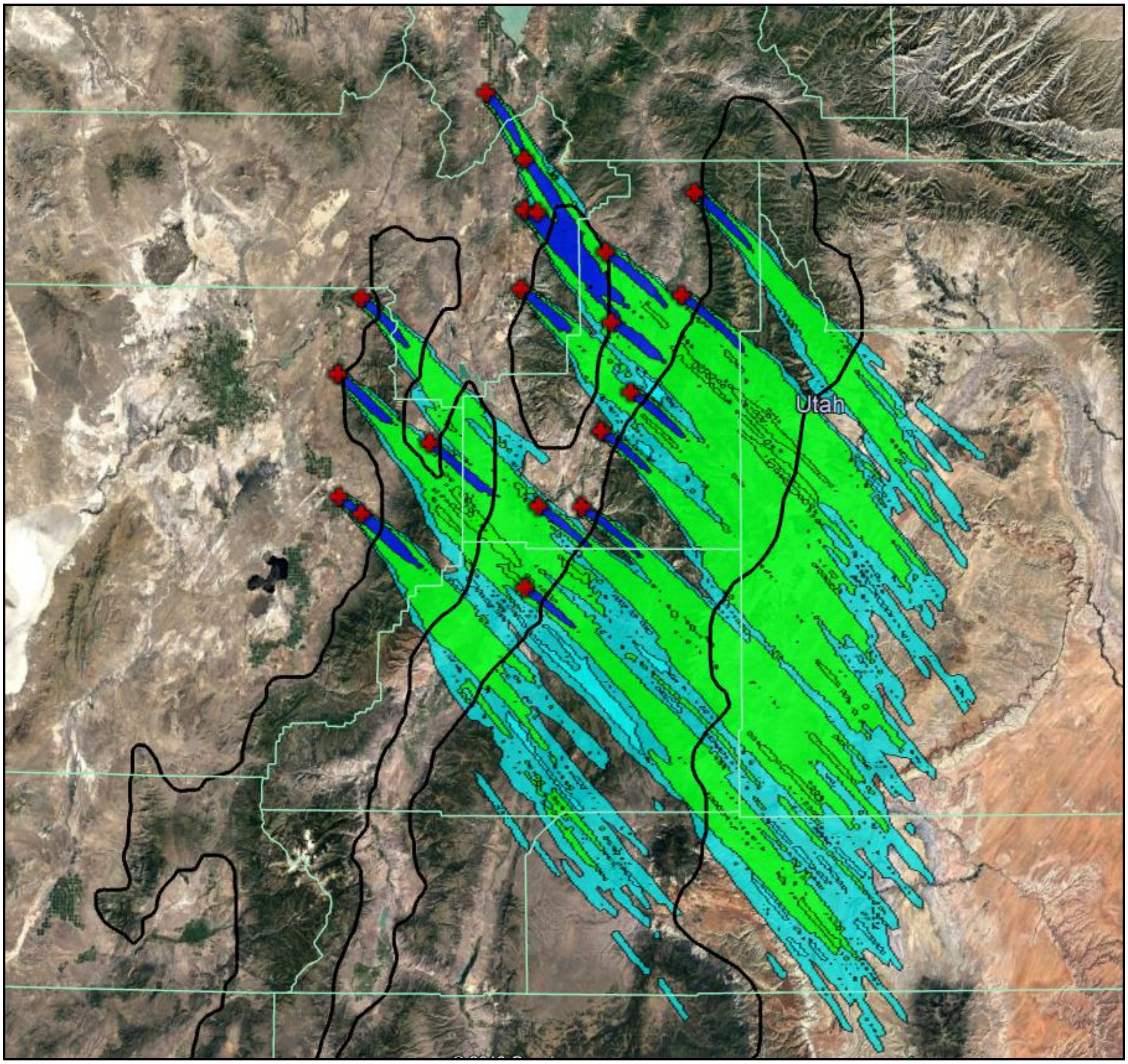

Figure 3.4 HYSPLIT plume dispersion forecast on the morning of April 10, for some portions of the target area in central Utah

Figure 3.5   Special instrument suite at Brian Head Ski Area

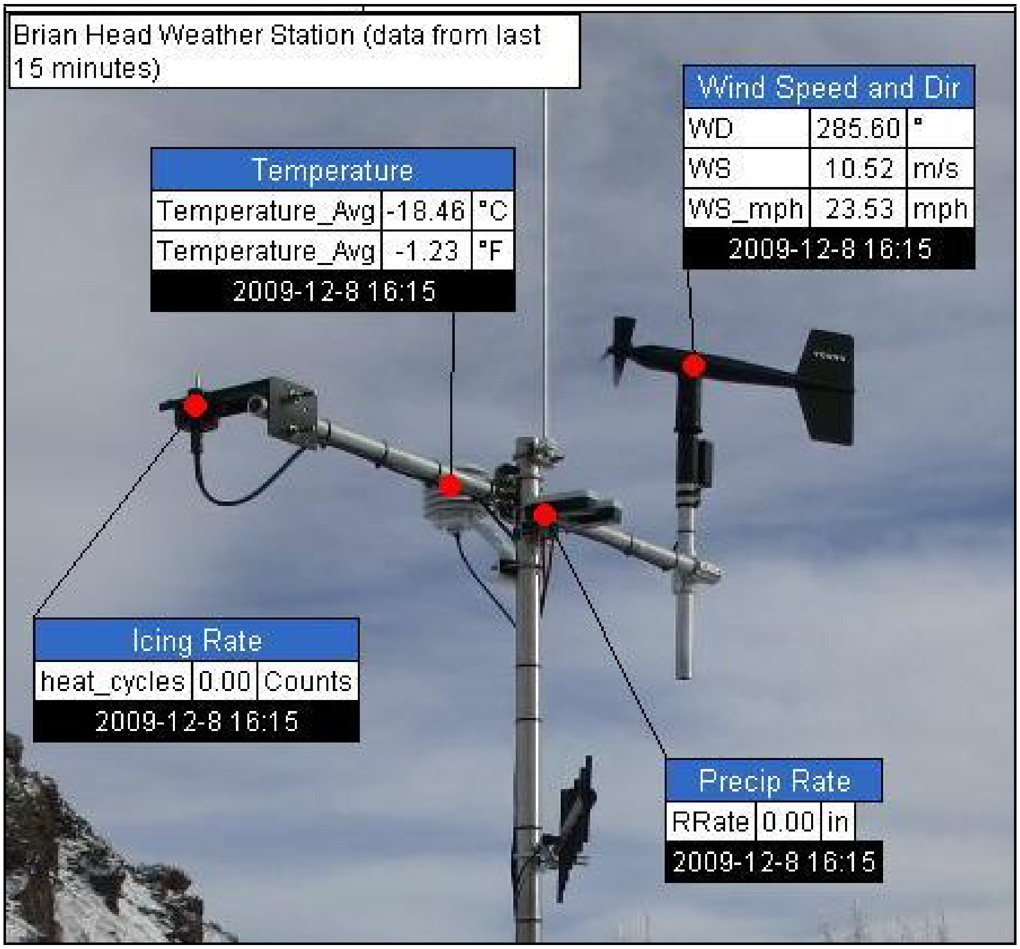

Figure 3.6 Close-up photo of the special instrument suite at Brian Head

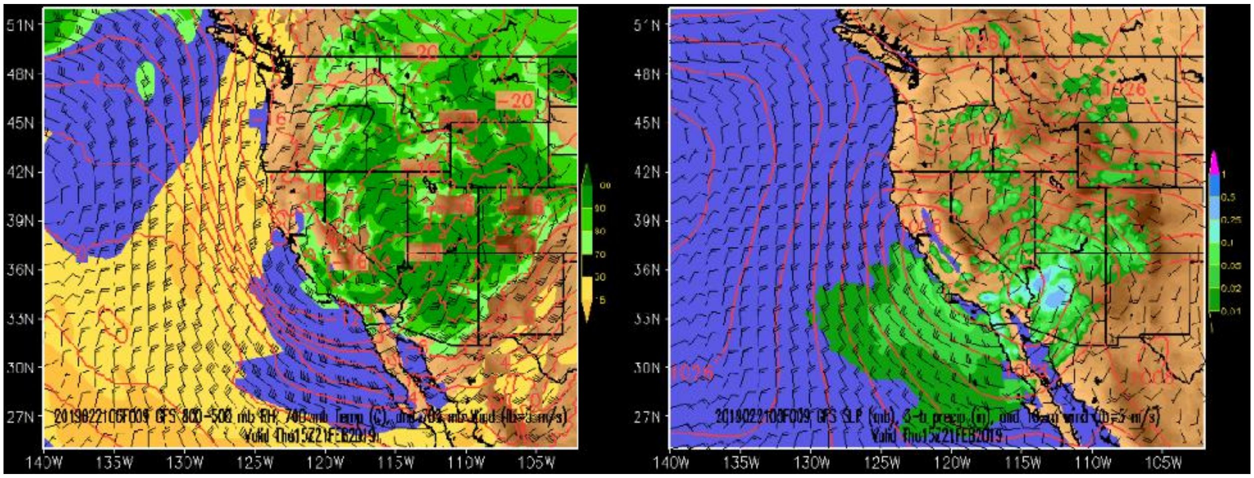

Figure 3.7 GFS model forecast during a storm event on February 21, 2019.

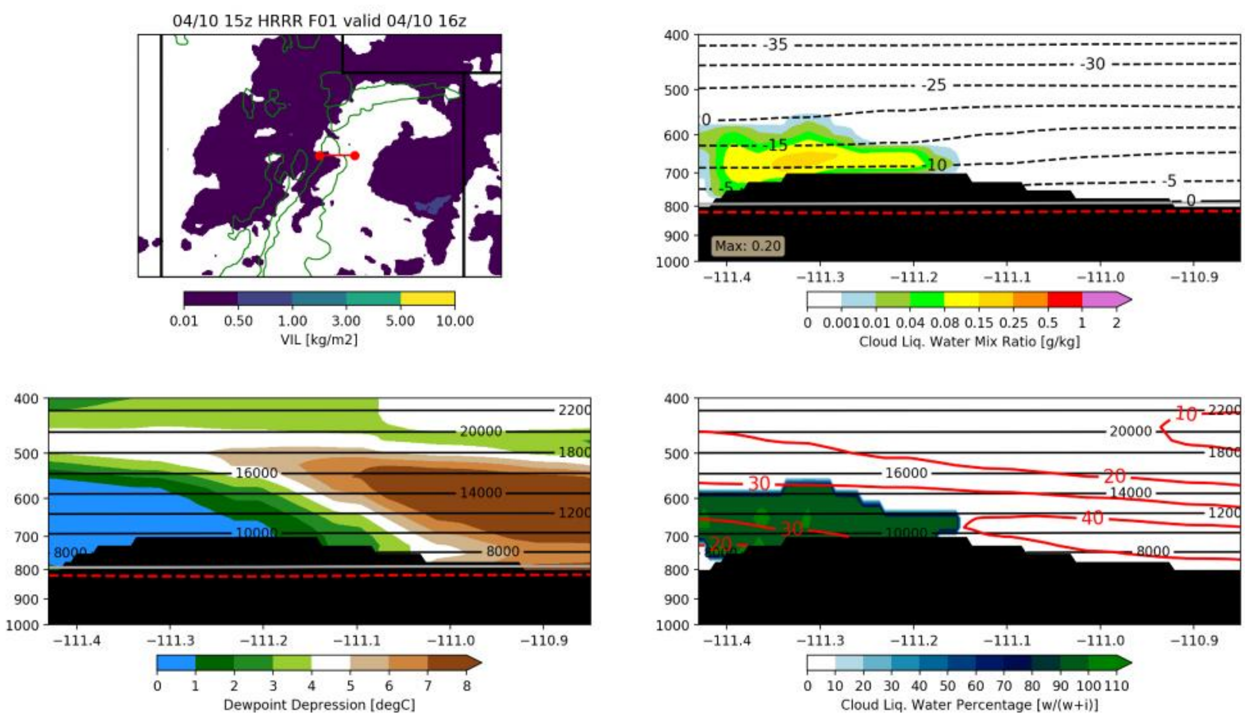

Figure 3.8 Data displays from the HRRR model: cross-section location and vertically integrated liquid (upper left); cross section of cloud liquid water and temperature (upper right); dew point depression, i.e. moisture saturation (lower left); and a plot of liquid vs. ice (lower right).

4.0 OPERATIONS

The core 2018-2019 cloud seeding program for central and southern Utah began on November 15, 2018 and ended on March 15, 2019. Time extensions, funded by the Lower Basin States, covered the periods of November 1-15, 2018 and March 16 – April 15, 2019 for the portions of the target area that potentially contribute runoff to the Colorado River. The seeding generators located in the central valley from approximately Milburn to Hatch were used in this program extension, as well as a few sites in the area near Koosharem, Antimony, and Loa, plus those in the vicinity of Brian Head and the Pine Valley Mountains. Seeding from the central valley sites would be expected to produce positive seeding effects on both the western and eastern slopes of the Wasatch Plateau. The eastern slopes of the Wasatch Plateau are tributary to the Colorado River. Seeding from these sites and those near Antimony would provide increases in precipitation on the western and eastern slopes of the Escalante Mountains (eastern slopes tributary to the Colorado River) and the Thousand Lakes and Boulder Mountains (also tributary to the Colorado River). Figure 4.1 provides a map of the sites available for seeding operations during the extension periods funded by the Lower Basin States.

A total of 22 storm events were seeded during the regular contract period, and 4 additional events were seeded during the spring extension period. There were no seeding opportunities during the November 1st-15th portion of the Lower Basin States extension. In all, there were three storm events seeded in November (including one which ended on December 1), seven additional events in December, four in January, four in February, six in March, and two in April. For the regular contract period, a cumulative 6,769.25 generator hours were utilized. For the Lower Basin extension, there was an additional 720.75 generator hours of seeding conducted. Figure 4.2 shows cumulative seeding hours for the core program this season. Table 4-1 shows the dates and number of CNG's used for each of the storm evens, and Table 4-2 shows usage for the individual CNG sites.

Beginning in early February, due to high snowpack accumulation at a number of SNOTEL sites in southern Utah, seeding suspensions were initiated that affected portions of the target area. Discussion with Utah Division of Water Resources about snowpack amounts on February 8 resulted in some limited seeding suspensions in portions of the southern Utah mountains. These suspensions pertained to the areas represented by the Gutz Peak, Long Flat, Harris Flat, and Agua Canyon SNOTEL sites. This portion of the program temporarily became active again during the latter part of February and beginning of March, but suspensions were then re-instated beginning on March 6 which included the Virgin River Basin and southernmost portions of the Upper Sevier River Basin. By March 11, snowpack in those areas averaged about 175% of the median values and the amounts in that area remained quite high, with suspensions remaining in place for the rest of the season.

Another seeding suspension was requested by DWR personnel on April 9, and affected a portion of southeastern Sanpete County that contributes runoff to Millsite Reservoir in western Emery County. This was due to construction at the reservoir. This latter suspension affected only the final two seeded periods of the season during the April 9-11 time frame.

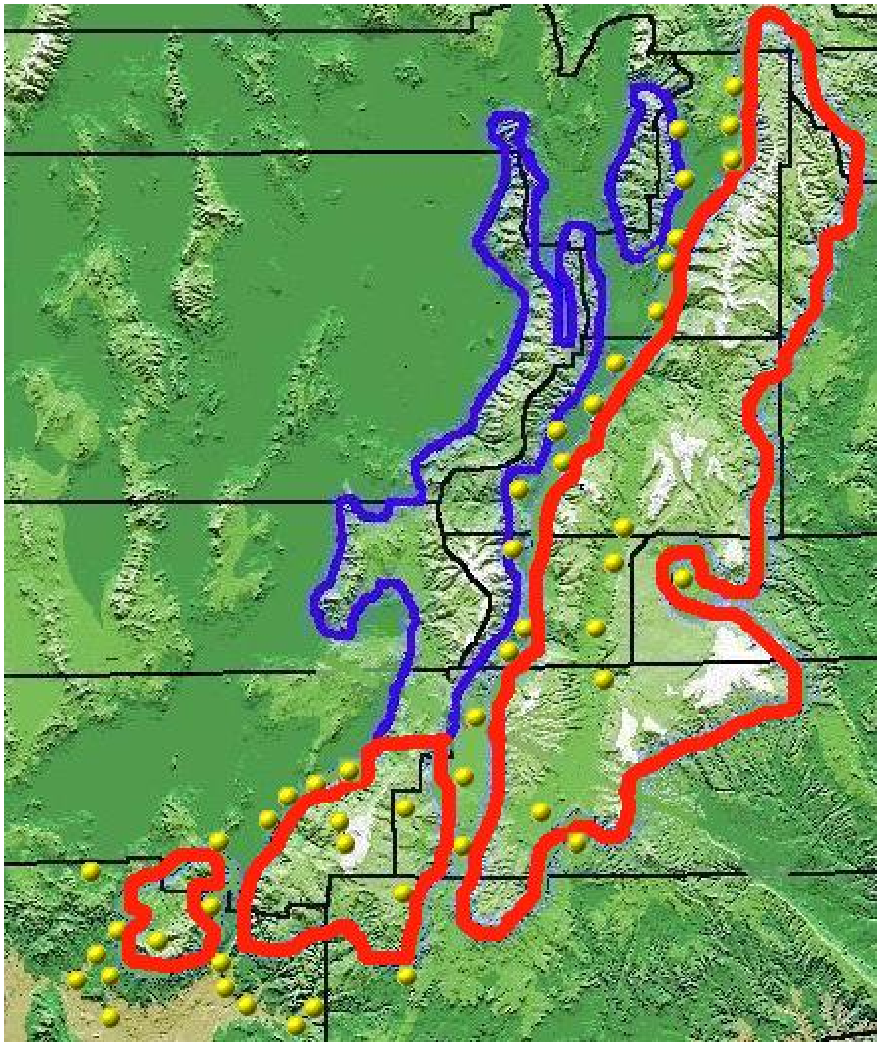

Figure 4.1 **Lower Basin extension areas (outlined in red), and generator sites (yellow dots) available for use during the extension periods of November 1-15, 2018 and March 16-April 15, 2019.**

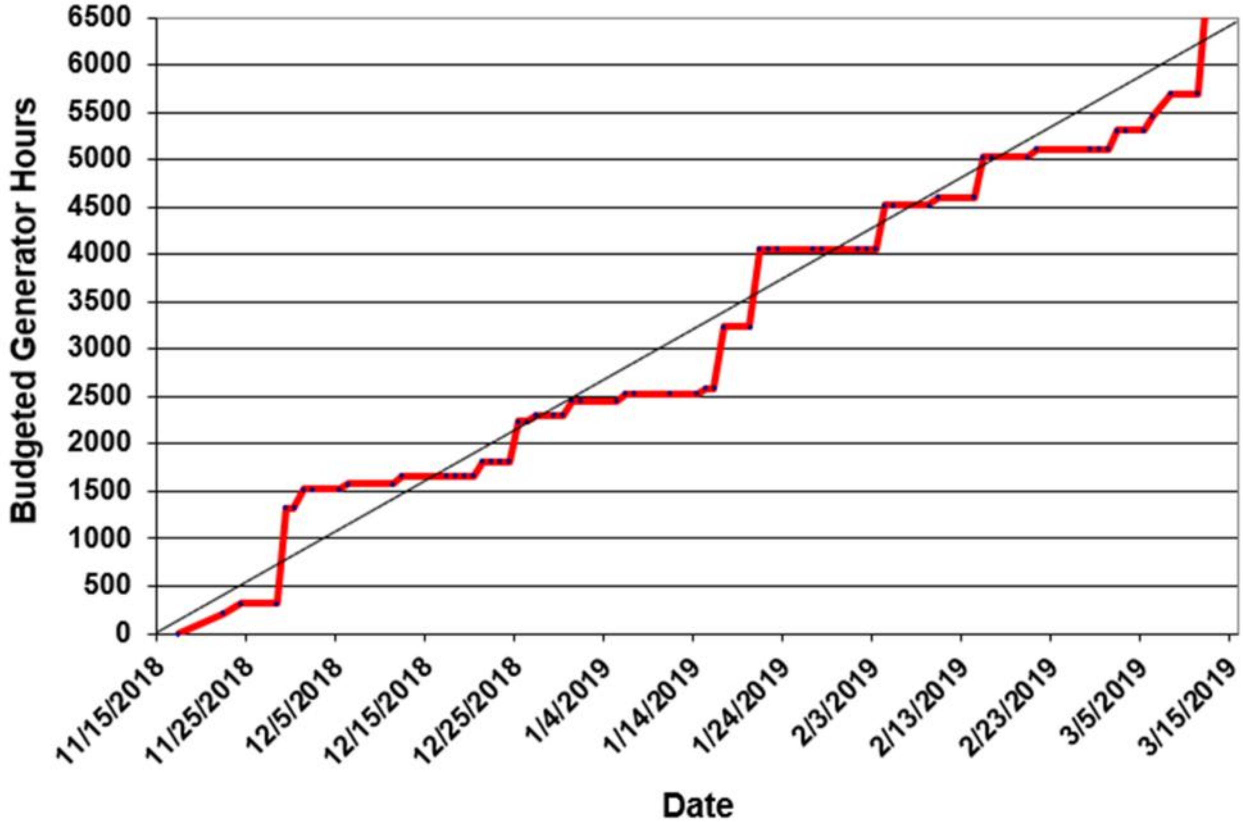

Figure 4.2 Cumulative and budgeted seeding hours for the southern/central Utah core program during the 2018-2019 season. Red line shows actual usage this season, while the black diagonal line depicts a linear usage of budgeted hours.

Table 4-1
Storm dates and generator usage, 2018-2019 season

Storm No.	Date(s)	Number of CNG Sites	Number of Generator Hours		
			Primary Contract	Lower Basin Extension	Total Hours
1	November 22	32	216		216
2	November 24	22	101.5		101.5
3	November 29 –	51	1003.75		1003.75
4	December 1-2	19	196.5		196.5
5	December 6-7	3	59.25		59.25
6	December 12	16	81.75		81.75
7	December 21-22	14	155.75		155.75
8	December 25-26	29	425.5		425.5
9	December 27-28	4	62		62
10	December 30-31	11	149.5		149.5
11	January 6	9	75		75
12	January 15-16	4	57.75		57.75
13	January 17-18	41	636.75		636.75
14	January 21-22	56	816.5		816.5
15	February 4-6	19	456		456
16	February 10	19	89.75		89.75
17	February 15-16	37	423.5		423.5
18	February 21-22	7	85		85
19	March 2-4	12	192		192
20	March 6-7	19	156.75		156.75
21	March 8	23	231.5		231.5
22	March 12-14	39	1,074.75		1,074.75
23	March 21	4		25*	25
24	March 28-29	18		251.25*	251.25
25	April 9-11	13		395.75*	395.75
26	April 11	8		48.75*	48.75
Total Hours			6769.25	720.75	7490

* Seeding funded by the Lower Basin States

Table 4-2a
Generator Hours – Central and Southern Utah, 2018-2019
Storms 1-9

Storm	1	2	3	4	5	6	7	8	9
Dates	**Nov 22**	**Nov 24**	**Nov 29 – Dec 1**	**Dec 1-2**	**Dec 6-7**	**Dec 12**	**Dec 21-22**	**Dec 25-26**	**Dec 27-28**
SITES									
10-1						3.75			
10-2		3.25	8.5	3.75		4	13	18.5	
10-3			7.75						
10-4									
10-6		5	9.5			4	13	18.5	
10-7									
10-8									
10-9	6	4							
10-10	6	5.75	8.25	3.75		4	12.75	18.5	
10-11	8	4				4	12.75	18.25	
10-12	6								
11-1	7.5	5	17.75			9.5	10.5	16.5	
11-2		5						16.25	
11-3	6.5	4.5	9				10.5	17	
11-4	8	4.75	9.5				10.5	17	
11-5									
13-1		4.5	7.75				10	16.75	
13-2		0	24						
13-3	7.5	5.5	19.25			6.25	10.5	17	
13-4	7.5	5.5	18.5			6.25			
13-5	7	5.5	18.75			6.5	10.5	17	
13-6	3	0	34.5			3.5	11.25	11.25	
13-7	9	4.5	25.5				10		
13-8	9	4.5	34.5			6	10		
13-10	7.5	5.5	25.25			6.25			
13-11	8	4.5	13					16	
13-12	7		20			6.25		16.75	
14-1	9	4.5						14.25	

Storm	1	2	3	4	5	6	7	8	9
Dates	Nov 22	Nov 24	Nov 29 – Dec 1	Dec 1-2	Dec 6-7	Dec 12	Dec 21-22	Dec 25-26	Dec 27-28
SITES									
14-2		4.5	8.5					14.25	
14-3								14.25	
14-4	9		8.5						
14-5	6	3.5	19	5				13.25	
14-6	6	3.25	5	7.5				13.25	
14-7			22.75						
17-1	6		34.75	7.5					
17-2	6		34	7.5					
17-3	6		25.75	7.5		4			
17-4	6.5		25	7.25		3.25			
17-5	6		34.5	6.5					
17-6			34						
17-7	7		17	21					
17-8									
17-9	6		34	21					
17-10	6		34	7.25					
18-2		4.5	34.5			4.25	10.5	16.25	
21-1			12						
21-2			13.25	11.5					
21-4									
21-5			15.5						
21-7			12						
21-8				12.75					
21-9			4	9					
21-10	6		24.25						14
21-11			17.25	11.75				2.5	
21-12									
21-13			15.75					4.75	
21-17			3						
22-1			19.75					7.5	
22-2			16.25					7.5	

Storm	1	2	3	4	5	6	7	8	9
Dates	Nov 22	Nov 24	Nov 29 – Dec 1	Dec 1-2	Dec 6-7	Dec 12	Dec 21-22	Dec 25-26	Dec 27-28
SITES									
22-3	6		24.25						
22-4			23.25						
22-5	6		25	11.75	19.75			22	16
22-7			23						
22-8	5		31.25	15.75	19.75			23.5	16.25
22-9			26.5	18.5	19.75			22.5	15.75
22-10									
22-11									
22-14									
22-15			15					6	
22-16								8.5	
Storm Total	**216**	**101.5**	**1003.75**	**196.5**	**59.25**	**81.75**	**155.75**	**425.5**	**62**

Table 4-2b
Generator Hours – Central and Southern Utah, 2018-2019
Storms 10-18

Storm	10	11	12	13	14	15	16	17	18
Dates	Dec 30-31	Jan 6	Jan 15-16	Jan 17-18	Jan 21-22	Feb 4-6	Feb 10	Feb 15-16	Feb 21-22
SITES									
10-1	17			16.75	5				
10-2	17			17.75	5		4.25		
10-3				17.75	4.75		4.25	14.5	
10-4							5		
10-6	17			16.5	5		5	14.25	
10-7				17	5.25			14	
10-8							5.5		
10-9				15					
10-10	17			16.75	5.5		4.25	14	
10-11	17				4.75		5	14	
10-12				18.5			5		
11-1				16.25	19.75			2	
11-2					20.5				
11-3					20.5				
11-4					20.5			12	
11-5								13	
13-1					20			10	
13-2					19.75				
13-3		8		15.5	20	17.75		12	
13-4				16.25	20.25			12	
13-5				20	0	17.75		12	
13-6				15	20.75		5.5	9.5	
13-7				16	20.75			12	
13-8				16.25	20.5			13	
13-10		8.75		15.5	19	17.75		12	
13-11				15	20.75		4.5	12	
13-12				16.25	20.25			12	
14-1				13.5	23.75				

Storm	10	11	12	13	14	15	16	17	18
Dates	**Dec 30-31**	**Jan 6**	**Jan 15-16**	**Jan 17-18**	**Jan 21-22**	**Feb 4-6**	**Feb 10**	**Feb 15-16**	**Feb 21-22**
SITES									
14-2				16.5	13.25	21		11.5	
14-3		9		14.5	13	21		10	
14-4				13.75	10	21		12.5	
14-5		8		12	24	21	2	11.5	
14-6				15.5	13		3	11.5	
14-7				14.75	24				
17-1	12.5							11.75	
17-2					23.5		5	12.25	
17-3	11	9		15	22		5.5	11.75	
17-4	12.5	9		15.25	20.5		5.5	2.5	
17-5	12	7.75		15	18.75		5.5	11.75	
17-6				15	17.5	17.5	4.5		
17-7				14	24.75	16		13	2
17-8					0				16.5
17-9				14.75	24.75	18.5		12.75	
17-10				16	18.75	16.5	5.5		
18-2				16			5	12	
21-1	12				5			10.5	
21-2						25			
21-4									
21-5					6.5				
21-7									
21-8				14.75	9.25			10	
21-9					8.75			10	
21-10					24			11.5	16.75
21-11					9.25	29.5			
21-12					5				
21-13					6.5	38.5			
21-17	4.5			13.75	12				
22-1				14	8.25				10
22-2		8.5	15		6.5	16.5			9

Storm	10	11	12	13	14	15	16	17	18
Dates	**Dec 30-31**	**Jan 6**	**Jan 15-16**	**Jan 17-18**	**Jan 21-22**	**Feb 4-6**	**Feb 10**	**Feb 15-16**	**Feb 21-22**
SITES									
22-3				13.75	10.5				14
22-4								10	
22-5		7	11	14.5	11.5	43.5			
22-7				14.75	12.25			12.5	16.75
22-8			16.75	17.75	21.75	13.75			
22-9			15	15	24	44.75			
22-10					4.75				
22-11				16.75	9				
22-14					5				
22-15					5.25	38.75			
22-16					6.25				
Storm Total	**149.5**	**75**	**57.75**	**654.5**	**821.25**	**456**	**89.75**	**423.5**	**85**

Table 4-2c
Generator Hours – Central and Southern Utah, 2018-2019
Storms 19-26

Storm	19	20	21	22	23*	24*	25*	26*	Site Total
Dates	Mar 2-4	Mar 6-7	Mar 8	Mar 12-14	Mar 21	Mar 28-29	Apr 9-11	Apr 11	
SITES									
10-1				20					62.5
10-2				34					129
10-3		17.5	7						73.5
10-4		12.25		19.5					36.75
10-6			7.75	20					135.5
10-7				26					62.25
10-8		15.25	7.75	12					40.5
10-9				32					57
10-10		4.5	7.25	16					144.25
10-11			7.75	20					115.5
10-12		15.5	7.75	15					67.75
11-1		7		30.75		22	32		196.5
11-2				35					76.75
11-3				33					101
11-4		6		36					124.25
11-5		7.75	9.75	18		22.5	31.75	6	108.75
13-1		5.5							74.5
13-2				35					78.75
13-3			9.75	36.25		23.5	31.5	6	246.25
13-4		6.5		36.75		22.5			152
13-5		6.75	9.75			22.5	31.5	6	191.5
13-6			11.75	18.5		14	13.25		171.75
13-7		6		34.75					138.5
13-8		6.5	11.75	34.75					166.75
13-10		7	9.75	35		10		6	185.25
13-11		6.25	11.75	34.75		9			155.5
13-12		8.25		37		22.5		6	172.25
14-1			11.75						76.75

Storm	19	20	21	22	23*	24*	25*	26*	Site Total
Dates	**Mar 2-4**	**Mar 6-7**	**Mar 8**	**Mar 12-14**	**Mar 21**	**Mar 28-29**	**Apr 9-11**	**Apr 11**	
SITES									
14-2		5.75	11.75	15					122
14-3		5.75	11.75	20					119.25
14-4				30					104.75
14-5									125.25
14-6			11.75	33					122.75
14-7			11.75	24					97.25
17-1	8.25			14.75					95.5
17-2	8.25			16	3.25	9	32		156.75
17-3				32.5		9	32	6.5	197.5
17-4			9.5	34		10.75	32.25	5.75	199.5
17-5			9.5	33		9	32	6.5	207.75
17-6			11.25	35	9	9	31.5		184.25
17-7			11.5	15		9	32		182.25
17-8				34.75					51.25
17-9	8		11.5	33	9.5	9	32		234.75
17-10	8			34.75		9	32		187.75
18-2		6.75				9			118.75
21-1	17.75								57.25
21-2									49.75
21-4									0
21-5									22
21-7									12
21-8									46.75
21-9									31.75
21-10	17.75								114.25
21-11									70.25
21-12									5
21-13									65.5
21-17									33.25
22-1	17.75								77.25
22-2									79.25

Storm	19	20	21	22	23*	24*	25*	26*	Site Total
Dates	Mar 2-4	Mar 6-7	Mar 8	Mar 12-14	Mar 21	Mar 28-29	Apr 9-11	Apr 11	
SITES									
22-3	26.25								94.75
22-4									33.25
22-5									188
22-7	26.25				3.25				108.75
22-8	18.75								200.25
22-9	17.5								219.25
22-10									4.75
22-11	17.5								43.25
22-14									5
22-15									5.25
22-16									66
Storm Total	192	156.75	231.5	1074.75	25	251.25	395.75	48.75	

* Seeding funded through lower basin extension

As of April 1, 2019, SNOTEL observations showed much above normal values area-wide, generally ranging from about 135-190% of the normal (median) SWE values. Water year precipitation (percent of mean) values generally ranged from about 130-150%. These are summarized in Table 4-3.

Table 4-3
Snowpack and Precipitation Percentages on April 1, 2019

River Basin	No. of Reporting Stations	Snow Water % of Median	Water Year Precip % of Mean
Tooele County	4	149%	130%
Price - San Rafael	11	144%	132%
Beaver River	2	136%	149%
Upper Sevier River	17	161%	134%
Southwestern Utah	13	189%	138%

Figure 4.3 provides the percent of median values of April 1 snow water content for Utah. Figures 4.4 – 4.6 show the seasonal snow water content and cumulative water year precipitation and normals at Mammoth-Cottonwood in central Utah, Webster Flat in southwest Utah, and Mining Fork in Tooele County (all NRCS SNOTEL sites).

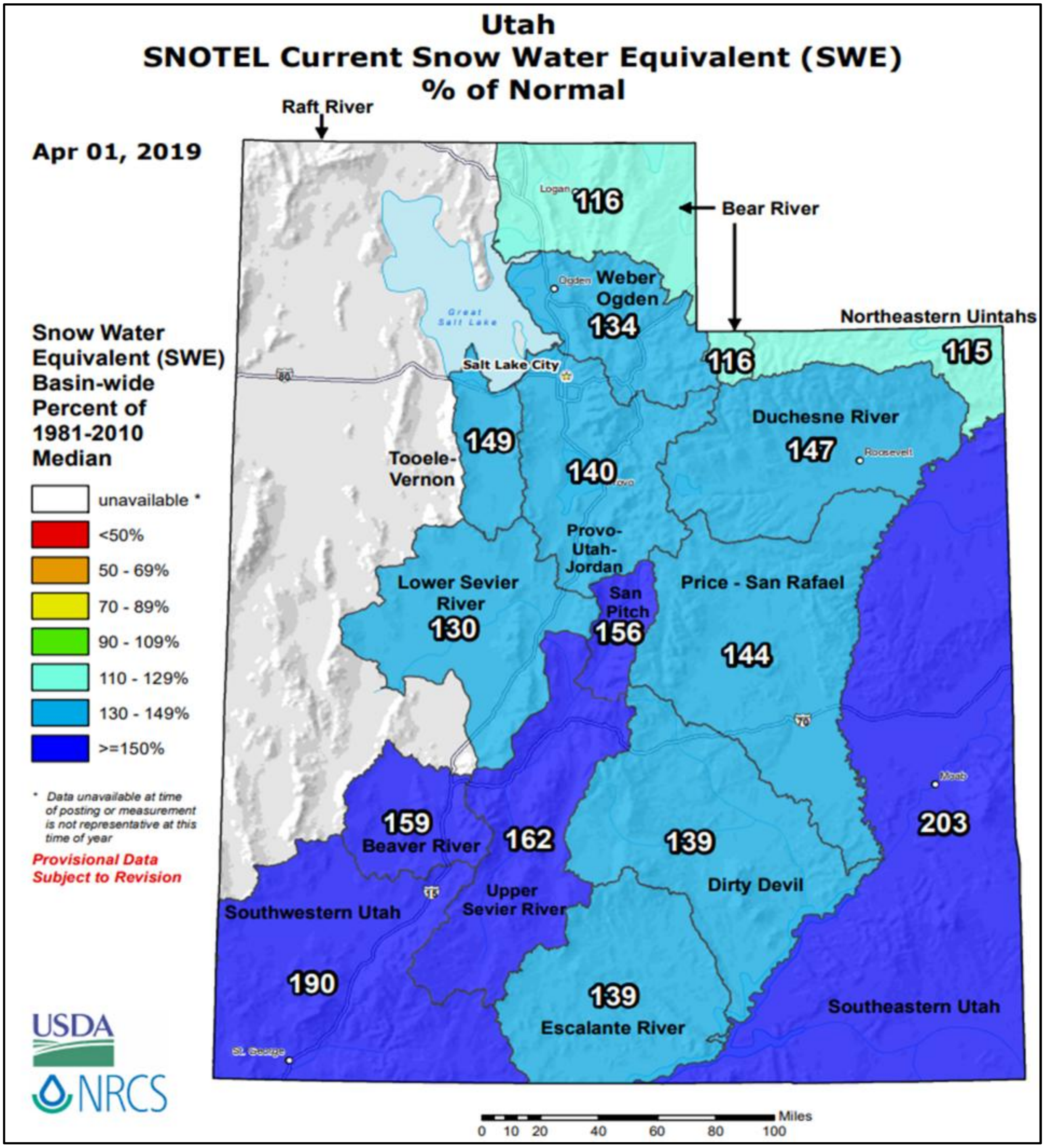

Figure 4.3 Snow water content in Utah on April 1, 2019 (percent of median)

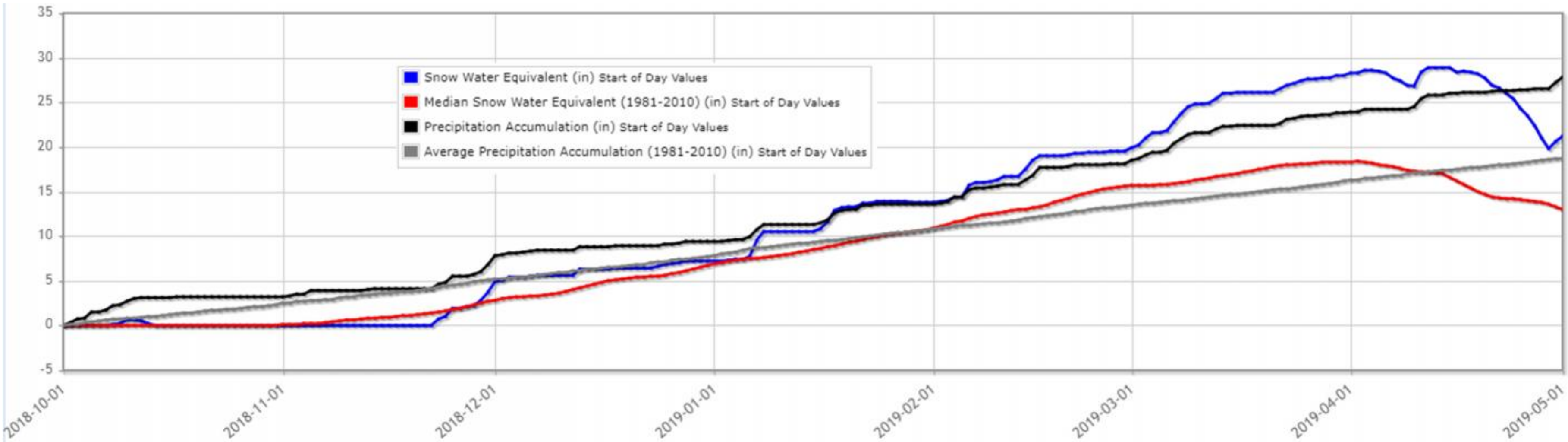

Figure 4.4 **NRCS SNOTEL snow and precipitation plot for October 1, 2018 through May 1, 2019 for Mammoth-Cottonwood, UT (in Sanpete County). Smoothed lines are the corresponding normals for the period.**

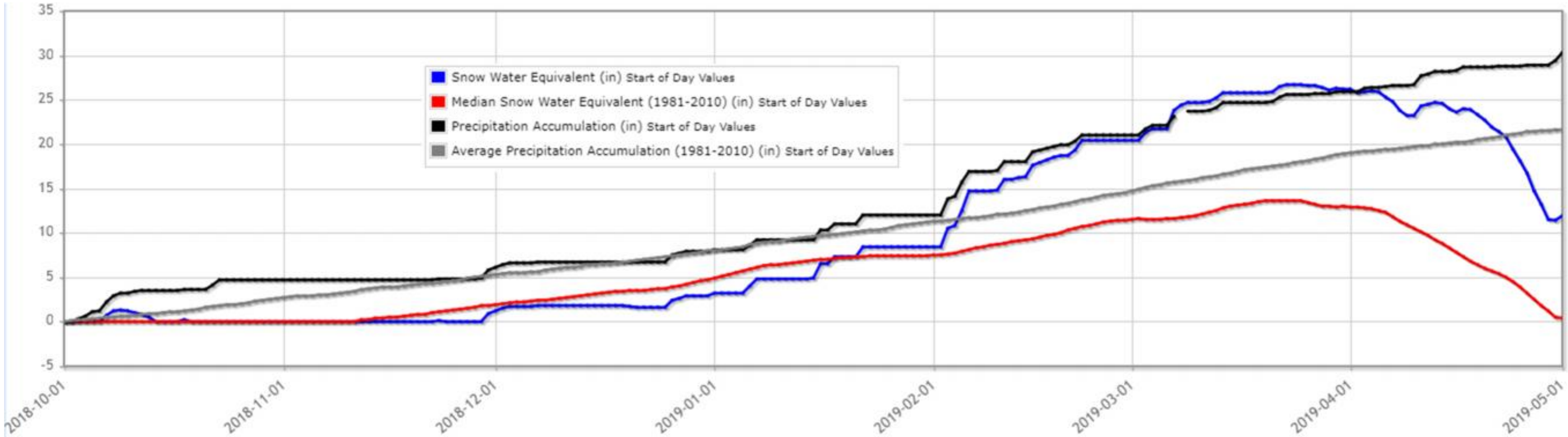

Figure 4.5 NRCS SNOTEL snow and precipitation plot for October 1, 2018 through May 1, 2019 for Webster Flat, UT (in the Virgin River Basin near Brian Head).

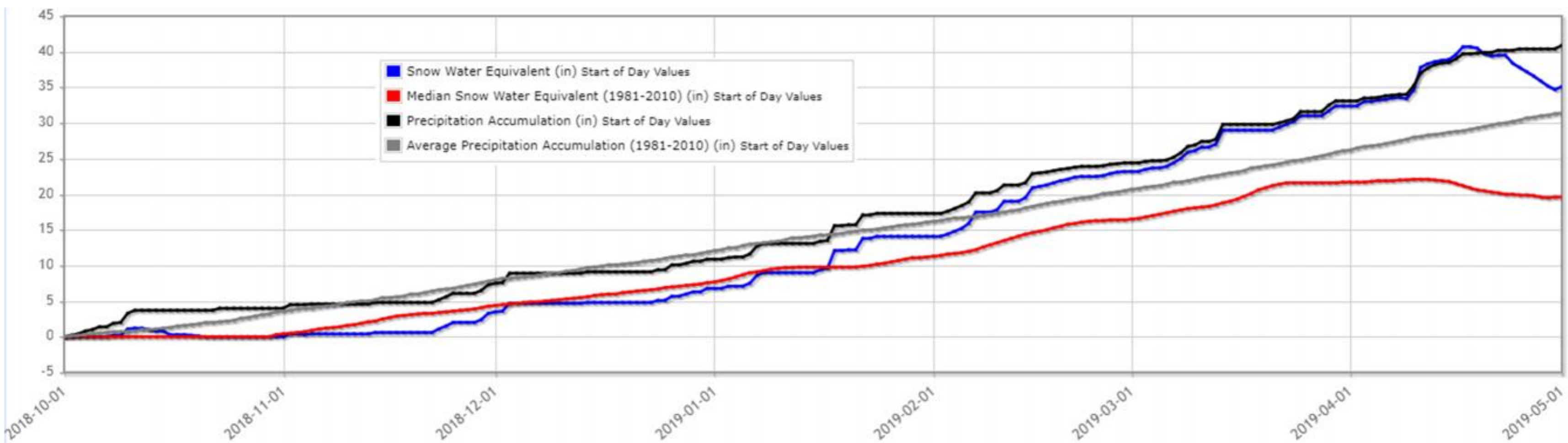

Figure 4.6 NRCS SNOTEL snow and precipitation plot for October 1, 2018 through May 1, 2019 for Rocky Basin Settlement, UT (in Tooele County).

Figures 4.7 through 4.12 show regional monthly precipitation, as a percentage of normal, for the months of November through April.

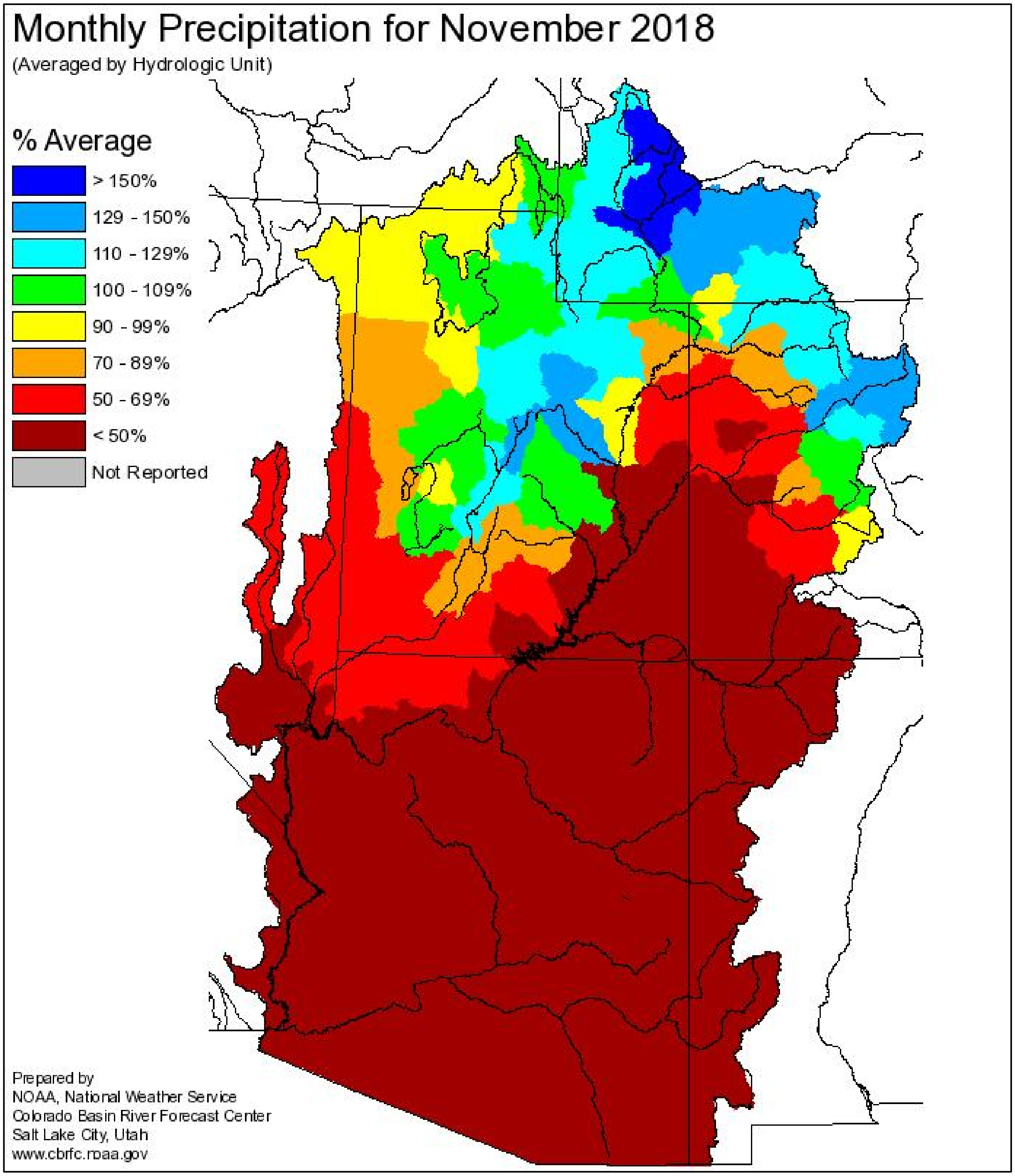

Figure 4.7 November 2018 precipitation, percent of normal

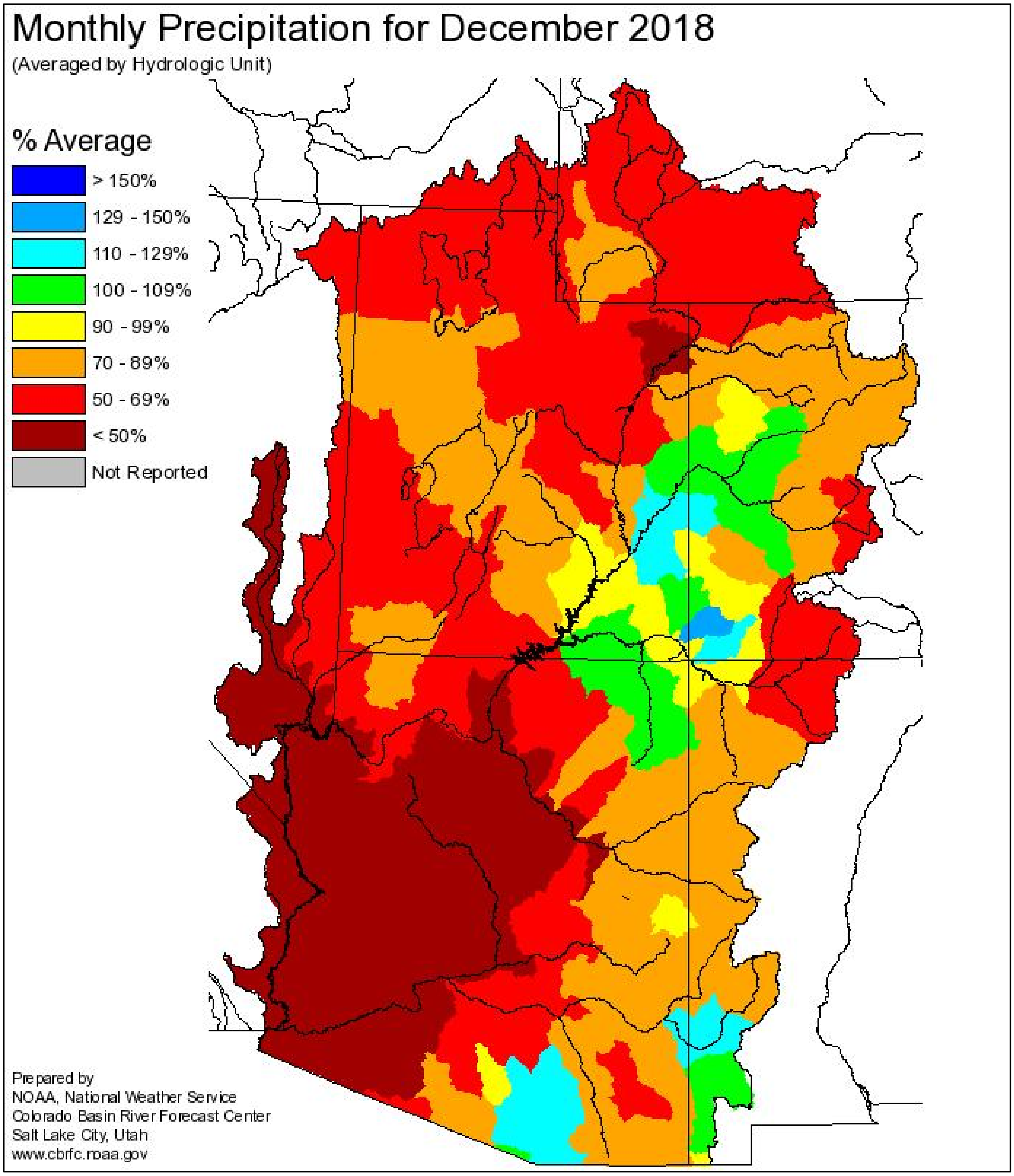

Figure 4.8 December 2018 precipitation, percent of normal

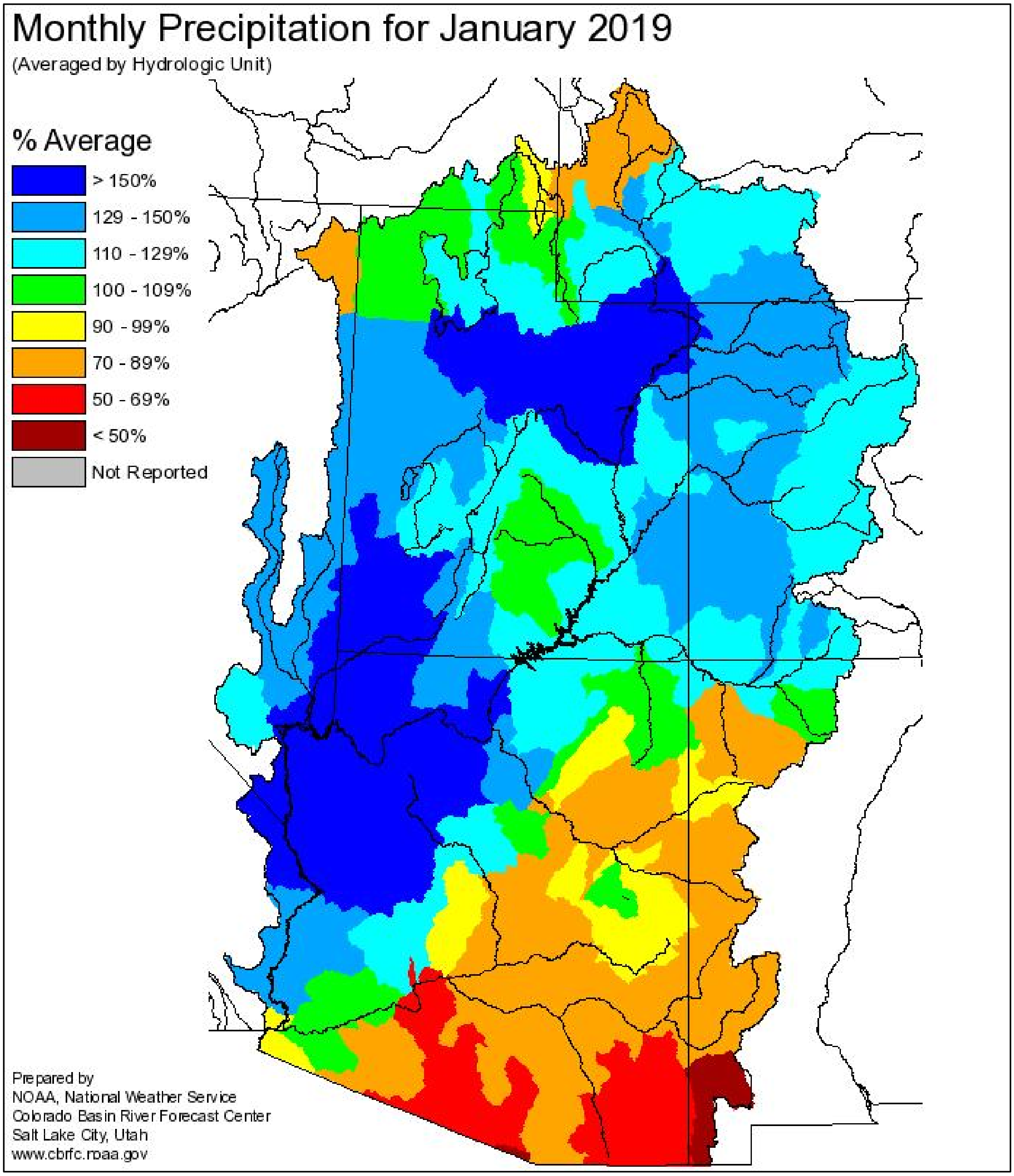

Figure 4.9 January 2019 precipitation, percent of normal

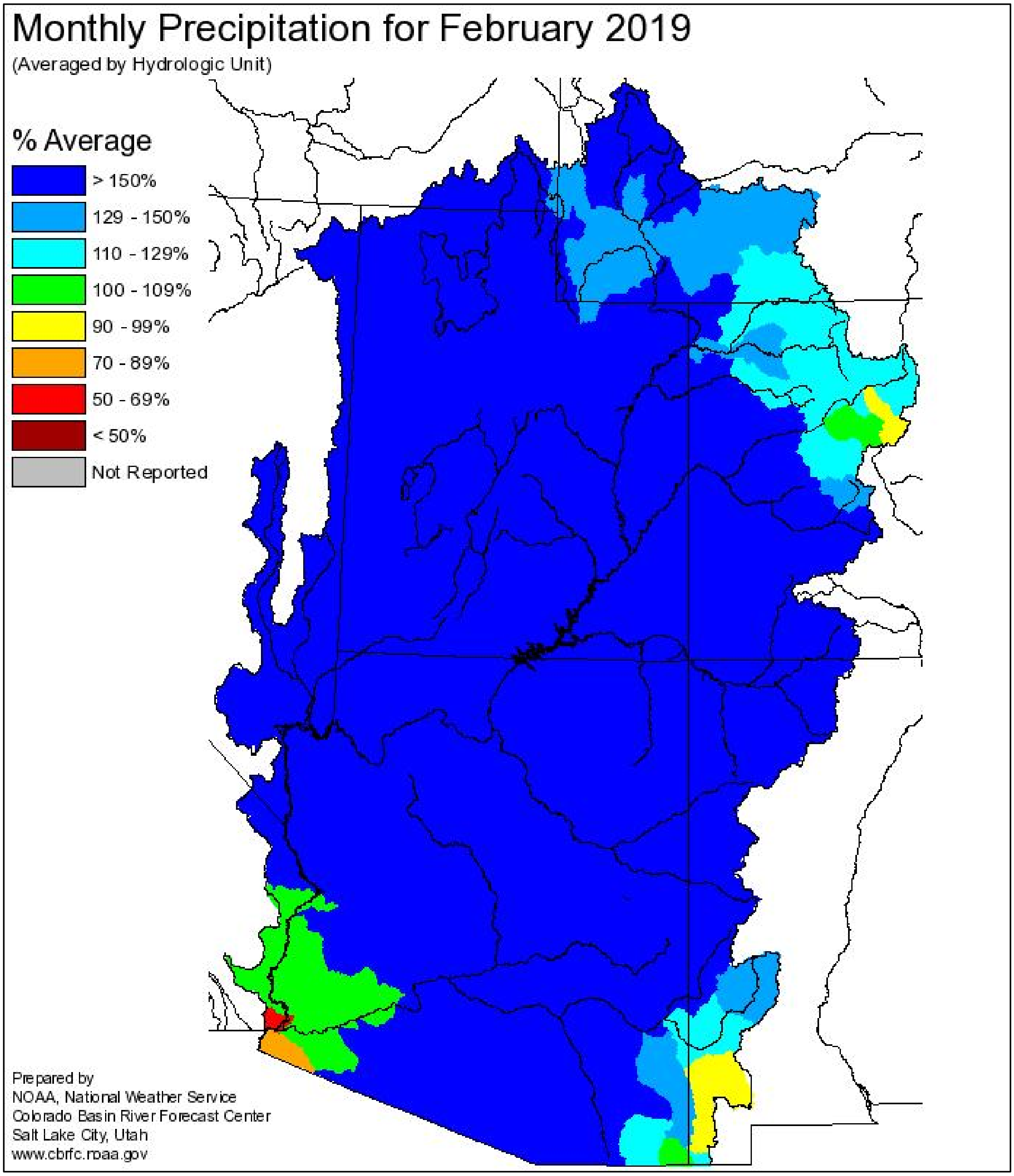

Figure 4.10 February 2019 precipitation, percent of normal

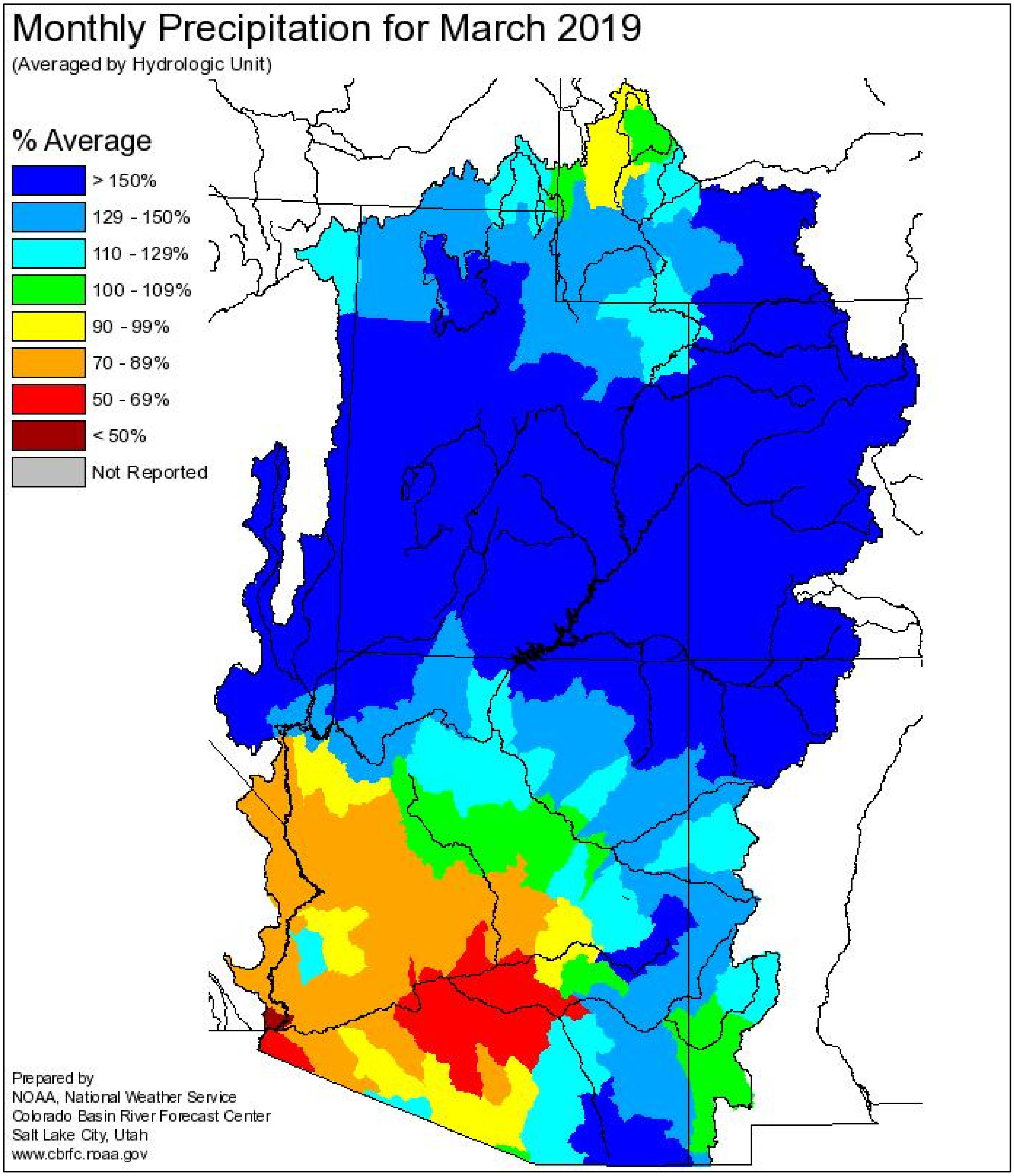

Figure 4.11 March 2019 precipitation, percent of normal

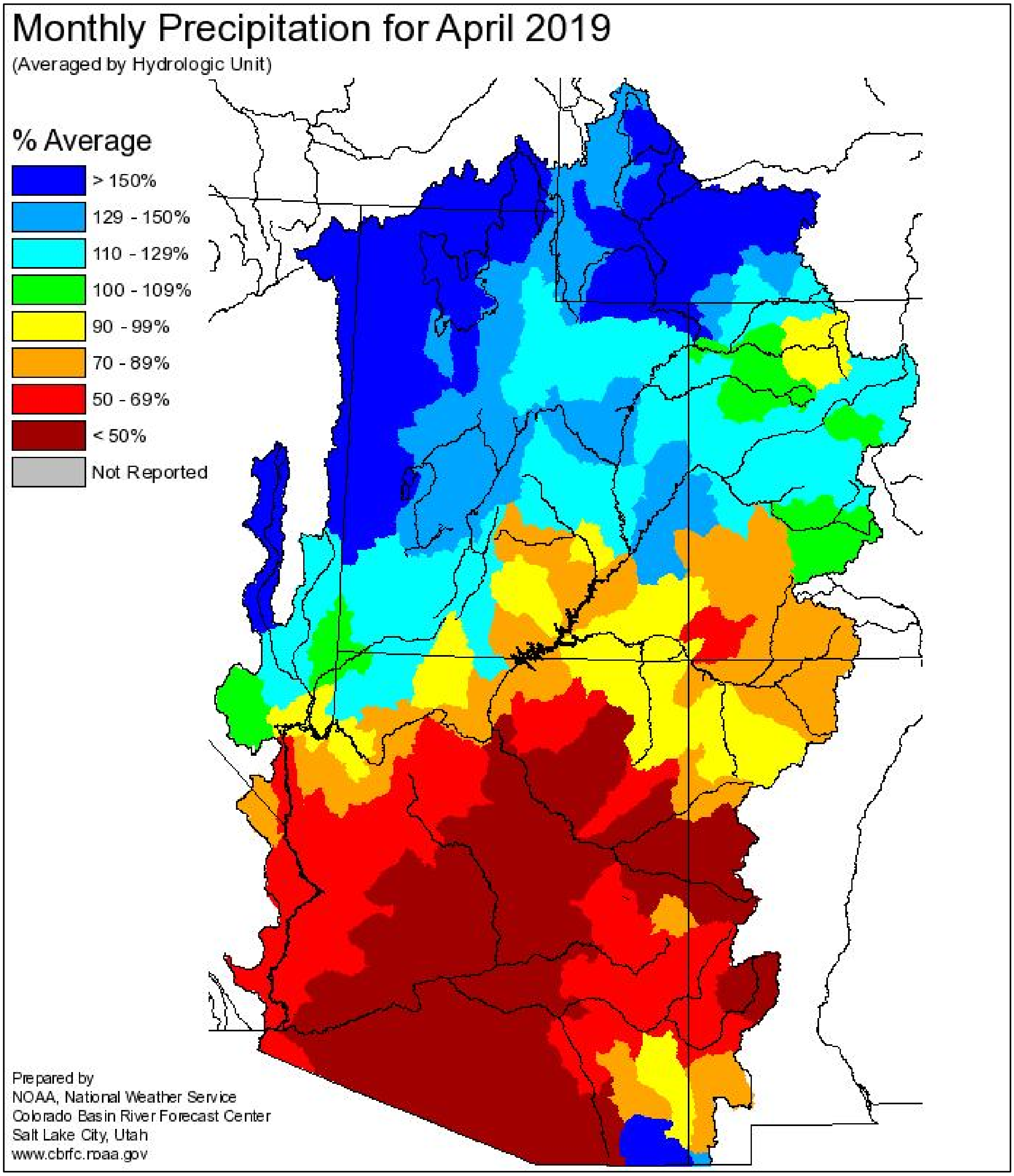

Figure 4.12 April 2019 precipitation, percent of normal

4.1 Operational Procedures

In operational practice, an approaching storm was monitored at the NAWC operations center in Sandy with the aid of continually updated online weather information. Outside typical business hours, NAWC's meteorologists monitored the weather information using computer systems at their residences. If the storm parameters met the seedability criteria presented in Table 2-1 of section 2.0 and no seeding curtailments or suspensions were in effect, an appropriate array of seeding generators was ignited and adjusted as conditions required. Seeding continued as long as conditions were favorable and precipitating clouds remained over the target areas. In a normal sequence of events, certain generators would be used in the early period of the storm passage, some of which might be turned off as the wind directions at various levels of the atmosphere changed, while others were used later to target the area in response to the evolving wind pattern. Some generator sites, due to their location, were used in a wider variety of wind flow situations than others and were thus used more often.

4.2 Operational Summary

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

November 2018

The program became operational on November 1st for portions of the target area that are included in the Lower Basin Extension area, and on November 15th for the remainder of the target area. There were three seeded storm events in November (which includes an event that ended on December 1), although none of these seeding opportunities occurred during the early season extension period. The early and middle portions of November were essentially dry, with the first seeding opportunity occurring on November 22.

A storm event on November 22 brought precipitation to much of Tooele County and central Utah with lighter totals in the south. Temperatures were too warming for seeding initially, but cooled into the -6 to -7° C range at 700 mb by the afternoon. Seeding was conducted in a westerly wind pattern through the afternoon and evening hours, ending late in the evening as precipitation was generally expected to end overnight. Precipitation totals from this event exceeded a half inch of water equivalent in portions of Tooele County and central Utah target areas, tapering off sharply to between about 0.1" in the southern mountains. There was a significant amount of icing at the Skyline site with about a dozen cycles during the late afternoon and evening of November 22. A period of heavy icing was also observed somewhat earlier (during the midday to early afternoon hours) at Brian Head.

A fast-moving cold front on November 24 affected primarily Tooele County and portions of central Utah from the morning into the early afternoon hours. The front mostly dissipated over central Utah by the afternoon with conditions remaining dry further south. Seeding was conducted for several hours in association with the frontal passage. Precipitation totals again averaged around a half inch or so for Tooele County and central Utah, with generally dry conditions further south. Seeding ended by later in the afternoon with clearing skies. Skyline recorded a period of icing during the morning hours in association with this cold front, with a brief period of heavy icing later (during the afternoon) at Brian Head.

An excellent and fairly extended seeding opportunity occurred with a November 29-30 storm event. Temperatures were warm initially, but widespread seeding was initiated on the evening of the 29th in southwesterly flow with 700-mb temps cooling below -5° C. A good deal of icing activity was observed at both Brian Head and Skyline on the 29th and continued overnight at Brian Head. Winds become westerly to northwesterly on the 30th with very good low-mid level moisture and continued cold advection, which led to extensive convective activity with widespread showers and some thundershowers on November 30. Widespread seeding continued through the day, with orographic and convective clouds types that appeared excellent for seeding. With lingering moisture and still some cold advection overnight, seeding continued in some areas, ending early on December 1. Approximately 1,000 generator hours of seeding were conducted during this event, making it one of the most heavily seeded of the season.

Precipitation totals during this event were significant, with generally between about 1.5 – 3.0” of water equivalent measured at target area SNOTEL sites.

December 2018

December was a fairly average month overall in terms of precipitation, with the majority of the storm activity occurring around the last week of the month. There were seven seeded storm periods in December.

A precipitation event on December 1-2 brought only fair conditions initially, with seeding initiated on the night of December 1 at a few sites. This mostly consisted of light snowfall from a higher deck and 700-mb temperatures around -8 to -10° C. Conditions improved during the day on December 2 and seeding operations were somewhat more widespread. The main dynamics of this system as well as the best seeding opportunity was in roughly the southern half of the state. Several single icing cycles were observed at Brian Head with this event. Most of the target areas received between about 0.5 – 1.0” of water equivalent, including Tooele County where some limited seeding was conducted. The Tooele County activity included a lake effect band over the Oquirrh mountains during the afternoon and evening hours of December 2.

A trough of low pressure near southern California affected mainly southern Utah on December 6-7, producing a marginal seeding event. Conditions were generally warm (around -5° C at 700 mb) and stable in the lower levels, but a few high elevation sites in the Brian Head area were utilized. There were some icing cycles noted at Brian Head. Precipitation amounts were light, generally under a quarter inch.

A frontal passage on December 12 affected mainly Tooele County and central Utah as a trough moved from the Pacific Northwest into the northern/central Rockies. Valley inversions were present initially but were mixed out with the frontal passage, as the 700-mb temperature fell from near -1° C early to around -13° C by the afternoon. Seeding was conducted for several hours in Tooele County and central portions of Utah. Precipitation amounts of about a quarter to half inch were observed at SNOTEL sites in these areas. There was one icing cycle at Skyline and very brief period of more significant icing at Brian Head with the frontal passage.

A frontal passage affected mainly northern/central Utah on the night of December 21-22, with seeding conducted in Tooele County and central portions of the state. The 700-mb temperature dropped to around -10 to -12° C around Tooele County and near -8° C in central Utah following the frontal passage, but generally remained above -5° C with dry conditions in the south. Seeding was conducted on the evening of the 21st and overnight, ending early on the 22nd. SNOTEL data indicated minimal precipitation amounts during this period. There were two icing cycle observed at Skyline during the night, around the time of the frontal passage. Some additional light precipitation occurred the following day (December 23) but was not favorable for seeding operations.

A strong system brought widespread snowfall to the area on December 25-26, with good conditions for seeding operations developing later in the day on the 25th and continuing into the 26th in some areas. The 700-mb temperature generally ranged between about -5 to -10° C, with winds shifting from southerly on the 25th to northwesterly on the 26th. Icing was noted at both sites overnight, with moderate to heavy icing (2-3 cycles per 15-minute period) during a couple of time periods at Brian Head. Several inches of snowfall were reported in many areas, with indications of mostly around a half inch to locally an inch of water equivalent at SNOTEL sites.

A cold trough of low pressure dropped southward through the Great Basin on December 27, with limited moisture and a generally high, icy cloud decks producing some light snowfall over the state. Conditions appeared generally unfavorable for seeding, although some light icing was observed at Brian Head from late morning through the evening as winds become more northerly there. A few seeding sites were activated to affect the Brian Head area which appeared the most promising for liquid water development. Seeding continued at these few sites overnight, but ended early on the 28th as clouds appeared to be nearly all ice with the 700-mb temperature around -15° C statewide. Precipitation totals at SNOTEL sites were mostly around a quarter to under a half inch of water equivalent, but with some higher totals at a few sites.

A trough moved southeastward into Utah on December 30, with 700-mb temps mostly in the -7 to -8° C range in northwesterly flow. Seeding operations began during the day on the 30th and continued overnight, although were limited to areas that appeared to have the best orographics as precipitation appeared to be mainly from a higher cloud deck. There was one icing cycle at Skyline during the early evening on December 30, and icing was recorded on the morning of the 31st at Brian Head. Precipitation totals appeared quite variable but were mostly between about a quarter and half inch based on SNOTEL data.

January 2019

January brought above normal precipitation and snowfall to nearly the entire state, although the relative significant of various storm events in contributing to this total varied quite substantially between different portions of the target area. There were four seeded storm periods in January, the latter two of which were quite significant in terms of the amount of seeding operations conducted.

A significant subtropical moisture plume in southwesterly flow brought some significant precipitation and limited seeding opportunity to central and southern portions of the state on January 6. Winds were generally from the west to southwest with 700-mb temperatures cooling below -5° C during the daytime hours on the 6th. Seeding was conducted from sites considered more favorable for targeting. Skies began to clear around sunset and seeding ended at that time. There was intermittent icing observed at Skyline on January 6, and significant (occasionally heavy) icing observed at the Brian Head site. Precipitation amounts observed at SNOTEL sites were highly variable, ranging from less than a half inch at some sites to apparently as much as 2”+ at other sites (such as Mammoth-Cottonwood in central Utah).

A large trough off the California coast on January 15 became disorganized and weakened fairly dramatically as is moved inland across the southwestern U.S. However, it did bring significant precipitation to some areas (notable southwestern Utah) and marked the beginning of a series of significant storm events. Conditions over Utah were relatively warm/stable on the 15th , although some seeding operations were initiated from high elevation sites in southwestern Utah during the evening hours. Temperatures remained marginal, around -4 to -5° C at 700-mb through January 16 with areas of precipitation. Brian Head had heavy (up to 6 cycles in 15 minutes) icing overnight (Jan 15-16) for a long time period, and Skyline had a couple of icing cycles. Seeding in this event remained limited to the higher elevation sites in southwestern Utah due to temperature and stability conditions. Precipitation totals ranged up to over an inch of water equivalent in southwestern Utah with lighter amounts elsewhere.

A large trough was centered off the west coast on January 17, with a deep moisture plume in southwesterly flow over Utah. Windy conditions were the rule with significant precipitation and warm temperatures initially, although a cold frontal passage later in the day provided improving conditions for the start of operations. The 700-mb temperature cooled from about -3 to -4° C in association with the deep moisture plume to around -10° C by the morning of the 18th. Widespread seeding was conducted from the evening of the 17th until midday on the 18th, when skies began to clear in most areas. Brian Head and Skyline both recorded significant icing activity, mainly during the cold frontal passage. Precipitation totals with this storm event were fairly generous, mostly in the 1-2” range, with the higher totals favoring Tooele County and central Utah and amounts well under an inch in some southern and southeastern portions of the target area.

An upper level trough was centered over Nevada on the morning of January 21, with a cold front traversing Utah. 700-mb temperatures ranged from around -5° C ahead of the cold front to -10 to -12° C behind it. Seeding began along and just ahead of the front in western Utah on the morning of the 21st, as well in in lower elevations of southern Utah due to favorable wind patterns there. Seeding operations expanded eastward during the day, although ended in the far south due to a shift to northwesterly winds. Icing activity began around midday at Brian Head and picked up significantly with northwesterly winds later in the day. The storm continued eastward overnight but conditions remained favorable for seeding in portions of the state, with model forecasts showing orographic snowfall continuing in some areas through the morning of the 22nd. By morning, however, skies had apparently cleared in most areas with little in the way of any favorable orographic snowfall observed, and seeding operations were terminated. Tooele County received some of the greatest precipitation amounts in this event with almost 2” of water equivalent at Rocky Basin Settlement SNOTEL, and generally around an inch at most central and southern Utah SNOTEL sites.

February 2019

After a dry period in late January, a very active weather pattern resumed across the area during February. In fact, during about the first week of February, enough precipitation occurred in southwestern Utah to bring the SWE percentages from just above normal (median) values to above the suspension criteria at some sites. This resulted in intermittent suspensions of seeding in this area after February 8. There was a total of four seeded storm events in February.

A large, cold trough centered near the northern California coast on February 4 began to bring widespread rain/snow to Utah. Winds were from the southwest with temperatures initially well above -5° C in most of the state. However, on the night of February 4-5 conditions improved with gradual cooling as the core of the trough moved onshore in California and widespread precipitation continued moving into Utah. Seeding was conducted overnight primarily in southwestern Utah, with more widespread seeding initiated as conditions improved on February 5. The core of the trough moved from California into Nevada by late on the 5th, with cooling temperatures (falling to below -5° C at 700mb) across Utah. Seeding continued for much of the target area through the night of February 5-6, then ended early on the 6th as the -15° C 700-mb isotherm was making its way into western Utah and clouds appeared to be essentially all ice. This storm period brought fairly generous precipitation amounts, between 1-2" of water equivalent to most target area sites with some locally higher totals especially in southwestern Utah. There was some infrequent icing activity (5 cycles in all) at Skyline on February 5 through early on the 6th, and some sporadic single-cycle icing activity at Brian Head on February 5 as well.

A strong cold front moved across Utah on February 10, with seeding operations conducted for several hours in Tooele County and central Utah. Winds were strong in association with the front, and temperatures mostly between about -7 to -10° C at 700 mb. Much colder but drier air was associated with the trough core to the west which arrived on the night of the 10th. Seeding was not conducted in southwestern portions of Utah due to the suspension in place there. All seeding ended by late in the evening as temperatures dropped to below -15° C at 700 mb with snowfall ending overnight. Precipitation amounts with this storm event ranged from about 0.5 – 1.0" of water equivalent at most SNOTEL sites. Interestingly, there was some icing activity observed early on the following morning (February 11) which consisted of only one cycle at Skyline, and a brief period of very heavy icing (spiking up to 7 cycles per 15-minutes) in association with a very cold site temperature around -20° C at Brian Head.

A large plume of subtropical moisture impacted Utah on February 13-14, with strong southerly winds accompanied by significant precipitation totals in most mountain areas. Temperatures were too warm for seeding during this period, but most of the target areas received over an inch of water equivalent. This moisture plume was followed by a strong cold front during the afternoon/evening hours of the 15th, continuing into southern portions of the area overnight. The 700-mb temperature dropped to around -12° C following the frontal passage, and widespread seeding was conducted in west to northwest flow following the front. Discussion between NAWC and the Division of Water Resources resulted in all areas being active for seeding operations during the cold portion of this event. Seeding continued overnight and ended early on February 16 as skies had mostly cleared at that point. This event produced the most widespread seeding opportunity during February, and SNOTEL data indicated up to an additional half inch or so of water equivalent during the cold (seeded) portion of this extended storm period. There were periods of moderate to heavy icing activity at both icing sites during the warm portion of this storm period (February 13-14), and an additional period of very heavy icing activity at Brian Head during the colder (seeded) portion of the storm on the night of February 15-16.

A limited seeding opportunity occurred on February 21-22, with a very cold trough of low pressure over the southwestern U.S. Lower elevations of southern Utah (and even Las Vegas!) had snow accumulations ranging up to several inches, with 700-mb temperatures generally below -13° C across the area. Winds were generally from the east across Utah which limited targeting ability, and SLW appeared to be very limited although Brian Head recorded a couple of single icing cycles. Based on continuing discussion between NAWC and the Division of Water Resources, the seeding program remained active in all areas for this storm event. Seeding was conducted from several sites in the far south that appeared favorable for targeting in an easterly wind pattern, on February 21 and through the overnight hours. By the morning of the 22nd, skies were clearing and seeding operations were terminated. This storm event only had much significance in far southern Utah with around an inch of water equivalent in some areas (such as the Webster Flat SNOTEL) while most of the state was generally under about 0.2” or so.

March 2019

March was another active weather month, particularly the first half of March with well above normal precipitation and snowfall. The second half of the month was somewhat drier in many areas, although snowpack and water year precipitation totals remained well above the seasonal averages in nearly all areas. After a seeded storm event near the beginning of March followed by another significant subtropical moisture plume on March 6, seeding operations were again suspended for portions of southwestern Utah and this suspension essentially remained in place for the rest of the season. By March 11, snowpack in the suspended areas of the Virgin River watershed averaged about 175% of the long-term median values. There were six seeded storm periods for the program in March.

Some seeding was conducted during the March 2-4 period, with some moisture in a fairly zonal flow pattern across southern and central Utah. Temperatures were marginal during much of this period, being on the warm side, but some convective activity helped to overcome this issue and seeding was conducted for much of southern (and some portions of central) Utah. Seeding operations remained active in southern Utah for this storm period. Skyline had some intermittent icing activity on the morning and the evening of March 2. Brian Head observed very heavy icing from mid afternoon through much of the evening on March 2 (peaking at 8 cycles per 15- minute period), with another period of heavy icing during the late afternoon and evening of March 3. Neither of these icing periods at Brian Head appeared to be associated with precipitation occurrence at the site. Precipitation totals in central and southern portions of the state ranged generally from about 0.5 – 1.0” during the March 2-4 time period.

A fairly concentrated plume of subtropical moisture affected the state on March 6, with 700-mb temperatures between about 0 and -3° C. This was too warm for seeding operations, and suspensions remained in portions of southwestern Utah due to high runoff and snowpack in that area. However, some cooling on the night of March 6-7 allowed for seeding operations in Tooele County and portions of central Utah as 700-mb temperatures cooled to around -5° C. The main long-wave trough remained to the north and west of Utah, amplifying over Nevada and bringing a more widespread seeding opportunity to these same areas on March 8 with a stronger cold frontal passage. Some fairly strong convective activity developed on the afternoon of March 8 with thundersnow (snow with thunder) reported over portions of Tooele County. By late in the day on the 8th, skies began to clear and seeding operations ended. Skyline recorded intermittent icing in the warm sector and also several icing cycles with the cold frontal passage on March 8. At Brian Head, there was sporadic icing early in the warm sector period, and then several periods of moderate to heavy icing during gradually cooling temperatures from the evening of March 7 through the 8th (with the site temperature cooling to -10° C by late on the 8th). Precipitation totals during the March 6-8 period ranged from about 1.5 – 3.0” in most of the target areas, with the totals fairly evenly divided among these three days at most SNOTEL sites.

Two systems merged over the western U.S. during the March 12-13 period, one initially over Arizona and the Four Corners region with a much colder system from the Pacific Northwest moving into Utah. These systems merged over Utah and Colorado, producing a very deep low center just east of the Rocky Mountains. In Utah, the 700-mb temperature fell to as cold as -15° C at times but remained mostly above this, with strong north to northwest winds developing as the deep low center developed to the east. A seeding suspension was in place for southern portions of the target area, but widespread seeding was conducted for an extended time period in Tooele County and in central Utah, resulting in highest total amount of seeding of any storm event this season (over 1,000 hours). Seeding began in most of these areas on the evening of March 12 and continued through March 13 and again overnight, as conditions appeared quite good with significant orographic and convective type clouds apparent on the afternoon/evening of the 13th. This included some lake effect activity that affected Tooele County. Skyline had limited icing activity, with one cycle recorded each night (March 12-13 and 13-14). At Brian Head there was some moderate to heavy icing activity, mostly on the evening and night of March 12-13 although the seeding program was suspended in that area. Snowfall slowly ended through the morning hours of March 14, but snowfall (and seeding) continued in some areas until late morning. Precipitation totals ranged between about 1-2" in most of the target area with this event, with some localized totals as high as 3" and portions of southern Utah received under an inch. This was the last seeded event for the core program, with the remainder of operations being conducted for the Lower Basin Extension areas. Seeding remained suspended in southwestern Utah, however, for the remainder of the season.

A limited seeding opportunity occurred on March 21, as a weak trough brought some light showers to portions of the target area. Both temperatures and winds were marginal during this time period, and only a few seeding sites were utilized during the daytime and early evening hours. About a quarter to half inch of precipitation was measured at SNOTEL sites. Although no icing was observed at Skyline, there was again a heavy period of icing at Brian Head during the late afternoon and early evening hours (the seeding program was not active in the Brian Head area at this point).

A frontal boundary produced some fairly strong convective activity over western Utah on the afternoon/evening of March 28, and seeding operations were initiated in portions of central Utah in the evening that pertain to the Lower Basin extension. Precipitation and seeding continued overnight in central Utah with the 700-mb temperature dropping to around -6° C behind the front. Snow showers continued through the day on March 29 in northern portion of central Utah, with significant icing noted at the Skyline site on the night/morning of March 28-29 up to about 0700 MST (icing cycles occurring regularly about an hour apart). Sanpete County was particularly favored for snow shower activity that lasted through the day on March 29, seeding finally ending during the evening hours. Precipitation totals of around a quarter to half inch were indicated at SNOTEL sites.

April 2019

The weather pattern remained somewhat active for the remainder of the Lower Basin seeding extension period during the first half of April. A significant storm event during the April 9-11 period brought substantial snowfall to the area, and this was the only seeded period during April. Seeding remained suspended for the Virgin River and far southern portions of the Upper

Sevier basins in southern Utah. In addition, a suspension for portions of southeastern Sanpete County that affected the Millsite Reservoir was added on April 9 due to a construction project, which reduced the amount of seeding that was conducted during the April 9-11 storm period.

A prolonged storm period with moderately cold temperatures and strong northwesterly winds resulted in some excellent seeding opportunity for portions of the extension area in central Utah on April 9-11. Seeding began on the evening of the 9th following a frontal passage, with strong northwesterly to northerly winds resulting in a strong orographic precipitation through April 10 and much of April 11. There was also intermittent convective activity during this time period, and Skyline observed regular icing activity (with roughly one cycler per hour) on the night of April 10-11. Although seeding was terminated briefly on the morning of April 11, it was re-initiated in some areas during the midday to afternoon hours due to the re-development of convective snow showers. The 700-mb temperature ranged from about -6 to -8° C in central Utah during most of the seeded storm period. Most of the central Utah mountains where seeding operations took place had storm totals in the 2-3” range of water equivalent based on SNOTEL data. Seeding operations ended on the evening of April 11, and this was the final seeded event of the season.

5.0 ASSESSMENTS OF SEEDING EFFECTS

5.1 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 percent for individual seasons, and in the range of 5-15 percent for the long-term average. This section of the report summarizes statistical evaluations of the effects of the cloud seeding on the precipitation and snowpack within the higher elevations of this program's targeted areas. When expressed as percentages, the increases may not initially appear to be particularly high. However, when considering that these increases are area-wide averages covering thousands of square miles, the volume of the increased runoff is impressive.

NAWC has used a commonly employed evaluation technique since this seeding project was first evaluated following the 1978 water year. This technique, referred to as the "target and control comparison", is based on evaluating the effects of seeding on a variable that would be affected by seeding (such as precipitation or snow). Records of the variable to be evaluated are acquired for an historical (unseeded) period of sufficient duration (20 years or more if possible). These records are partitioned into those that lie within the designated seeded "target area" of the project and those in a nearby "control area". Ideally the control area consists of sites well-correlated with the target area sites, but which would be unaffected by the seeding. All the historical data, e.g., 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 actually occurred.

This target and control technique works well where a good statistical correlation can be found between the target and control area variables. Generally, the closer the control sites are to the seeding target area, the higher the correlation will be. Control sites which are too close to the target area, however, can be subject to contamination by the seeding activities. This can 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 percent 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.

5.2 Evaluation Approach

Precipitation data used in the analyses were obtained from the Natural Resources Conservation Service (NRCS) and/or from the National Climatic Data Center, and represent the official published records of those organizations. Snowpack water content, also known as snow water equivalent (SWE), records were obtained from the NRCS as well. The SWE records were used in a snowpack analysis, separate from the precipitation analysis but using many of the same measurement sites. The current winter season NRCS data are considered provisional as of the time of this report.

Historically, Utah has had snowpack measurements taken at (usually) monthly intervals for many years and, unlike many other states, precipitation measurements from storage gages were also available from some of these same high elevation sites. Consequently, both precipitation and snow course (water equivalent) measurements are available for a period of more than 30 years from a number of sites in Utah and surrounding states.

As with the precipitation storage gage and SNOTEL precipitation gage network, the state of Utah also has an excellent snow course and SNOTEL snow pillow reporting system. In many cases, the same reporting stations are available for snow water measurements as for high-elevation precipitation measurements. Consequently, it was deemed worthwhile to examine the snow water content measurements to compare with the precipitation analyses, at collocated sites and others.

April 1 snowpack readings are hydrologically strategic and have generally been accepted for use in seeding project evaluations in mountainous regions, since at high elevation sites they frequently represent the maximum snow accumulation for the winter season. Most streamflow and reservoir storage forecasts are made on the basis of 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). Also, 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 (e.g., in this case, prior to November 15th). 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 than if only the seeded period was evaluated.

Most of the snowpack data used in this analysis are from sites that were originally snow course sites and became SNOTEL sites after approximately 1980. The data set that was utilized in some prior season evaluations contained both snow course and SNOTEL data for these sites. However, it was recognized that this could present a problem because of potential differences between the snow course and SNOTEL measurement techniques. The NRCS has recognized and addressed the potential problem of discrepancies in the data set due to varying measurement techniques. Their solution was to obtain concurrent data at the newly established SNOTEL sites using both (collocated) measurement techniques for an overlap period of approximately 10 years in duration. They then developed correlations between the two types of measurements and applied a site-specific correction factor at each site that converted the previous monthly snow course measurements to estimated values as if the SNOTEL measurements had been available at these sites. The NRCS also attempted to correct the timing problem in these estimates to reflect first of the month values. In other words, if an historical year had a measurement taken on the 25th of January instead of the first of February, the NRCS used adjacent precipitation data to estimate the snow water content on the first of February. The resulting estimated data at some sites were very similar to the original snow course data, while differences of 10-15% were found at some of the sites. After careful consideration, NAWC decided to use the NRCS adjusted data in place of the mixture of manual snow course and SNOTEL measurements. We believe that using these NRCS estimates (rather than the previously used snow course data) can help to at least partially adjust for any inherent systematic bias between data obtained using the manual snow course and SNOTEL measurement systems, although some question exists regarding how well the mathematical adjustments at some sites really do work. In similar fashion, NAWC used NRCS-adjusted precipitation from high elevation storage gages that had been acquired manually before the advent of SNOTEL.

Most of the target and control sites used by NAWC in the evaluation of precipitation or snowpack have remained the same for a significant period of time. Consequently, these evaluations can be considered *a priori* (from before) in nature. Some minor changes have occurred of necessity when a precipitation or snowpack observing site is discontinued. These changes have had only a minor effect on the regression equations and their results.

5.3 Precipitation Evaluations – NAWC Target/Control Method

In past years several target areas have been evaluated to assess the efficacy of cloud seeding, by examining the precipitation observed at the gages within the seeded targets. For the current water year, two target areas (see Figure 1.1) were again evaluated. An attempt has been made to consistently utilize the same groups of target and control sites from one season to the next, although there have been a few changes over the years as some sites were discontinued. The following describes the techniques that were used in selection of the target and control sites.

5.3.1 Precipitation Target Sites

The northernmost seeded target in the Central/Southern program is the East Tooele Target (ETT). That area contains the mountain watersheds of the Stansbury and Oquirrh Mountains, located in the eastern portions of Tooele County, south of the Great Salt Lake. Due to the scarcity of available target sites, this target group also includes a valley-level precipitation gage (Tooele, just over 5,000 feet MSL), as well as a site (Vernon Creek) somewhat south of the official target areas. The locations of the three remaining precipitation gages that were used in the evaluation for this target are listed in the target area portion of Appendix C and shown in Figure 5.1. The three target SNOTEL gages are located in the Stansbury and Oquirrh Mountain ranges. The average elevation of the target gages is 7,157 feet, MSL. Additional high elevation sites in the Stansbury and Oquirrh Mountain Ranges would be desirable in order to provide a more accurate evaluation of seeding effects in these target areas.

The Primary Target area is represented by 25 precipitation gage sites. A few of the target site gages are NWS cooperative observer sites, but the large majority consists of SNOTEL storage gages. These sites are shown in Figure 5.2. The sites are located throughout the target area and should provide a representative data set for the evaluation. The average elevation for the target gage array is about 8,800 feet MSL.

5.3.2 Precipitation Control Areas

The control site array for the precipitation evaluation of the Eastern Tooele Target seeding operation was the same group of control sites used in recent seasons' evaluations. The control group consists of six gage sites, listed in Appendix C and shown in Figure 5.1. Four sites are located in eastern Nevada and two in northern Utah.

The precipitation evaluation control sites used for the Primary Target (PT) area evaluation are located in eastern Nevada and north central Arizona (bracketing the PT area on the northwest and southeast). The locations of these sites are shown in Figure 5.2.

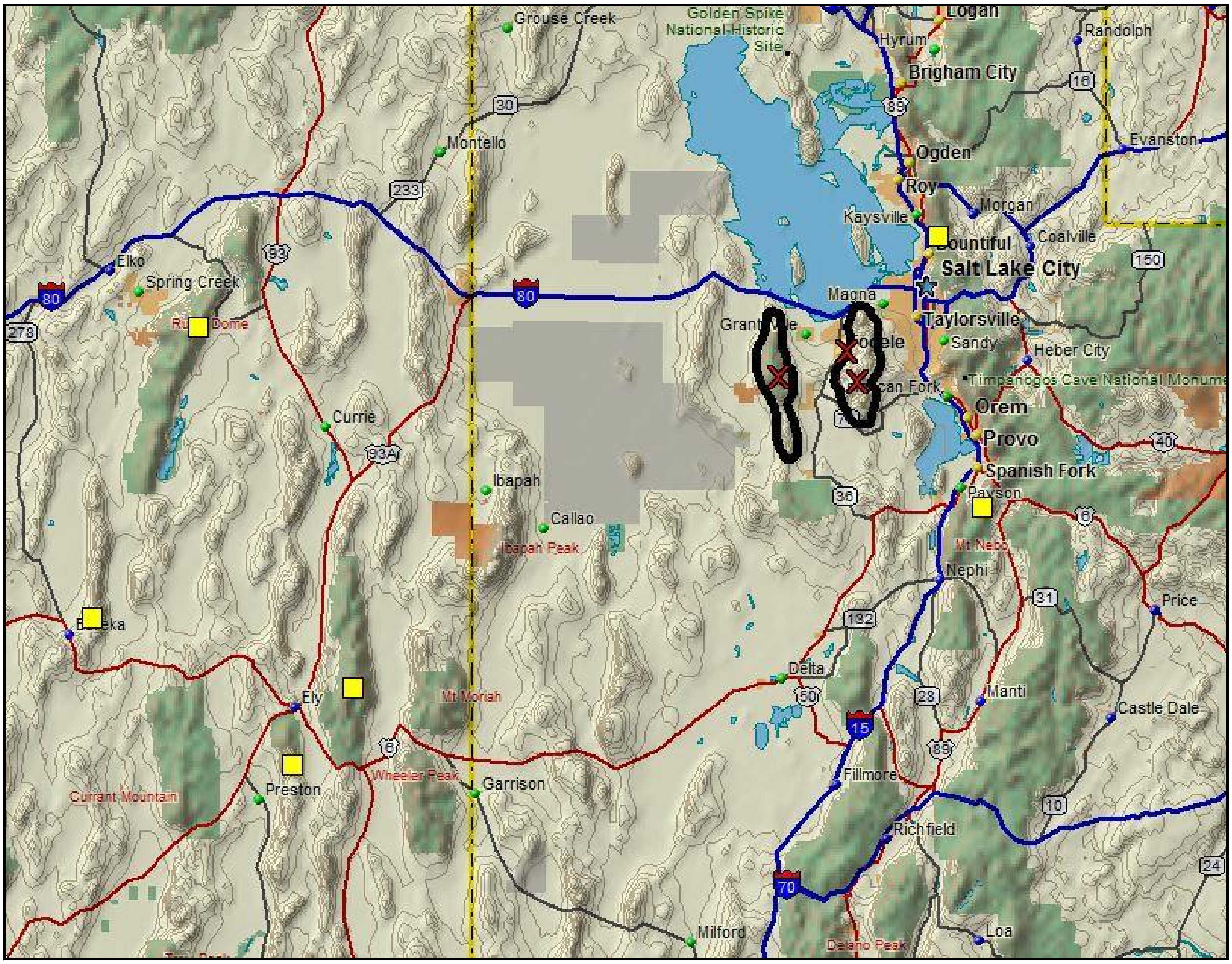

Figure 5.1 Precipitation sites for Eastern Tooele target/control evaluation; control sites are depicted as squares and target sites with an X

These sites have remained the same for a significant number of years, except for a few minor changes during the last few years, involving elimination or replacement of some valley co-op sites due to missing data or poor data quality. The remaining control group should be representative of storm systems that move across the target from northwest, west or southwesterly directions. The majority of the sites in the control area are NRCS SNOTEL gages at mountain locations.

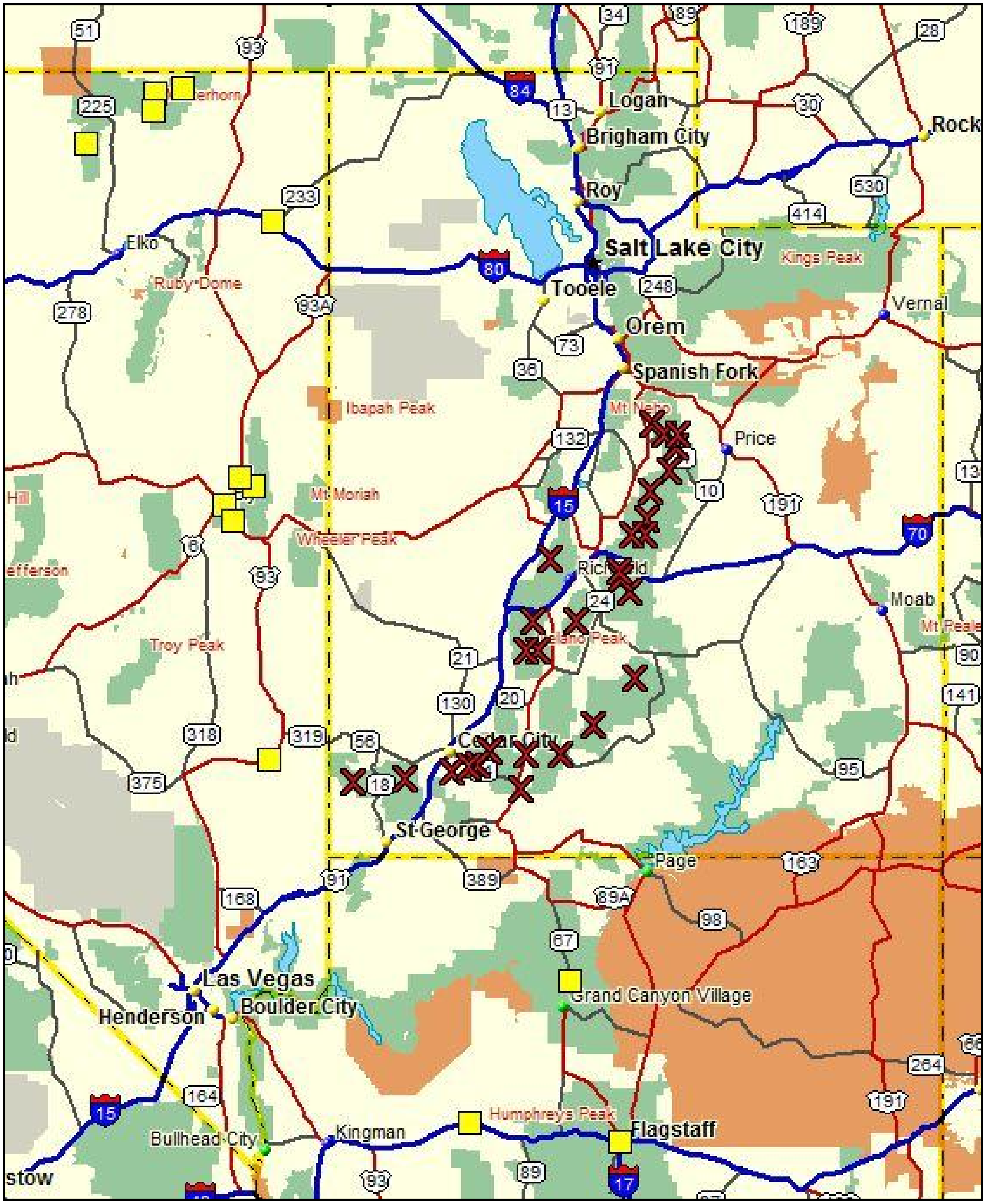

Figure 5.2 Precipitation target (X) and control (square) sites, primary target area

5.3.3 Precipitation Data Compilation

The evaluation was conducted for the December through March period, since this represents the period during which operational cloud seeding has been conducted in nearly all the seeded water years, although in a few years the latter half of March has not been seeded. Precipitation data for some of the higher elevation target sites were obtained from storage gage sites. Observations were taken at approximately monthly intervals before the conversion to the NRCS SNOTEL technology, which typically occurred in the early 1980's. There were some missing data in the earlier records. Some observations were made before and sometimes after the first of the month. As a consequence, NAWC had previously estimated some data and adjusted some data to more accurately represent the first of the month amounts for some of these early records. The adjustments were based upon inter-station relations using surrounding lower elevation precipitation records. With the advent of the NRCS SNOTEL system, data are available on a daily and even hourly basis, which eliminates some of the timing problems in the earlier data sets. Precipitation amounts for the December-March period were summed for each station, in the two target areas and their respective control areas. Averages were calculated for each of the groups for each individual four-month (December-March) season. The four-month averages for the historical (unseeded) seasons were then used to develop a linear regression equation for the target, which was in turn used to estimate the target area natural precipitation for the seeded period.

In the ETT, the historical (non-seeded) base period extends from 1957 through 1973, and also includes 1984 (18 seasons). The 1984 water year has been included in the historical period because no seeding was conducted in Utah during that water year. The decision was made in 2009 to update the historical regression (non-seeded) equations for eastern Tooele County with the addition of the 1974-75, 1983, 1985-88, and 1993-1995 water years. This addition of these 10 historical seasons expanded the regression period to a total of 28 non-seeded seasons (1957-75, 1983-88, and 1993-95). Seeded years in the ETT target include water years 1976-1982, 1989-1992, and 1996-2016 (32 seeded seasons). A reasonably good correlation between the control and target stations was established, with a correlation coefficient (r value) of 0.78, and a variance

(r^2 value) of 0.61, although these are somewhat lower than for the original (shorter) regression period. Target and control sites are listed in Appendix C. The control area sites are shown schematically on Figure 4.1 relative to the East Tooele Target area. Their average elevation is 8,348 feet MSL.

The historical period in the PT consists of an 18-year period (1957-73 and 1984). Seeded years began in 1974 in the PT, and continued through 1983. Although seeding resumed in the southern portion of the PT in 1985, it was not until 1988 that a majority of the PT was being seeded again. Therefore, the 1985-87 period has been excluded from the evaluation, with target-wide seeding resuming in 1988 and continuing through the current water year. This provides a total of over 40 seeded seasons for evaluation. The regression analysis between the 12-site control area and the 25-site target area for the 18-year historical period (December-March, 1957-73, 1984 water years) provided an excellent correlation between the two groups. The correlation coefficient (r) is 0.96, with a variance (r^2) of 0.91. This is a very strong correlation and should provide an accurate assessment of predicted natural precipitation in the target area during seeded seasons. The sites that make up the control and target areas are listed in Appendix C. The control area sites (denoted by squares) are shown schematically on Figure 4.2 relative to the Primary Target area. Their average elevation is 7,032 feet MSL.

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:

$SE = (Y_O - Y_C) / (Y_C *100)$

The regression equations and the historical correlation coefficients for the two target areas are presented in Table 5-1. The stations which constitute each control/target group are listed in Appendix C.

5.3.4 Results of Precipitation Analyses

Table 5-2 provides the ratios of the observed average target area December-March precipitation to the calculated (from the regression equation described above) for the two target areas. A ratio equal to 1.0 would indicate no difference between the observed and predicted precipitation amounts. The difference between these values is also provided to show the average difference (inches) in precipitation during the seeded periods. Tables 5-3a and 5-3b list the results for each seeded season for the Eastern Tooele Target Area and Primary Target Area, respectively.

Table 5-1
Correlation coefficients, variances, and regression equations for precipitation evaluations

Target Group	Equation	Corr. Coeff.(r)	Variance (r^2)
E. Tooele (ETT)	$Y_C = 0.88(X_6) - 0.69$	0.78	0.61
Primary Target (PT)	$Y_C = 1.69(X_{12}) - 3.17$	0.96	0.91

Where:

Y_C = Average calculated precipitation for target (December - March)

X_6 = Average two state (NV/UT) control area observed precipitation for December - March for 6 sites

X_{12} = Average two state (AZ/NV) control area observed precipitation for December - March for 12 sites

Table 5-2
Precipitation evaluation results for the 2018-2019 December-March season and for all seeded seasons

Target Group	**Seeded Period**	**Ratio**	**Increase (inches)**
E. Tooele Co.	35 Seeded Water Years	1.12	1.3
	2019 Water Year	1.09	1.5
Primary Target	42 Seeded Water Years	1.12	1.3
	2019 Water Year	1.03	0.4

Where:

Ratio = Ratio of average observed target area precipitation to average calculated target area precipitation

Increase = Average difference (in inches) between observed and calculated precipitation at target gages

Table 5-3a
Eastern Tooele Co. (ETT) Target area
Summary of December - March precipitation evaluations

Water Year	Observed	Predicted	Ratio Obs/Predicted	Excess Water Content (inches)
1976	10.3	9.4	1.10	0.9
1977	6.6	6.9	0.96	-0.2
1978	20.7	16.3	1.27	4.4
1979	12.5	11.5	1.09	1.0
1980	19.6	15.8	1.24	3.8
1981	8.9	9.3	0.95	-0.5
1982	15.5	16.3	0.95	-0.8
1989	11.0	10.8	1.02	0.2
1990	9.8	7.7	1.27	2.1
1991	8.4	7.4	1.13	1.0
1992	7.4	7.4	1.01	0.1
1996	14.2	14.2	1.00	0.0
1997	15.0	12.9	1.16	2.1
1998	20.2	14.6	1.39	5.6
1999	9.3	8.8	1.05	0.5
2000	15.2	12.5	1.21	2.6
2001	9.4	8.3	1.12	1.0
2002	8.4	8.4	1.00	0.0
2003	8.7	7.6	1.14	1.1
2004	15.0	11.1	1.34	3.8
2005	15.4	13.4	1.15	2.0
2006	15.4	14.7	1.05	0.7
2007	9.9	8.3	1.19	1.6
2008	14.7	12.7	1.15	2.0
2009	13.6	13.2	1.03	0.4
2010	11.5	11.2	1.03	0.3
2011	16.6	14.9	1.11	1.6
2012	8.5	7.1	1.19	1.3
2013	9.5	8.3	1.15	1.2
2014	10.4	9.0	1.15	1.3
2015	6.2	6.0	1.03	0.2
2016	13.2	11.9	1.10	1.2
2017	18.8	16.8	1.12	2.0
2018	8.6	7.8	1.10	0.8
2019	17.3	15.8	1.09	1.5
Seeded Mean	12.4	11.1	1.12	1.3

Table 5-3b
Primary Target (PT) area
Summary of December - March precipitation evaluations

Water Year	Observed	Predicted	Ratio Obs/Predicted	Excess Water Content (inches)
1974	11.3	11.3	1.00	0.0
1975	12.8	12.1	1.06	0.7
1976	9.9	9.9	1.01	0.1
1977	6.4	4.6	1.40	1.8
1978	20.3	18.7	1.08	1.6
1979	16.3	14.5	1.12	1.8
1980	20.5	16.7	1.23	3.9
1981	9.3	8.0	1.16	1.3
1982	16.9	16.1	1.05	0.8
1983	17.5	15.0	1.17	2.5
1988	9.8	7.2	1.36	2.6
1989	10.2	10.3	0.99	-0.1
1990	9.1	7.8	1.17	1.3
1991	10.8	8.0	1.34	2.7
1992	10.2	7.6	1.34	2.6
1993	19.7	19.0	1.04	0.7
1994	8.7	6.5	1.35	2.3
1995	14.0	12.0	1.17	2.0
1996	12.9	12.2	1.05	0.7
1997	12.2	11.6	1.05	0.5
1998	14.4	12.6	1.14	1.8
1999	6.9	6.4	1.07	0.4
2000	12.4	10.8	1.15	1.7
2001	9.5	6.8	1.39	2.7
2002	6.2	6.7	0.92	-0.6
2003	9.6	6.6	1.45	3.0
2004	11.0	9.2	1.20	1.8
2005*	15.9	14.2	1.13	1.8
2006	13.7	13.1	1.04	0.5
2007	7.2	7.4	0.98	-0.2
2008	15.1	11.7	1.28	3.3
2009	13.1	11.6	1.13	1.5

Water Year	Observed	Predicted	Ratio Obs/Predicted	Excess Water Content (inches)
2010	13.8	11.1	1.24	2.7
2011	16.6	14.3	1.16	2.3
2012	8.7	7.9	1.09	0.7
2013	9.2	8.9	1.04	0.4
2014	7.9	7.1	1.10	0.7
2015	8.4	7.7	1.09	0.7
2016	11.4	11.7	0.98	-0.3
2017	16.1	18.0	0.89	-2.0
2018	8.6	7.2	1.20	1.4
2019	15.7	15.3	1.03	0.4
Seeded Mean	12.1	10.8	1.12	1.3

*Widespread seeding suspensions during the 2005 water year may have influenced results

5.3.4.1 Eastern Tooele Target Results

Seeding began in the ETT in 1976 and continued through the 1982 water year. Seeding resumed in 1989 and continued through 1992. After a break in seeding during water years 1993-95, seeding resumed in the 1996 water year and has been conducted each year through the present. Thus, there are 35 seeded seasons and 28 non-seeded seasons in the regression period. Tables 5-2 and 5-3 show an estimated 9 percent increase for the 2018-2019 winter season based on this regression relationship. It is important to remember that single-season evaluation results can vary significantly due to variability in precipitation patterns from one year to another, and, thus, a single-season result carries very little statistical significance. This variability primarily affects the results of the evaluation, not necessarily the actual effectiveness of the seeding. **During the 35 seeded seasons the observed precipitation within the target has averaged 12 percent greater than might have been expected from calculations based on the control precipitation averages. That increase is equal to an average additional 1.3 inches of water per seeded season.** Note that the December-March evaluations do not estimate any possible additional effects of seeding which was conducted outside this four-month core evaluation period (e.g., November 15-30, April 1-15).

Figure 5.3 is a scatterplot showing a comparison between the seeded and non-seeded data sets in the eastern Tooele County precipitation linear regression. The linear regression equation (e.g. best linear fit to the historical non-seeded data, shown in black) is represented by the black diagonal line. Note that the vast majority of the seeded season data (red dots) lie above the regression line, indicative of greater target area precipitation in seeded seasons than that predicted from the regression equation based upon control area precipitation.

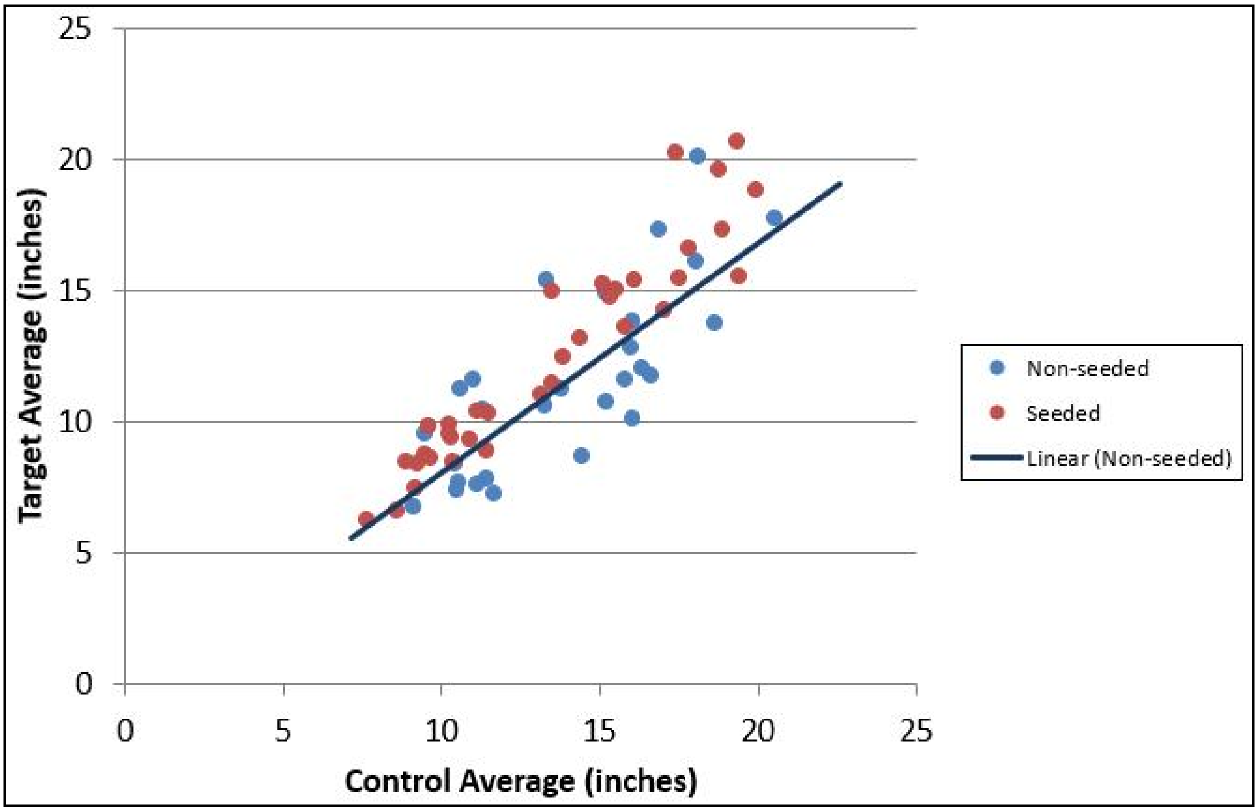

Figure 5.3 Scatterplot of historical non-seeded (blue) vs seeded (red) data points for the eastern Tooele County precipitation evaluation. The diagonal line represents the linear regression equation for the non-seeded period.

5.3.4.2 Primary Target Results

Seeding was conducted in the target area beginning in the 1974 water year, continued until seeding was suspended in February 1983, and then discontinued entirely during water year 1984 because of excessively wet weather. However, seeding began again over portions of

Washington County (mainly the Pine Valley Mountains) in 1985 and continued to spread northward in 1986 and 1987 into other parts of the target area. By 1988, seeding was again being conducted over essentially all of the previously seeded primary target area. The seeding program has continued to target most of the mountainous areas of central and southern Utah up through the current season. There have been 42 seeded seasons, excluding those when seeding was conducted over only a portion of the current target, and 18 seasons in the historical unseeded database. The 25 SNOTEL or cooperative observer sites located within the PT provide good areal coverage of the area targeted by cloud seeding. The high-density site coverage and distribution within this target area should ensure that the target area measurement sites are representative of the overall target area.

In the 2019 water year, the target/control precipitation evaluation results (from Table 5-2) yielded an observed/predicted ratio of 1.03; in other words, the observed target area precipitation was 3% more than the predicted value for the season. As mentioned earlier, single-season results should be viewed with appropriate caution. **Over the 42 seeded years included in the long-term seeded record, 12 percent more precipitation has been observed (on average) than would have been expected from the control area-based predictions. This has provided an annual average excess of over 1.3 inches of water throughout the target area.** Statistical tests show the long-term average to be very meaningful (i.e, not the result of chance), even though individual-year results are not statistically significant. A one-tail significance test for the predicted vs. observed values (all seeded seasons) yielded a P value of 0.06 for this evaluation. This suggests only a 6% probability of the results being due to chance. The December-March evaluations do not estimate any possible effects of seeding which was conducted outside of this four-month core evaluation period (e.g., Nov. 15-30 or during April).

Figure 5.4 is a scatterplot similar to Figure 5.3. Again, note that almost all of the seeded seasons are above the regression line indicating increases in precipitation. Appendix C contains the historical and seeded regression equation information for both target areas.

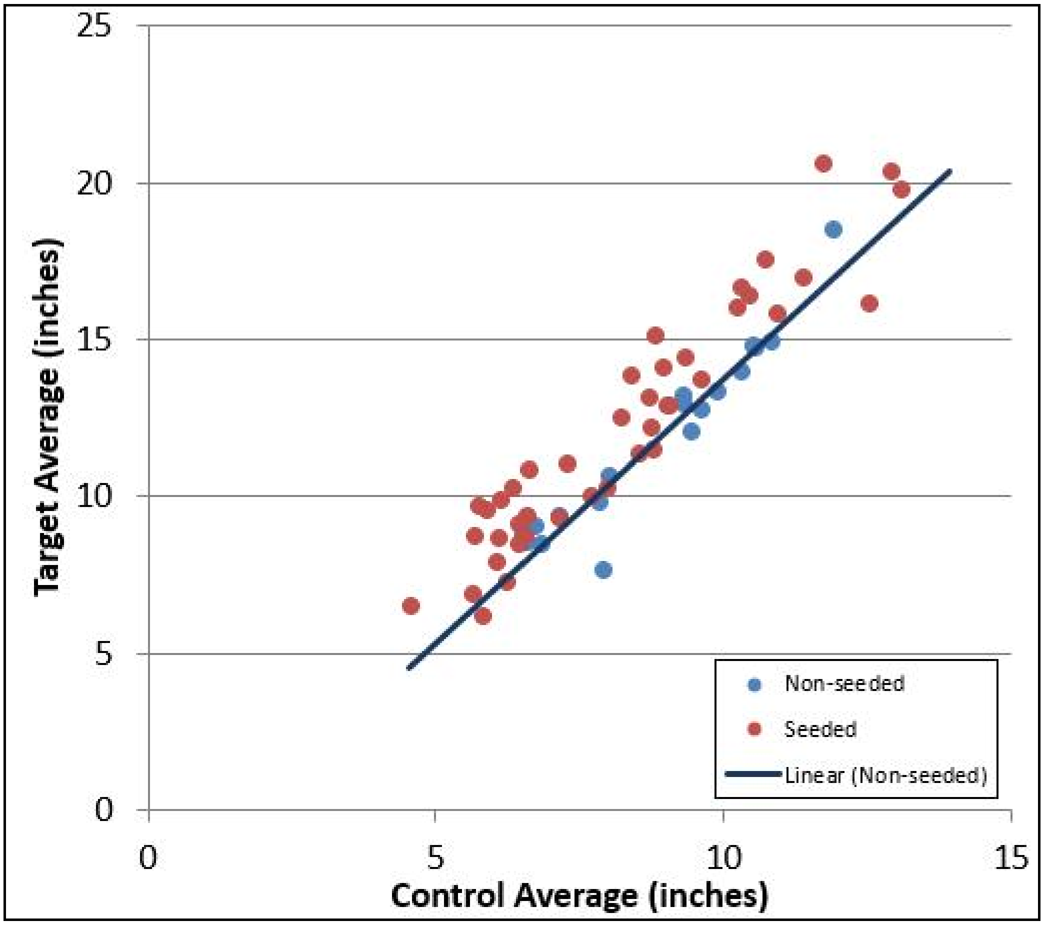

Figure 5.4 Scatterplot of historical non-seeded (blue) vs seeded (red) data points for the primary target precipitation evaluation. The diagonal line represents the linear regression equation for the non-seeded period.

5.4 Snowpack Evaluations – NAWC Target/Control Method

The procedure for evaluating the effect of cloud seeding on the snowpack water equivalent (SWE) as observed on April 1 was essentially the same as was done with the precipitation evaluations. In general, the control area snow sites have been drawn from approximately the same areas as were used in the precipitation evaluation, but they are limited to the availability of mountain sites, while lower elevation control sites were taken into consideration for the precipitation analysis. The snowpack analysis data presented in this section utilizes NRCS SNOTEL estimates for pre-SNOTEL years. This is intended to help eliminate any potentially confounding effects of systematic differences between manual snow course and SNOTEL data.

Another reason for the differences is that we have found that some of the data used in previous evaluations for the pre-SNOTEL period (i.e., primarily the historical regression periods) seemed to differ from the published data sets. For some reason(s) that we have been unable to ascertain, most of these differences occurred in the Primary Target control sites. Some of these differences may be due to the application of estimation techniques in an attempt to correct for variations in the measurement date when these dates were different from April 1. Recall that the snow course observations could be made a few days before or after the end of the month, although such measurements, in general, were referred to as April 1 data. Due to these discrepancies, the desire to not mix the types of data (manual snow course versus SNOTEL snow pillows as discussed in section 5.2), and the fact we would be dealing with a published data set, the change was made in 2004 to the NRCS SNOTEL observations which became available in the early 1980's and the NRCS-adjusted snow course data. The adjustments made by NRCS are based upon approximately 10-year overlap periods when both types of measurement data (manual snow course and automated SNOTEL) were available for each site.

5.4.1 Snowpack Target Areas

Many of the same target sites (either snow course or snow pillow) that were used in the precipitation evaluation were also used in the snowpack evaluation. However, not all the sites that measure precipitation also measure snowpack, and vice-versa, so the coverage within the Eastern Tooele Target and the Primary Target is slightly different from the precipitation evaluations. The four (originally six) target snowpack site locations used for the ETT are shown in Figure 5.5 as X's. Two target area measurement sites used in earlier evaluations (Deseret Peak pillow and snow course) are no longer in operation. Two of the remaining target sites are snow courses, while the other two are snow pillows (SNOTEL sites). The average elevation for the four target sites is 7,463 feet MSL.

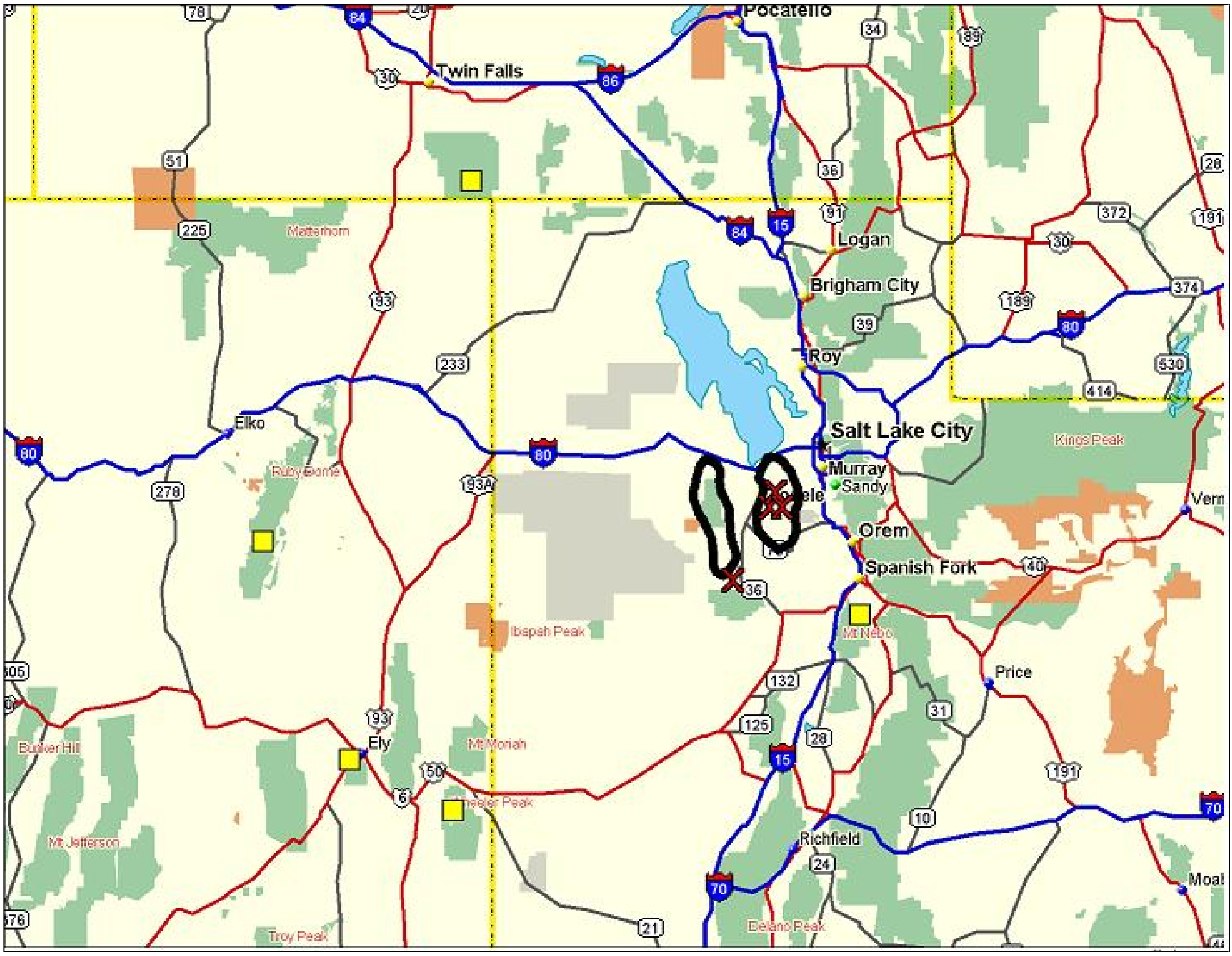

Figure 5.5 Snowpack sites for Eastern Tooele target/control evaluation (squares are control sites, X's are target sites)

A total of 30 target area snowpack measuring sites were utilized in the Primary Target. Figure 5.6 shows target and control site locations. The average elevation for the target area sites is approximately 9,090 feet MSL. Actual site locations and elevations are listed in Appendix C for both target areas.

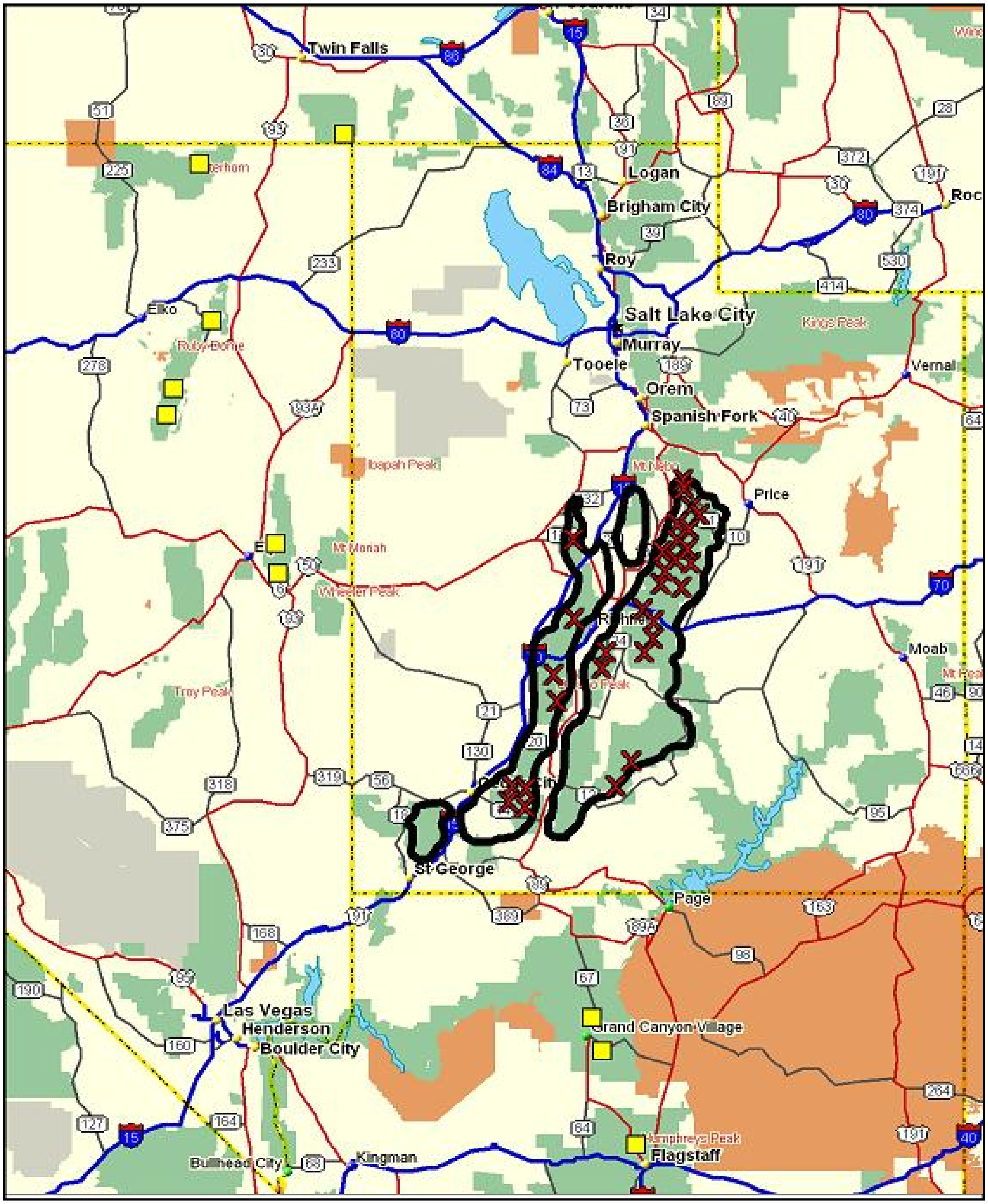

Figure 5.6 Snowpack sites for Primary Target evaluation (squares are control sites, X's are target sites)

5.4.2 Snowpack Control Areas

The selection of sites in the control group was determined primarily by their degree of correlation with the target area. Thus, control area sites (for the ETT and the PT) were selected individually from a large number of potential sites available in surrounding regions and assessed regarding their effects on the group correlations.

The control group used in the snowpack evaluation for the Eastern Tooele County target area (ETT) consists of five snow measurement sites. These sites extend from southern Idaho (one site) through eastern Nevada (three sites) into the Wasatch Mountains of Utah (one site southeast of the target area). The correlation coefficient (r) of 0.79 indicates a moderately good correlation between control and target areas, and is slightly lower than that for the shorter regression period (0.82). Detailed information on the five SNOTEL/snow course sites utilized in this control is given in Appendix C, and the sites are shown in Figure 5.5. The average elevation of the control group about 8,050 feet MSL. Some data estimation was necessary for one of the sites (Vernon Creek) for the period prior to 1967, as SNOTEL/snow course data were unavailable. The estimation was based on data at two other target sites closest to Vernon Creek (Rocky Basin Settlement and Bevan's Cabin).

The Primary Target control group consists of ten SNOTEL/snow course sites located from southern Idaho southward through eastern Nevada into north-central Arizona. This control group provided a good correlation (r = .94) with the Primary Target, with a variance (r^2) of .88, indicating that 88% of the variability in the historical data used to predict the expected snowpack was explained in the regression equation. The locations of the ten sites used as the control area are listed in the control section of Appendix C and are shown as yellow squares in Figure 5.6. The average elevation of this control group is 8,800 feet MSL.

5.4.3 Snowpack Regression Equation Development

The procedure was essentially the same as was done for the precipitation evaluation, i.e., control and target area stations were selected and average values for each were determined from the historical snowpack data. The regression equation for the Tooele County snowpack evaluation is based on a 29-year non-seeded period (1956-75, 1983-88, and 1993-95). The regression period for the primary target is shorter, consisting of 18 years (1957-73, and 1984). The snowpack regression equations developed for the ETT and PT areas, using historical SNOTEL and estimated SNOTEL April 1st snow water content data, are provided in Table 5-4.

Note that, for the eastern Tooele County snowpack evaluation, one of the four target sites (Middle Canyon snow course) was discontinued this season. This was confirmed through email communications with the NRCS. This leaves only 3 target snowpack sites instead of the original 4 sites.

Table 5-4
Correlation coefficients, variances and regression equations for snowpack evaluation

Target Group	Equation	Corr Coeff(r)	Variance (r^2)
E. Tooele	$Y_C = 1.069(X_5) – 0.81$	0.77	0.59
Primary (PT)	$Y_C = 1.04(X_{10}) - 0.38$	0.94	0.88

Where:

Y_C = Average calculated snowpack (water content) for target (April 1)

X_5 = Average three state (ID/NV/UT) control area snowpack (April 1) for 5 sites

X_{10} = Average three state (AZ/ID/NV) control area snowpack (April 1) for 10 sites

5.4.4 Results of Snowpack Water Content Analyses

The results of the snow water evaluations for current water year and the average for all seeded seasons for the ETT and PT are presented in Table 5-5. In some seasons, a large number of SNOTEL sites have experienced large decreases from peak snowpack (10-50+%) prior to April 1. For this reason, April 1 snowpack evaluation results for water years 2007, 2012, 2015 and 2017 were excluded due to excessive pre-April 1 snow melt. Tables 5-6 and 5-7 list the results for each seeded season for the ETT and PT, respectively. Appendix D contains the historical and seeded year regression equation and evaluation result information for both target areas.

Table 5-5
Snowpack water content evaluation results for the 2018-2019 season, and for all seeded seasons

Target Group	Seeded Period	Ratio Y_o/Y_c	Increase $Y_o - Y_c$
E. Tooele Target	31 water years*	1.10	1.3
	2019 water year	1.08	1.6
Primary Target	38 water years*	1.04	0.6
	2019 water year	1.03	0.6

* 2007, 2012, 2015 and 2017 results not included in long-term mean due to excessive pre-April 1 snow melt

Ratio = Ratio of average observed target area snowpack to average calculated target area snowpack

Increase = Average difference (in inches) between observed and calculated water content in snowpack at target gages on April 1

5.4.4.1 Eastern Tooele Results

Table 5-5 shows the Eastern Tooele target group snow water evaluation results for the current water year and for all seeded seasons**.** As in the snowpack evaluation for the Primary

Target area, the 2007, 2012, 2015 and 2017 (April 1) Tooele County snowpack evaluation results are excluded from the long-term mean due to excessive pre-April 1 snowmelt. Table 5-6 shows individual year results for the ETT snowpack evaluation. The long-term result of this evaluation, a ratio of 1.10 equivalent to a 10% increase, is also close to the 1.12 ratio for the ETT precipitation evaluation (see Table 5-2 for comparison). The difference in observed versus calculated snow water (in inches of water) showed an average of 1.3 inches more water observed than calculated per year for both (snow and precipitation) analyses in the Tooele County portion of the program. Results for the current season are also shown, although it should again be emphasized that single-season results carry very little statistical significance.

Table 5-6
Eastern Tooele Co. (ETT) Target area, April 1 snow water content evaluation

Water Year	Observed	Predicted	Ratio Obs/Predicted	Excess Water Content
1976	15.6	16.0	0.98	-0.4
1977	9.3	5.8	1.59	3.5
1978	21.1	17.8	1.18	3.3
1979	18.0	19.4	0.93	-1.4
1980	24.4	19.5	1.25	4.8
1981	12.5	9.2	1.36	3.3
1982	19.6	22.1	0.89	-2.5
1989	9.9	14.1	0.70	-4.2
1990	12.4	10.7	1.16	1.7
1991	10.5	10.1	1.05	0.5
1992	10.3	8.5	1.21	1.8
1996	12.8	14.7	0.87	-1.9
1997	17.9	15.0	1.19	2.9
1998	23.4	15.0	1.56	8.4
1999	8.8	10.0	0.88	-1.2
2000	15.9	11.2	1.42	4.7
2001	11.4	8.5	1.35	3.0
2002	11.0	11.2	0.98	-0.2
2003	9.6	8.3	1.16	1.3
2004	15.0	10.1	1.49	4.9
2005	20.2	18.5	1.09	1.7

Water Year	Observed	Predicted	Ratio Obs/Predicted	Excess Water Content
2006	16.3	17.0	0.96	-0.6
2007*	7.2	6.4	1.11	0.7
2008	17.5	14.4	1.21	3.1
2009	13.9	12.6	1.10	1.2
2010	13.0	12.2	1.06	0.8
2011	21.9	16.3	1.34	5.5
2012*	7.2	7.9	0.91	-0.7
2013	10.0	7.7	1.30	2.3
2014	8.3	9.9	0.83	-1.7
2015*	1.5	3.6	0.43	-2.0
2016	12.0	13.8	0.87	-1.8
2017*	13.8	13.0	1.06	0.8
2018	5.3	8.1	0.66	-2.8
2019	21.4	19.8	1.08	1.6
Seeded Mean	14.5	13.1	1.10	1.3

* Results excluded from long-term average due to excessive early-season snowmelt

5.4.4.2 <u>Primary Target Results</u>

Table 5-7 shows the individual and combined season results of the April 1 snowpack evaluation for the Primary Target areas. As discussed in the previous section, the 2007, 2012, 2015 and 2017 April 1 snowpack evaluation results are excluded from the long-term mean due to excessive early season snowmelt in those seasons. The data for the combined seeded seasons included in the evaluation indicates a ratio of observed to calculated snow water of 1.04. This ratio (1.04) is much less than the ratio of 1.12 for the precipitation evaluation for this primary target group, and the resulting statistical significance (one-tail P value of 0.29) is less as well. Indications of excess snow water content provided by the snowpack evaluation are also less than in the precipitation results, with an average of 0.6 inches per year produced in the snow water analysis and 1.3 inches per year indicated by the precipitation evaluation. These differences are discussed in section 5.7.

Table 5-7
Primary Target (PT) area
April 1 snow water content evaluation

Water Year	Observed	Predicted	Ratio Obs/Predicted	Excess Water Content (in)
1974	15.6	14.0	1.11	1.6
1975	17.3	18.3	0.95	-1.0
1976	12.9	12.8	1.01	0.2
1977	8.2	8.0	1.02	0.2
1978	21.8	18.9	1.15	2.9
1979	21.4	18.2	1.17	3.2
1980	23.6	19.6	1.20	4.0
1981	10.2	9.6	1.06	0.6
1982	20.5	20.7	0.99	-0.2
1983	26.0	23.6	1.10	2.4
1988	13.1	10.5	1.25	2.7
1989	11.3	14.6	0.77	-3.4
1990	10.5	9.1	1.16	1.4
1991	12.8	12.3	1.04	0.5
1992	12.1	11.7	1.04	0.4
1993	21.3	20.4	1.04	0.9
1994	10.8	9.3	1.17	1.6
1995	16.6	18.0	0.92	-1.4
1996	14.6	13.8	1.06	0.8
1997	15.1	15.7	0.96	-0.6
1998	16.7	17.4	0.96	-0.7
1999	8.1	10.3	0.79	-2.2
2000	13.7	12.9	1.06	0.8
2001	11.3	10.8	1.04	0.5
2002	9.6	10.4	0.92	-0.8
2003	12.1	9.5	1.28	2.6
2004	10.2	9.2	1.11	1.0
2005	20.1	21.1	0.95	-1.0

Water Year	Observed	Predicted	Ratio Obs/Predicted	Excess Water Content (in)
2006	17.4	16.9	1.03	0.5
2007*	6.8	7.8	0.87	-1.0
2008	16.1	15.2	1.06	0.8
2009	12.7	13.0	0.98	-0.2
2010	15.1	14.8	1.02	0.3
2011	20.1	16.2	1.24	3.9
2012*	7.9	7.1	1.11	0.8
2013	9.3	8.8	1.06	0.5
2014	9.9	9.4	1.05	0.5
2015*	6.1	4.7	1.28	1.3
2016	12.8	14.4	0.89	-1.5
2017*	13.9	16.6	0.84	-2.7
2018	7.9	8.1	0.97	-0.2
2019	19.5	18.9	1.03	0.6
Seeded Mean	14.7	14.1	1.04	0.6

* Results not included in long-term average due to excessive early-season snowmelt

5.5 <u>Multiple Linear Regression Analyses</u>

A variation of the linear regression technique is a multiple linear regression. In the linear regression averages of the control site data and target site data are used in development of the equation. In a multiple linear regression typically an average of all the target site data is correlated with each individual control site resulting in an equation with a number of terms depending upon the number of control sites. Past work with multiple linear regression evaluations highlighted some potential problems with this type of evaluation under certain circumstances. For example, a multiple linear regression equation containing independent control variables (e.g. single control sites) that are too similar to each other may yield an unrealistic regression equation. Such an equation typically produces highly variable results (that is, very high and/or very low individual season observed/predicted ratios) when applied to seeded season data.

One way to reduce or eliminate problems with the multiple regression analysis is to group control sites into 2 (or more) sets, with each set containing an average of a grouping of control sites. Ideally, control sites with similar characteristics (such as those at a higher latitude in comparison to much of the target area, and those at a lower latitude) can be grouped for this purpose, allowing the multiple linear regression equation to distinguish between the two groups in a meaningful way. Testing the standard deviation of the resulting individual seeded year ratios provides a useful comparison between a linear and corresponding multiple linear regression technique. Although a multiple linear regression equation containing the same control sites will typically have a better correlation (higher r-value) than the linear, ideally the resulting individual year observed/predicted ratios should have less variability (lower standard deviation) as well. This indicates that the multiple linear regression equation is helping to reduce some of the natural variability or "noise" inherent in the target /control relationship.

Most of the multiple linear regression equations developed for the southern/central Utah seeding program produced much more variable seeded season results than did the linear regression equations, and so the results from most of these have not been considered very reliable for this program. However, for the primary target area, it was found that a multiple linear snowpack regression equation containing two control sets (one an average of the five northern-most control sites, and the other an average of the five southern-most sites) reduced the variability in the seeded season results slightly. For the seeded period as a whole, this multiple linear snowpack regression produced an observed/predicted ratio of 1.03 (similar to the 1.04 long-term result for the linear regression equation).

5.6 Double Mass Plots

A double mass plot is an engineering tool designed to display data in a visual format in which it can readily be seen if there has been a change in the relationship between two variables.

NAWC has applied this technique to the central/southern Utah cloud seeding program. Figures 5.7 and 5.8 provide plots of the data used by NAWC in target area evaluations of December – March precipitation, for the Primary Target and Eastern Tooele County Target areas. Target and control area-average seasonal values for both the historical (not-seeded) and the seeded periods are plotted on the figures. The December – March precipitation data are used in these plots since these data best represent the seeded season. The plotted values are cumulative; each new season is added to the sum of all of the previous seasons. In each figure, a line has been drawn through the points during the not-seeded base period. The plots show stable linear relationships prior to the beginning of cloud seeding. For comparison with the seeded period, the line describing the not-seeded period is extended at a constant slope through the seeded period. The Eastern Tooele County plot (Fig. 5.8) is more complex since there were two non-seeded intervals (from 1983-88 and 1993-95) even after the beginning of initial seeding operations in 1976. However, the line in this plot is drawn to fit the pre-seeding historical period of 1957-1975. The scales in Figures 5.7 and 5.8 are different, so the first-glance visual impression of a larger seeding effect in the ETT target area versus the PT is not actually the case since the linear regression analyses suggest average increases of 11% in the ETT and 12% in the PT.

Figures 5.7 and 5.8 show a distinct change in the relationship between the target and control areas (a sustained change in the slope of the line representing the seeded seasons) that begins at approximately the same time as the start of the cloud seeding programs in the mid to late 1970s. Beginning at/near this time the plots in each case show generally greater precipitation in the target area compared to the control area. NAWC believes that this demonstates evidence of a consistent positive seeding effect. A separate line could be drawn through the data points since seeding began in each case. Such a line would also have a fairly constant slope, departing from the slope of the line describing the not-seeded base period.

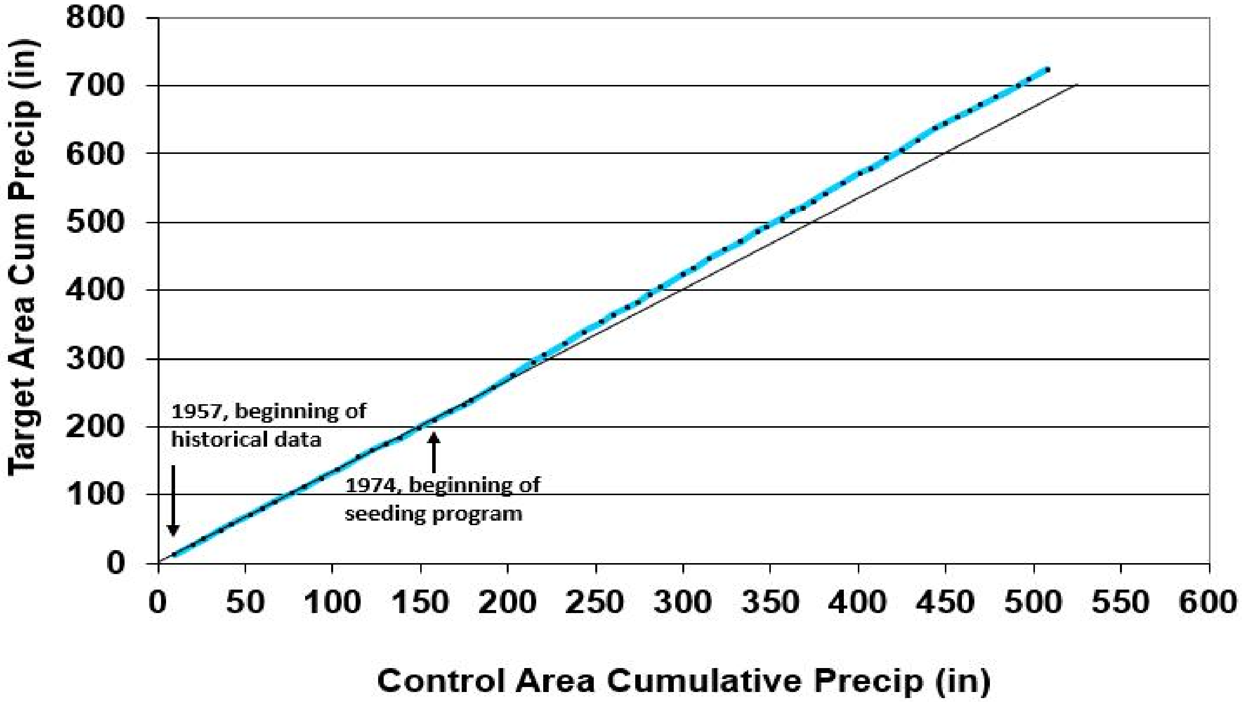

Figure 5.7 Double-Mass plot for Primary Target; all seasons shown after 1974 in this plot were seeded, and all the seasons plotted previous to this were not seeded

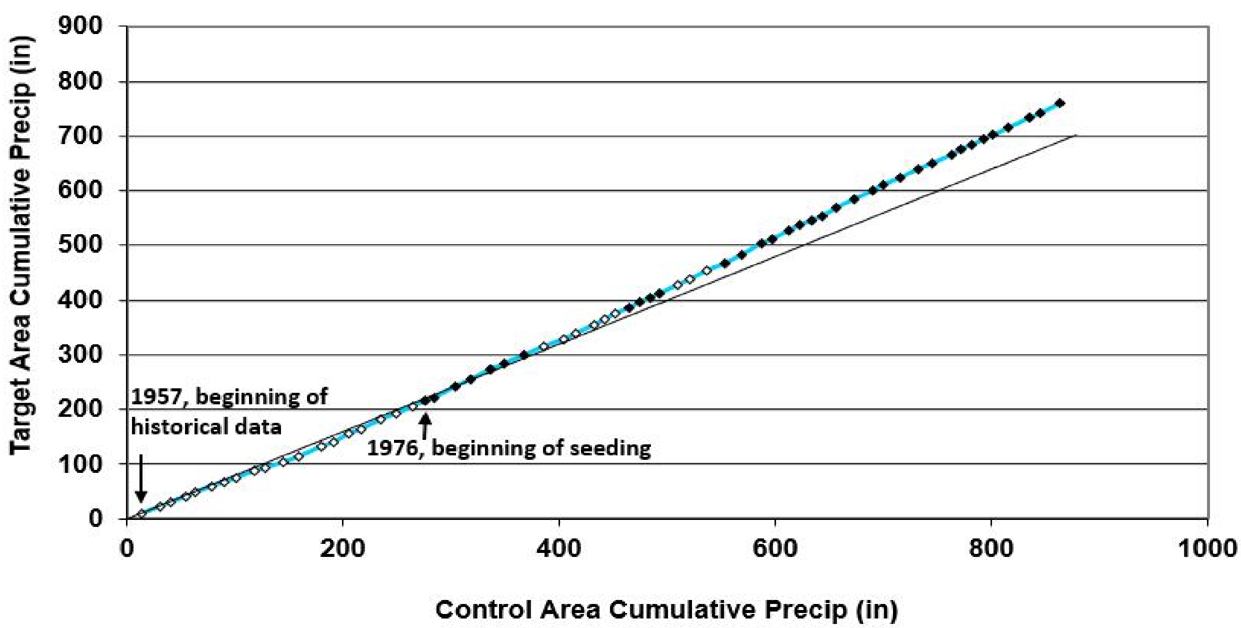

Figure 5.8 Double-Mass plot for Eastern Tooele County Target; smaller data points denote non-seeded seasons, and larger, darker points are the seeded seasons

5.7 Summary of Evaluation Results

Table 5-8 summarizes the results of the seeding evaluations, both for the ETT and PT target areas, for precipitation and snowpack. Combined results of all seeded season evaluations suggest an approximate 10-12% increase in precipitation/snow water for the ETT, with a range of 3-12% increases indicated for the PT in the various evaluations.

Table 5-8
Summary of ratios from precipitation and snowpack evaluations

	2019 Water Year	Long-term Average
ETT Precipitation Linear	1.09	1.12
ETT Snowpack Linear	1.08	1.10
PT Precipitation Linear	1.03	1.12
PT Snowpack Linear	1.03	1.04

The reader will note some differences in results between the precipitation and snowpack analyses, which have persisted even though the target and control groups have had minor adjustments over time (usually due to loss of site data availability). An analysis was performed in 2004 to investigate possible reasons for the differences in indicated seeding effects in the PT target area when using April 1st snow water content, versus December through March precipitation data (i.e., 4% versus 15% average increases in 2004). **One factor is that snowpack accumulation usually begins before the seeded portion of the season, and therefore the seeding effects on snow water content are diluted by the early season non-seeded period. The seeding program in some years has ended by mid-March, making this a potential factor in the spring as well. <u>Also, it was determined that the change in snowpack measurement methods (the advent of SNOTEL) which occurred in about 1980, and the ensuing data adjustments applied by NRCS, may result in an underestimate of seeding effects in the snowpack evaluation for the Primary Target, as was discussed in further detail in earlier reports. Based on these considerations, it is concluded that the estimates of</u>**

cloud seeding effectiveness for the Primary Target for December through March precipitation are more reliable than those based upon April 1st snow water content.

As a side note, the December-March precipitation evaluations do not estimate any possible effects of seeding which was conducted outside of this four-month core evaluation period (e.g., November 15-30 or during April). NAWC performed an analysis of the potential increases in streamflow from these extension periods (Griffith, *et al*, 2010) at the request of a Lower Basin States representative. This analysis provided estimates of **average** March – July increases in streamflow to Lake Powell (20,271 acre-feet) and to Lake Mead (8,331 acre-feet). The estimated cost per acre-foot of the calculated average increases were $1.22 per acre-foot for inflow to Lake Powell and $1.81 per acre-foot for inflow to Lake Mead.

A technical paper, published in the WMA's *Journal of Weather Modification* (Griffith, *et al*, 2009), provides a summary of four different seeding programs being conducted in Utah and includes a summary of the indicated increases from these programs. This paper may be found on NAWC'S web site (www.nawcinc.com) under the publications tab.

6.0 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

6.1 Summary

The Southern/Central Utah seeding program has been in operation since 1974, with seeding operations conducted during 42 winter seasons to date. Its basic design incorporates the use of a large array of over 70 manually-operated, ground-based seeding sites, emitting silver iodide particles as the seeding agent. The mountainous target areas for the overall project encompass approximately 10,000 square miles, extending from eastern Tooele County to northern Washington and Kane Counties. Specific seeding suspension criteria are in-place, so that seeding may be temporarily curtailed as water conditions and public safety considerations may dictate. Annual statistical assessments are conducted, to estimate the magnitude (if any) of the seeding affects.

Snowpack/precipitation was well above normal in central and southern Utah during the 2018-2019 winter season. As of April 1, 2019, snowpack water equivalent ranged from 136% to 189% of the median in the southern and central Utah Basins, with basin average water year precipitation amounts from 130% to 149% of the mean. These percentages were summarized by basin in Table 4-3.

A total of 22 storm events were seeded during the regular contract period, and 4 additional events were seeded during the spring extension period. There were no seeding opportunities during the November 1st-15th portion of the Lower Basin States extension. In all, there were three storm events seeded in November (including one which ended on December 1), seven additional events in December, four in January, four in February, six in March, and two in April. For the regular contract period, a cumulative 6,769.25 generator hours were utilized. For the Lower Basin extension, there was an additional 720.75 generator hours of seeding conducted. Figure 4.2 shows the cumulative seeding hours for the core program this season. Figure 6.1 shows the April 1 USDA snowpack basin percentage map. There were some intermittent, partial program suspensions beginning in February due to high snowpack and other factors, summarized in Section 4.0.

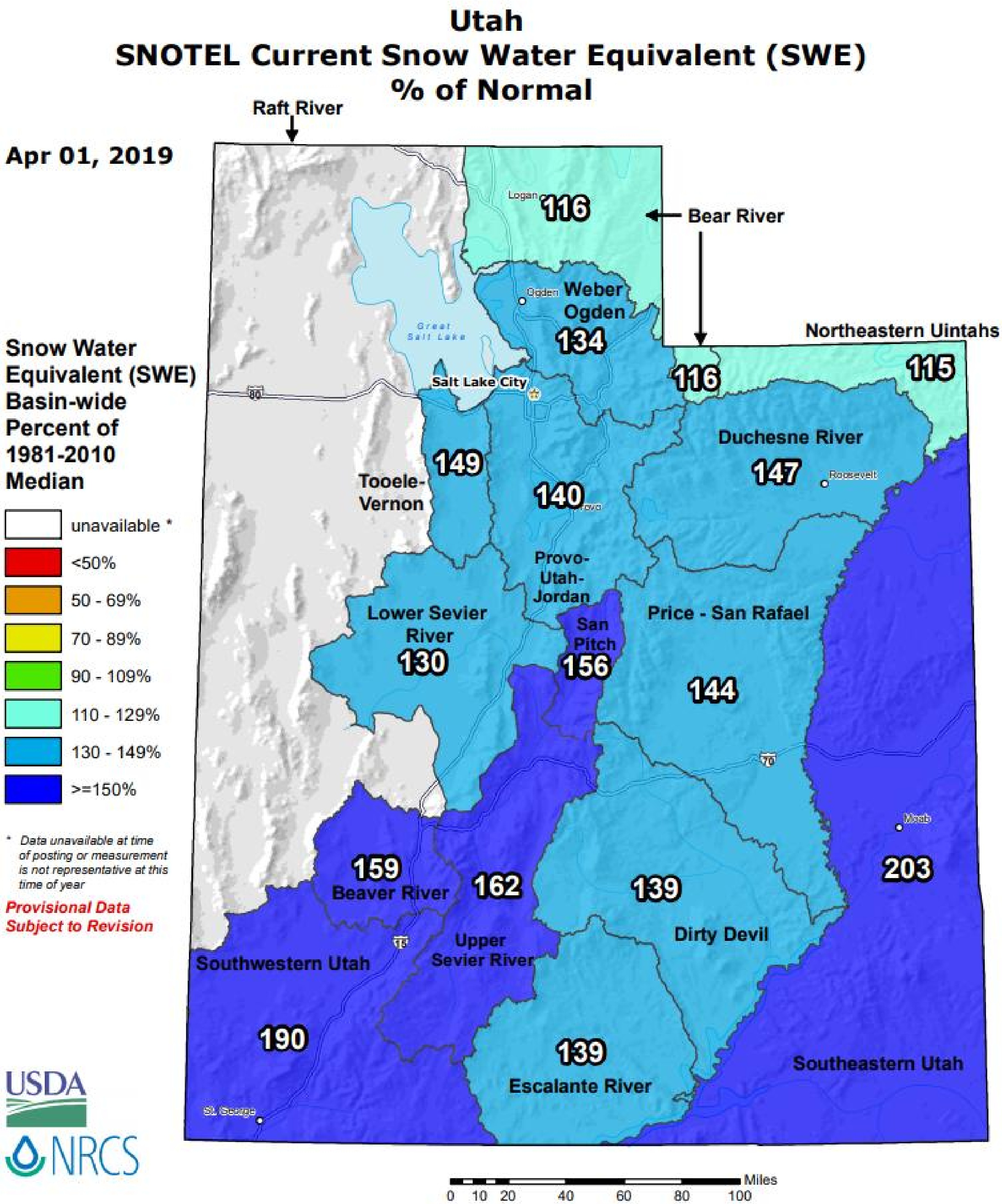

Figure 6.1 Western U.S. Percent of Median April 1, 2019 Snow Water Content

Precipitation linear regression evaluations for the December-March period this season yielded a ratio of 1.09 for the Eastern Tooele Target (ETT) area and a ratio of 1.03 for the Primary Target (PT) area. **<u>Long-term</u> ratios of 1.12 were obtained for both ETT and PT precipitation evaluations, based on 35 seeded seasons in the ETT and 42 seeded seasons in the PT. These ratios suggest about a 12% average precipitation increase during the seeded seasons, which may be attributed to seeding operations. A one-tail statistical test resulted in a P value of 0.06 for the PT precipitation evaluation suggests only a 6% probability of this result being due to chance. The 12% indicated precipitation increase for the ETT and PT precipitation evaluations is equivalent to approximately 1.3 inches of additional water per season for the ETT and PT, respectively.**

Snowpack evaluations for the current season yielded ratios of 1.08 (ETT) and 1.03 (PT). **<u>Long-term</u> results of the snowpack evaluations are 1.10 and 1.04 for the ETT and PT, based on 31 and 38 seeded seasons, respectively. As described in previous reports and in Section 5 of this season's report, the 2007, 2012, 2015 and 2017 snowpack data were excluded due to abnormal early season snowmelt in these years. <u>Due to some of the potential problems regarding snowpack observations (as discussed in Section 5.5), we believe that the multi-season December through March precipitation evaluations are likely more representative for the Primary Target area than are the snowpack evaluations.</u>**

As stated earlier, the seasonal average increases indicated by the December through March precipitation evaluation in the PT is an average of 1.3 inches of additional precipitation over the entire seeded PT area, and an average of 1.3 inches for the ETT. These values are probably underestimates of the actual seeding effect since they are specific to the December through March period; seeding in many winter seasons has been conducted outside of this period (e.g., during the month of April). For the PT, no attempt was made to evaluate the effects of seeding specific to the extension periods made possible through funding provided by the three Lower Colorado River Basin States, although similar increases (percentage-wise) would be expected as those which have been indicated for the core program. NAWC's experience has been that short time periods (e.g., one month) provide lower correlations than in a seasonal evaluation, and that evaluation of short periods (e.g., one month) is extremely difficult unless the effects of seeding are very large. Fortunately, we now have enough seeded seasons to result in a high level of confidence in the indications of the degree of increases in December through March target area precipitation.

6.2 Conclusions

Winter season cloud seeding in Utah, the nation's second-driest state, offers a viable method of increasing water supplies at very attractive benefit/cost ratios. The operational seeding program conducted over the central and southern Utah mountain watersheds during over 42 winter seasons appears to have consistently provided additional precipitation.

The value of the cloud seeding program was clearly demonstrated in an independent study performed by the Utah Division of Water Resources entitled "Utah Cloud Seeding Program, Increased Runoff/Cost Analyses" (Stauffer and Williams, 2000). The report used estimates of increases in April 1st water content from an earlier NAWC annual project report (similar to this one), but with verification of those numbers by the Division, to estimate increases in streamflow due to cloud seeding. This report was updated in 2012 (Hasenyager, *et* al, 2012). The results from this report for the various seeding target areas in Utah are summarized in Table 6-1.

Table 6-1
Increased Runoff and Cost for the Utah Cloud Seeding Projects

Project	Increased Runoff (ac-ft)	Cost ($)	Cost ($/ac-ft)
Northern Utah	56,300	87,097	1.55
Central and Southern	72,089	188,768	2.62
Western Uintas	17,122	45,703	2.67
High Uintas	36,190	90,432	2.50
Total	181,700	412,000	2.27

This report estimated an average annual increase in runoff due to cloud seeding in Utah of 181,700 acre-feet, which is an increase of 5.7 percent. The resulting cost per acre-foot for the additional water was $2.27 based upon the 2009-2010 total project costs.

An independent analysis of the Central/Southern Utah program **primary target area** seeding effectiveness was conducted by a statistical consulting firm (Mason and Chaara, 2007). Their summary statement regarding that evaluation follows: "This difference falls in a range of 0.218 to 2.437 inches of increase in average December through March precipitation in the target area. The analysis led to a p-value of 0.0465 for the Mann-Whitney test for difference; this is significant at the 5% level. It is noted that these data were from a non-randomized data set." The stated difference would be in the range of 2-20%. Importantly, the 5% significance level indicates a 95% statistical confidence that the indicated increase is not due to chance. The consultant further states that their analysis "supports the claim that the seeding program leads to a 10% or more increase in precipitation".

It is concluded, based on NAWC's evaluations, the UDWR independent analysis, and the evaluation conducted by the statistical consultant, that winter season weather modification in Utah is a viable, cost-effective method for enhancing water supplies. The cost to produce the additional water is very low and the attendant program benefit/cost ratio very attractive.

6.3 Recommendations

It is recommended that the winter seeding programs over the mountainous portions of central and southern Utah 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.

Other reasons to conduct the program in an ongoing fashion, rather than only during drier-than-normal winters, are that 1) it is very difficult to predict a wet or dry season in advance, 2) a season could start out wet, but then turn dry (the earlier seeding opportunities in the wet period would be missed), 3) drier seasons, by definition, will have fewer seeding opportunities, which means the total water increase due to seeding will be less, and 4) seeding in normal and above-normal water years will provide additional water supplies (surface and underground carryover) for use in dry periods.

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APPENDIX A

CLOUD SEEDING SUSPENSION CRITERIA

<u>Utah 2018-2019 Burn Area Suspension Criteria</u>

1. Introduction

North American Weather Consultants (NAWC) has operated a large winter operational cloud seeding program in the mountainous areas of central and southern Utah most winter seasons since 1974. Eleven to twelve counties in this area have sponsored these programs, which are administered by the Utah Water Resources Development Corporation, a non-profit Utah corporation. Grant monies provided by the State of Utah, Division of Water Resources have been used to provide financial support to these programs. The goal of these programs has been to enhance the snowpack in these mountainous target areas. This enhanced snowpack then results in additional spring and summer stream flow used for irrigated agriculture and municipal water supplies.

NAWC obtains licenses and permits each fall from the Utah Division of Water Resources (UDWRe) in order to conduct these programs. Seeding suspension criteria, administered by the UDWRe, are built into the design of these programs.

There were several wildfires in Utah during the summer of 2017. Some of these fires were located in or near one of the four cloud seeding target areas that will be active this winter season.

The following sections outline modifications of the standard seeding suspension criteria that have been adopted for the upcoming winter season for the burn areas in or near one of the four target areas.

2. Situations of Concern Regarding Burn Areas

There are two different types of concerns related to possible debris flows within the cloud seeding context: 1) High freezing level storms that cause rain not snow over these burn areas and 2) Snowpack accumulation above some percent of normal values.

2.1 High Freezing Level Storms that Cause Rain not Snow over these Burn Areas

NAWC has recognized the potential problems associated with cloud seeding operations during storm periods with high freezing levels which result in rainfall impacting high elevations during winter storms in Utah. The following illustrates how NAWC has addressed these situations:

> <u>The potential for wintertime flooding from rainfall on low elevation snowpack is fairly high in some (especially the more southern) target areas during the late winter/early spring period. Every precaution must be taken to insure accurate forecasting and timely</u>

suspension of operations during these potential flood-producing situations. The objective of suspension under these conditions is to eliminate both the real and/or perceived impact of weather modification when any increase in precipitation has the potential of adding to a potential flood hazard.

Fortunately, these situations are relatively easy to recognize in advance based upon the output from a variety of atmospheric forecast models. These suspension criteria are designed to avoid seeding during potential flash flood producing events.

These conditions are perhaps the situation of highest concern regarding the burn areas. Such storm periods that are warm and produce significant amounts of precipitation (e.g. > 0.50") especially those that have embedded high intensity rainfall periods may cause near instantaneous debris flows. Freezing levels associated with these events are typically above 8,000 and often above 9,000 feet MSL or higher. Fortunately, this type of situation is relatively rare during the winter months in Utah. Extreme southwestern Utah (e.g. Washington County) is the prime area where these conditions have occurred in the past.

NAWC will follow the standard suspension criteria (underlined above) to avoid seeding over any of the burn areas identified in Figure 1.

Independent of the above discussion, it should be noted that NAWC's general suspension criteria calls for suspension of seeding activities in areas for which the National Weather Service (NWS) issues a flash flood warning. Most of these warnings will be issued under the conditions described in the above but this may not always be the case. For example, the NWS may issue flash flood warnings for these burn areas in recognition of the potential for debris flows whereas without a burn area such warnings might not be issued.

2.2 Snowpack Accumulation Percent of Normal

NAWC has traditionally followed seeding suspension criteria that are based upon percent of normal snowpack values which vary from month to month. The Natural Resources Conservation Service (NRCS) maintains a network of high elevation snowpack measurement sites in the State of Utah, known as the SNOTEL network. SNOTEL automated observations are now readily available, updated as often as hourly. The following criteria were previously developed through collaboration between the UDWR and NAWC and have been used routinely and effectively in previous winter seasons. These criteria are based upon target area SNOTEL site observations as follows:

a. 200 % of average on January 1

b. 180 % of average on February 1

c. 160 % of average on March 1

d. 150 % of average on April 1

Suspensions based upon these criteria have occurred fairly often in past winter seasons. The decisions to suspend involve close coordination between the UDWR and NAWC. Sometimes these suspensions are short-lived; other suspensions have been as long as a few months in duration. Some suspensions have been for relatively small geographical portions of one of the Utah cloud seeding target areas. Other suspensions have encompassed entire river drainages. Since SNOTEL data are available daily, these suspension criteria can be reviewed daily. For example, on January 15th, interpolating between January 1st and February 1st, the cutoff suspension criteria would be 190% of normal. Some suspensions could be based upon single sites' percent of normal. More commonly there is a group of sites in a given region that exceed the criteria. Seeding operations are then conducted to avoid enhancing snowfall in this area but seeding operations may continue in adjacent areas that are below the suspension criteria. NAWC meteorologists consider low-level wind directions and plume transport predictions to determine which generators may be used near the suspension areas that would avoid seeding over the suspended areas.

This approach will be applied to the impacted burn areas. NAWC will select representative SNOTEL sites to represent these burn areas in order to perform these analyses.

Situations may arise concerning possible suspensions related to potential debris flows that are not covered in the above. NAWC will consider such situations on a case by case basis and may consult with UDWRe personnel. NAWC may temporarily suspend seeding operations that may impact these areas based upon these assessments.

The Utah UDWRe has created an interactive GIS map that is quite useful. It contains maps of the burn areas, generator locations and SNOTEL locations. One can zoom in on the map to better view the burn areas. Clicking on the SNOTEL locations can provide observational data. Here is the sign-in information:
http://arcg.is/2gW8JEh
login: cloudseeding_user
password : cloudhydro&91

NAWC's Standard Utah Winter Cloud Seeding Suspension Criteria

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

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

1. Excess snowpack accumulation

2. Rain-induced winter flooding

3. Severe weather

These situations are detailed in the following sub-sections.

1. Excess Snowpack Accumulation

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

a. 200 % of average on January 1

b. 180 % of average on February 1

c. 160 % of average on March 1

d. 150 % of average on April 1

Snowpack-related suspension considerations will be assessed on a geographical division or sub-division basis. The NRCS has divided the State of Utah into 13 such divisions as follows: Bear River, Weber-Ogden Rivers, Provo River-Utah Lake-Jordan River, Tooele Valley-Vernon Creek, Green River, Duchesne River, Price-San Rafael, Dirty Devil, South Eastern Utah, Sevier River, Beaver River, Escalante River, and Virgin River. Since SNOTEL observations are available on a daily basis, suspensions (and cancellation of suspensions) can be made on a daily basis using linear interpolation of the first of month criteria.

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

2. Rain-induced Winter Floods

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

3. Severe Weather

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

- **Snow Advisory** - This product is issued by the NWS when four to twelve inches of snow in 12 hours, or six to eighteen inches in 24 hours, are forecast to accumulate in mountainous regions above 7000 feet. Lower threshold criteria (in terms of the number of inches of snow) are issued for valleys and mountain valleys below 7000 feet.

- **Heavy Snow Warning** - This is issued by the NWS when it expects snow accumulations of twelve inches or more per 12-hour period or eighteen inches or more per 24-hour period in mountainous areas above 7000 feet. Lower criteria are used for valleys and mountain valleys below 7000 feet.

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

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

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

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

NAWC's project meteorologists have the authority to temporarily suspend localized seeding operations due to development of hazardous severe weather conditions even if the NWS has not issued a warning. This would be a rare event, but it is important for the operator to have this latitude.

APPENDIX B

HYSPLIT MODEL

The HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model is the newest version of a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations. Developed as a result of a joint effort between NOAA and Australia's Bureau of Meteorology, the model computes the advection and dispersion of any free-floating material released into the air from given point (or points). It is often used to forecast dispersion of smoke plumes, for example, but can also be utilized for a seeding material release (either real or hypothetical).

The dispersion of particles released into the atmosphere is calculated by assuming either puff or particle dispersion. In the puff model, puffs expand until they exceed the size of the meteorological grid cell (either horizontally or vertically) and then split into several new puffs, each with its share of the pollutant mass. In the HYSPLIT particle model, a fixed number of initial particles are advected about the model domain by the mean wind field and a turbulent component. The model's default configuration assumes a puff distribution in the horizontal and particle dispersion in the vertical direction. In this way, the greater accuracy of the vertical dispersion parameterization of the particle model is combined with the advantage of having an ever-expanding number of particles represent the pollutant distribution.

The model can be run interactively on the Web through the READY system on the NOAA site, or the code executable and meteorological data can be downloaded to a Windows PC. The Web version has been configured with some limitations to avoid computational saturation of the web server. The registered PC version is complete with no computational restrictions, except that the user must download the necessary meteorological data files. The unregistered version is identical to the registered version except that it will not work with forecast meteorology data files.

NAWC has utilized the HYSPLIT model to assist in the conduct of its wintertime cloud seeding programs. Section 3 of the report contains an example of HYSPLIT output from the past winter season.

APPENDIX C

PRECIPITATION AND SNOWPACK CONTROL/TARGET STATIONS

PRIMARY TARGET - PRECIPITATION

Site Name	Lat(N)	Long(W)	Elev (Ft)
Control Sites			
Bear Creek Tel, Nv	41°50'	115°27'	8040
Berry Creek Tel, Nv	39°21'	114°39'	9100
Caliente, NV	37°37'	114°31'	4440
Ely, NV	39°17'	114°51'	6250
Flagstaff Airport, AZ	35°08'	111°40'	7000
Jacks Peak Tel, NV	41°32'	116°01'	8420
McGill, Nv	39°24'	114°46'	6340
Pole Creek RS, Tel Nv	41°52'	115°15'	8330
Seligman, Az	35°19'	112°53'	5250
Seventy-Six Ck Tel Nv	41°42'	115°28'	7100
Ward Mountain, Tel #2 Nv	39°08'	114°49'	9200
Wupatki NM, Az	35°31'	111°22'	4908
Target Sites			
Alton	37°26'	112°29'	7040
Beaver Dams	39°08'	111°33'	8000
Big Flat	38°18'	112°21'	10290
Black Fl. UM Ck.	38°41'	111°36'	9400
Box Creek	38°30'	112°02'	9300
Buck Flat	39°08'	111°27'	9800
Castle Valley	37°40'	112°44'	9580
Dills Camp	39°02'	111°28'	9200
Farnsworth Lake	38°46'	111°40'	9600
Gooseberry R.S.	38°48'	111°41'	7920
Hatch	37°39'	112°26'	6910
Kimberly Mine	38°29'	112°23'	9300
Kolob	37°32'	113°03'	9250
Little Grassy Ck.	37°29'	113°51'	6100
Long Flat	37°30'	113°25'	8000
Mammoth-Cottonwood	39°41'	111°19'	8800
Merchant Valley	38°18'	112°26'	8750
Midway Valley	37°34'	112°50'	9800
Pickle Keg Spring	39°02'	111°35'	9600
Pine Creek	38°53'	112°15'	8800

PRIMARY TARGET - PRECIPITATION (continued)

Site Name	Lat(N)	Long(W)	Elev (Ft)
Target Sites			
Red Pine Ridge	39°27'	111°16'	9200
Scofield-Skyland Mine	39°41'	111°12'	8710
Seeley Ck. R.S.	39°19'	111°26'	10000
Webster Flat	37°35'	112°54'	9200
Widtsoe-Esc. # 3	37°50'	111°53'	9500

EASTERN TOOELE TARGET - PRECIPITATION

Site Name	Lat(N)	Long(W)	Elev (Ft)
Control Sites			
Berry Creek, NV	39°21'	114°39'	9100
Diamond Peak, NV	39°34'	115°51'	8040
Farmington Cyn Upr, UT	40°58'	111°48'	8000
Lamoille #3, NV	40°38'	115°24'	7700
Payson R.S., UT	39°56'	111°38'	8050
Ward Mtn #2, NV	39°08'	114°49'	9200
Target Sites			
Rocky Basin Setlmnt, UT	40°26'	112°13'	8900
Tooele, UT	40°32'	112°18'	5072
Vernon Creek, UT	39°56'	112°25'	7500

PRIMARY TARGET - SNOW COURSE AND SNOW PILLOW

Site No.	Lat(N)	Long(W)	Elev (Ft)
Control Sites			
Bright Angel Sc, Az	36°13'	112°04'	8400
Grand Canyon Sc, Az	35°58'	111°58'	7500
Snowbowl #2 Sc, Az	35°19'	111°42'	11,200
Bostetter RS Pil, Id	42°10'	114°11'	7500
Berry Creek, Pil, Nv	39°21'	114°39'	9100
Dorsey Basin Pil, Nv	40°53'	115°12'	8100
Green Mountain Pil, Nv	40°23'	115°32'	8000
Corral Canyon Pil, Nv	40°17'	115°32'	8500
Ward Mountain #2 Pil, Nv	39°08'	114°49'	9200
Pole Creek RS, Pil, Nv	41°52'	115°15'	8330
Target Sites			
Beaver Dams Pil	39°08'	111°33'	8000
Big Flat Pil	38°18'	112°21'	10290
Black Fl UM Creek Pil	38°41'	111°36'	9400
Box Creek Pil	38°30'	112°02'	9300
Buck Flat Pil	39°08'	111°27'	9800
Dill's Camp Pil	39°03'	111°27'	9200
Farnsworth Lake Pil	38°46'	111°40'	9600
Fish Lake Sc	38°33'	111°43'	8700
GBRC Alp Mead. Sc	39°18'	111°27'	10000
GBRC Headqts. Sc	39°19'	111°29'	8700
Gooseberry RS Pil	38°47'	111°41'	8400
Huntington Hrshoe Sc	39°37'	111°19'	9800
Kimberly Mine Pil	38°29'	112°23'	9300
Mammoth-Ctnwood Pil	39°41'	111°19'	8800
Mt. Baldy RS Sc	39°08'	111°30'	9500
Oak Creek SC	39°21'	112°21'	7760
Pickle Keg Spring Pil	39°02'	111°35'	9600
Pine Creek Pil	38°53'	112°15'	8800
Red Pine Ridge Pil	39°28'	111°16'	9200
Seeley Creek R.S. Pil	39°19'	111°26'	10000
Box Springs Pil*	38°30'	112°00'	9300
Thistle Flat Sc	39°14'	111°37'	8500
Upper Joes Valley Sc	39°26'	111°15'	8900

* Box Springs SNOTEL was previously the Squaw Springs snow course site

PRIMARY TARGET - SNOW COURSE AND SNOW PILLOW (continued)

Site Name	Lat(N)	Long(W)	Elev (Ft)
Wrigley Creek Sc	39°09'	111°20'	9000
Bryce Canyon Sc	37°38'	112°12'	8000
Castle Valley Pil	37°40'	112°44'	9500
Long Flat Pil	37°30'	113°25'	8000
Midway Valley Pil	37°34'	112°51'	9800
Tall Poles Sc	37°43'	112°51'	8800
Webster Flat Pil	37°59'	112°54'	9200
Widtsoe Esc. #3 Pil	37°50'	111°53'	9500
Yankee Res. Sc	37°32'	112°48'	8700

EASTERN TOOELE TARGET - SNOW COURSE AND SNOW PILLOW

Control Sites			
Baker Creek #2, NV	38°58'	114°17'	8950
Bostetter RS, ID	42°10'	114°11'	7500
Corral Canyon, NV	40°17'	115°32'	8500
Murray Summit, NV	39°14'	114°58'	7250
Payson R.S., UT	39°56'	111°38'	8050
Target Sites			
Bevan's Cabin, UT	40°28'	112°15'	6450
Rocky Basin Settlement, UT	40°26'	112°13'	8900
Vernon Creek, UT	39°56'	112°25'	7500

APPENDIX D

PRECIPITATION AND SNOWPACK ANALYSIS RESULTS TABLES

Note: In the following analyses, the current season data are considered preliminary.

Primary Target Linear Regression
Dec-Mar Precipitation

YEAR	Control	Target	Predicted	Ratio	Increase
Regression (non-seeded) period:					
1957	9.6	12.7	13.1	0.97	-0.4
1958	10.3	13.9	14.3	0.98	-0.3
1959	6.6	8.8	7.9	1.11	0.9
1960	9.3	13.2	12.6	1.05	0.6
1961	6.6	8.5	8.0	1.06	0.5
1962	10.9	14.9	15.2	0.98	-0.3
1963	6.7	9.0	8.2	1.10	0.8
1964	6.9	8.4	8.4	1.00	0.0
1965	9.9	13.3	13.6	0.98	-0.3
1966	7.2	9.3	8.9	1.04	0.4
1967	9.5	12.0	12.8	0.94	-0.8
1968	9.3	12.9	12.6	1.03	0.3
1969	11.9	18.4	17.0	1.09	1.5
1970	8.0	10.6	10.4	1.02	0.2
1971	7.9	9.7	10.1	0.96	-0.4
1972	8.0	7.6	10.3	0.74	-2.7
1973	10.6	14.7	14.7	1.00	0.0
1984	10.6	14.8	14.6	1.01	0.1
Historical Mean	8.9	11.8	11.8	1.00	0.0

Seeded period:

YEAR	Control	Target	Predicted	Ratio	Increase
1974	8.6	11.3	11.3	1.00	0.0
1975	9.1	12.8	12.1	1.06	0.7
1976	7.7	9.9	9.9	1.01	0.1
1977	4.6	6.4	4.6	1.40	1.8
1978	13.0	20.3	18.7	1.08	1.6
1979	10.5	16.3	14.5	1.12	1.8
1980	11.8	20.5	16.7	1.23	3.9
1981	6.6	9.3	8.0	1.16	1.3
1982	11.4	16.9	16.1	1.05	0.8
1983	10.8	17.5	15.0	1.17	2.5
1985*	7.0	11.3	8.6	1.31	2.7
1986*	9.1	10.9	12.2	0.89	-1.3
1987*	6.6	9.7	8.0	1.21	1.7
1988	6.2	9.8	7.2	1.36	2.6
1989	8.0	10.2	10.3	0.99	-0.1

YEAR	Control	Target	Predicted	Ratio	Increase
1990	6.5	9.1	7.8	1.17	1.3
1991	6.6	10.8	8.0	1.34	2.7
1992	6.4	10.2	7.6	1.34	2.6
1993	13.1	19.7	19.0	1.04	0.7
1994	5.7	8.7	6.5	1.35	2.3
1995	9.0	14.0	12.0	1.17	2.0
1996	9.1	12.9	12.2	1.05	0.7
1997	8.8	12.2	11.6	1.05	0.5
1998	9.4	14.4	12.6	1.14	1.8
1999	5.7	6.9	6.4	1.07	0.4
2000	8.3	12.4	10.8	1.15	1.7
2001	5.9	9.5	6.8	1.39	2.7
2002	5.9	6.2	6.7	0.92	-0.6
2003	5.8	9.6	6.6	1.45	3.0
2004	7.3	11.0	9.2	1.20	1.8
2005	10.3	15.9	14.2	1.13	1.8
2006	9.7	13.7	13.1	1.04	0.5
2007	6.3	7.2	7.4	0.98	-0.2
2008	8.8	15.1	11.7	1.28	3.3
2009	8.7	13.1	11.6	1.13	1.5
2010	8.4	13.8	11.1	1.24	2.7
2011	10.3	16.6	14.3	1.16	2.3
2012	6.6	8.7	7.9	1.09	0.7
2013	7.1	9.2	8.9	1.04	0.4
2014	6.1	7.9	7.1	1.10	0.7
2015	6.5	8.4	7.7	1.09	0.7
2016	8.8	11.4	11.7	0.98	-0.3
2017	12.6	16.1	18.0	0.89	-2.0
2018	6.1	8.5	7.2	1.18	1.3
2019	11.0	15.7	15.3	1.03	0.4
Seeded Mean	8.3	12.1	10.8	**1.12**	**1.3**

*Seeding conducted in adjacent areas, but not target area

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.955721
R Square	0.913403

	Coefficients
Intercept	-3.173422
X Variable 1	1.688715

Eastern Tooele Target Linear Regression
Dec-Mar Precipitation

YEAR	Control	Target	Predicted	Ratio	Increase
Regression (non-seeded) period					
1957	13.3	10.6	10.9	0.97	-0.4
1958	16.7	11.7	13.9	0.84	-2.2
1959	10.5	8.4	8.4	0.99	-0.1
1960	13.8	11.2	11.4	0.98	-0.2
1961	9.2	6.7	7.3	0.92	-0.6
1962	15.8	11.6	13.2	0.88	-1.6
1963	10.6	7.7	8.6	0.89	-0.9
1964	11.4	7.8	9.3	0.84	-1.5
1965	16.4	12.0	13.6	0.88	-1.6
1966	10.5	7.4	8.5	0.87	-1.1
1967	16.1	10.1	13.4	0.75	-3.3
1968	15.2	10.7	12.6	0.85	-1.9
1969	20.6	17.7	17.3	1.02	0.4
1970	11.7	7.2	9.5	0.76	-2.3
1971	13.3	15.4	11.0	1.40	4.4
1972	11.2	7.6	9.1	0.84	-1.5
1973	18.2	20.1	15.2	1.32	4.9
1974	14.5	8.7	12.0	0.73	-3.3
1975	16.0	12.8	13.3	0.96	-0.5
1983	18.1	16.1	15.1	1.06	1.0
1984	18.7	13.7	15.6	0.88	-1.9
1985	11.0	11.6	8.9	1.29	2.6
1986	16.1	13.8	13.4	1.03	0.4
1987	10.6	11.2	8.6	1.30	2.6
1988	9.5	9.5	7.6	1.25	1.9
1993	16.9	17.3	14.1	1.23	3.3
1994	11.4	10.4	9.3	1.13	1.2
1995	15.3	14.8	12.6	1.17	2.2
Historical Mean	14.0	11.6	11.6	1.00	0.0

Seeded period:

YEAR	Control	Target	Predicted	Ratio	Increase
1976	11.5	10.3	9.4	1.10	0.9
1977	8.6	6.6	6.9	0.96	-0.2
1978	19.4	20.7	16.3	1.27	4.4
1979	13.9	12.5	11.5	1.09	1.0
1980	18.8	19.6	15.8	1.24	3.8
1981	11.5	8.9	9.3	0.95	-0.5
1982	19.4	15.5	16.3	0.95	-0.8
1989	13.2	11.0	10.8	1.02	0.2
1990	9.6	9.8	7.7	1.27	2.1
1991	9.3	8.4	7.4	1.13	1.0

YEAR	Control	Target	Predicted	Ratio	Increase
1992	9.2	7.4	7.4	1.01	0.1
1996	17.1	14.2	14.2	1.00	0.0
1997	15.5	15.0	12.9	1.16	2.1
1998	17.5	20.2	14.6	1.39	5.6
1999	10.9	9.3	8.8	1.05	0.5
2000	15.1	15.2	12.5	1.21	2.6
2001	10.3	9.4	8.3	1.12	1.0
2002	10.4	8.4	8.4	1.00	0.0
2003	9.5	8.7	7.6	1.14	1.1
2004	13.5	15.0	11.1	1.34	3.8
2005	16.1	15.4	13.4	1.15	2.0
2006	17.6	15.4	14.7	1.05	0.7
2007	10.3	9.9	8.3	1.19	1.6
2008	15.4	14.7	12.7	1.15	2.0
2009	15.9	13.6	13.2	1.03	0.4
2010	13.6	11.5	11.2	1.03	0.3
2011	17.9	16.6	14.9	1.11	1.6
2012	8.9	8.5	7.1	1.19	1.3
2013	10.3	9.5	8.3	1.15	1.2
2014	11.1	10.4	9.0	1.15	1.3
2015	7.7	6.2	6.0	1.03	0.2
2016	14.4	13.2	11.9	1.10	1.2
2017	20.0	18.8	16.8	1.12	2.0
2018	9.7	8.6	7.8	1.10	0.8
2019	18.9	17.3	15.8	1.09	1.5
Seeded Mean	13.5	12.4	11.1	**1.12**	**1.3**

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.782368
R Square	0.612099
Adjusted R Square	0.59718
Standard Error	2.231851
Observations	28

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	-0.69476	1.959753	-0.354514	0.725813	-4.72309
X Variable 1	0.875061	0.136616	6.405266	8.73E-07	0.594243

Primary Target
Apr 1 Snow Water Content

YEAR	Control	Target	Predicted	Ratio	Increase
Regression (non-seeded) period:					
1956	14.9	12.3	15.1	0.82	-2.7
1957	15.3	16.9	15.4	1.10	1.5
1958	20.2	20.6	20.5	1.00	0.1
1959	9.6	10.4	9.6	1.09	0.8
1960	12.4	13.9	12.5	1.11	1.4
1961	12.7	11.3	12.7	0.89	-1.4
1962	20.3	20.1	20.6	0.98	-0.5
1963	8.9	10.3	8.8	1.17	1.5
1964	12.0	11.4	12.1	0.95	-0.7
1965	16.2	17.9	16.4	1.09	1.5
1966	11.2	10.5	11.2	0.93	-0.7
1967	11.5	10.8	11.5	0.94	-0.7
1968	13.5	16.8	13.6	1.24	3.3
1969	21.0	23.1	21.4	1.08	1.7
1970	14.3	15.2	14.4	1.06	0.8
1971	14.9	14.4	15.1	0.96	-0.6
1972	12.2	8.4	12.3	0.69	-3.9
1973	21.6	20.7	21.9	0.94	-1.2
1984	23.8	24.1	24.2	0.99	-0.2
Historical Mean	15.1	15.2	15.2	1.00	0.0

YEAR	Control	Target	Predicted	Ratio	Increase
1974	13.9	15.6	14.0	1.11	1.6
1975	18.0	17.3	18.3	0.95	-1.0
1976	12.7	12.9	12.8	1.01	0.2
1977	8.1	8.2	8.0	1.02	0.2
1978	18.6	21.8	18.9	1.15	2.9
1979	18.0	21.4	18.2	1.17	3.2
1980	19.3	23.6	19.6	1.20	4.0
1981	9.6	10.2	9.6	1.06	0.6
1982	20.3	20.5	20.7	0.99	-0.2
1983	23.1	26.0	23.6	1.10	2.4
1985*	16.3	16.5	16.5	1.00	0.0
1986*	13.8	15.7	13.9	1.13	1.8
1987*	11.2	13.0	11.2	1.17	1.9
1988	10.5	13.1	10.5	1.25	2.7
1989	14.5	11.3	14.6	0.77	-3.4
1990	9.2	10.5	9.1	1.16	1.4
1991	12.3	12.8	12.3	1.04	0.5
1992	11.7	12.1	11.7	1.04	0.4
1993	20.1	21.3	20.4	1.04	0.9
1994	9.3	10.8	9.3	1.17	1.6

YEAR	Control	Target	Predicted	Ratio	Increase
1995	17.8	16.6	18.0	0.92	-1.4
1996	13.7	14.6	13.8	1.06	0.8
1997	15.5	15.1	15.7	0.96	-0.6
1998	17.1	16.7	17.4	0.96	-0.7
1999	10.3	8.1	10.3	0.79	-2.2
2000	12.8	13.7	12.9	1.06	0.8
2001	10.8	11.3	10.8	1.04	0.5
2002	10.4	9.6	10.4	0.92	-0.8
2003	9.5	12.1	9.5	1.28	2.6
2004	9.3	10.2	9.2	1.11	1.0
2005	20.8	20.1	21.1	0.95	-1.0
2006	16.7	17.4	16.9	1.03	0.5
2007**	7.9	6.8	7.8	0.87	-1.0
2008	15.1	16.1	15.2	1.06	0.8
2009	12.9	12.7	13.0	0.98	-0.2
2010	14.7	15.1	14.8	1.02	0.3
2011	16.0	20.1	16.2	1.24	3.9
2012**	7.3	7.9	7.1	1.11	0.8
2013	8.9	9.3	8.8	1.06	0.5
2014	9.5	9.9	9.4	1.05	0.5
2015**	5.0	6.1	4.7	1.28	1.3
2016	14.2	12.8	14.4	0.89	-1.5
2017**	16.4	13.9	16.6	0.84	-2.7
2018	8.2	7.9	8.1	0.97	-0.2
2019	18.7	19.5	18.9	1.03	0.6
Seeded Mean	14.0	14.7	14.1	1.04	0.6

* Seeding conducted in adjacent areas but not target area
** Results not included in average due to early snowmelt

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9355563
R Square	0.8752657
Adjusted R Square	0.8679284
Standard Error	1.7407636
Observations	19

	Coefficients
Intercept	-0.37896640
X Variable	1.03556085

Primary Target
Apr 1 Snow Water Content Multiple Regression with Two Control Groups (North, South)

YEAR	North Ctrl	South Ctrl	Target	Predicted	Ratio	Increase
Regression period:						
1956	20.5	9.3	12.3	14.5	0.85	-2.2
1957	16.8	13.7	16.9	15.9	1.06	1.0
1958	25.5	14.9	20.6	20.3	1.02	0.3
1959	12.3	6.9	10.4	9.5	1.10	0.9
1960	13.7	11.2	13.9	12.9	1.08	1.0
1961	17.6	7.7	11.3	12.3	0.93	-0.9
1962	22.8	17.7	20.1	21.1	0.96	-0.9
1963	10.2	7.6	10.3	9.1	1.14	1.2
1964	17.1	6.9	11.4	11.5	0.99	-0.1
1965	20.0	12.4	17.9	16.4	1.09	1.5
1966	11.1	11.3	10.5	11.9	0.88	-1.4
1967	14.4	8.5	10.8	11.4	0.94	-0.7
1968	12.6	14.3	16.8	14.6	1.16	2.3
1969	21.1	21.0	23.1	22.5	1.03	0.6
1970	18.1	10.4	15.2	14.3	1.07	1.0
1971	21.0	8.9	14.4	14.4	1.00	0.0
1972	19.1	5.4	8.4	11.3	0.75	-2.9
1973	20.9	22.3	20.7	23.3	0.89	-2.6
1984	36.7	10.9	24.1	22.3	1.08	1.8
Historical Mean	18.5	11.6	15.2	15.2	1.00	0.0

YEAR	North Ctrl	South Ctrl	Target	Predicted	Ratio	Increase
Seeded Period:						
1974	20.9	7.0	15.6	13.1	1.19	2.5
1975	24.4	11.6	17.3	17.7	0.98	-0.4
1976	18.2	7.1	12.9	12.1	1.07	0.8
1977	9.9	6.3	8.2	8.1	1.01	0.1
1978	19.5	17.7	21.8	19.7	1.11	2.1
1979	19.0	17.0	21.4	19.0	1.13	2.4
1980	19.6	19.0	23.6	20.6	1.15	3.0
1981	10.1	9.1	10.2	10.1	1.01	0.1
1982	25.8	14.9	20.5	20.4	1.00	0.0
1983	24.6	21.6	26.0	24.4	1.06	1.6
1985*	17.8	14.9	16.5	17.1	0.97	-0.5
1986*	16.2	11.3	15.7	14.0	1.12	1.6
1987*	12.2	10.2	13.0	11.6	1.12	1.4
1988	13.5	7.4	13.1	10.3	1.27	2.8

YEAR	North Ctrl	South Ctrl	Target	Predicted	Ratio	Increase
1990	11.3	7.0	10.5	9.2	1.15	1.4
1991	12.7	11.9	12.8	13.0	0.99	-0.1
1992	10.0	13.3	12.1	12.8	0.95	-0.7
1993	17.2	22.9	21.3	22.2	0.96	-0.9
1994	9.9	8.7	10.8	9.7	1.12	1.1
1995	15.7	19.8	16.6	19.5	0.85	-2.9
1996	20.4	7.0	14.6	12.9	1.13	1.7
1997	19.7	11.3	15.1	15.5	0.97	-0.4
1998	18.3	15.9	16.7	18.0	0.93	-1.3
1999	14.8	5.7	8.1	9.7	0.83	-1.6
2000	16.0	9.6	13.7	12.8	1.07	0.9
2001	11.3	10.3	11.3	11.3	1.00	0.0
2002	15.8	5.0	9.6	9.7	0.99	-0.1
2003	10.1	8.9	12.1	9.9	1.22	2.2
2004	12.7	5.9	10.2	8.9	1.15	1.3
2005	18.4	23.1	20.1	22.8	0.88	-2.7
2006	23.9	9.4	17.4	16.0	1.09	1.4
2007**	11.2	4.5	6.8	7.4	0.91	-0.6
2008	17.7	12.5	16.1	15.4	1.04	0.6
2009	15.3	10.5	12.7	13.1	0.97	-0.4
2010	14.0	15.3	15.1	15.8	0.95	-0.7
2011	19.6	12.4	20.1	16.2	1.24	3.9
2012**	9.5	5.1	7.9	7.1	1.12	0.9
2013	12.0	5.8	9.3	8.6	1.08	0.7
2014	14.1	4.8	9.9	8.8	1.12	1.0
2015**	6.0	3.9	6.1	4.9	1.26	1.2
2016	21.0	7.4	12.8	13.5	0.95	-0.6
2017**	18.8	13.9	13.9	16.9	0.82	**-3.0**
2018	12.1	4.3	7.9	7.7	1.03	0.3
2019	21.9	15.4	19.5	19.2	1.02	0.4
Seeded Mean	16.6	11.4	14.7	14.3	**1.03**	**0.4**

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.949996055
R Square	0.902492504

	Coefficients
Intercept	-0.260923565
X North	0.417766179
X South	0.666458753

Eastern Tooele Target
Apr 1 Snow Water Content

YEAR	Control	Target	Predicted	Ratio	Increase
Regression (non-seeded) period:					
1956	16.3	8.9	16.7	0.54	-7.7
1957	14.2	16.0	14.4	1.11	1.6
1958	20.9	16.2	21.6	0.75	-5.4
1959	10.6	10.2	10.5	0.97	-0.3
1960	12.0	16.2	12.0	1.35	4.2
1961	12.8	10.5	12.9	0.82	-2.3
1962	20.7	18.8	21.3	0.88	-2.5
1963	7.9	7.1	7.6	0.93	-0.5
1964	13.8	14.0	14.0	1.00	0.0
1965	17.0	16.3	17.4	0.93	-1.1
1966	11.1	9.4	11.1	0.85	-1.6
1967	12.7	11.9	12.7	0.93	-0.9
1968	12.5	14.0	12.6	1.12	1.4
1969	22.4	25.5	23.2	1.10	2.3
1970	14.7	11.9	14.9	0.79	-3.1
1971	16.6	16.6	17.0	0.98	-0.4
1972	15.3	8.7	15.5	0.56	-6.9
1973	20.4	32.1	21.0	1.53	11.1
1974	17.2	13.1	17.6	0.74	-4.5
1975	18.1	20.1	18.6	1.08	1.5
1983	22.4	21.0	23.2	0.90	-2.2
1984	27.1	30.8	28.1	1.10	2.7
1985	15.0	20.3	15.2	1.33	5.1
1986	16.0	12.8	16.3	0.79	-3.5
1987	11.3	15.3	11.3	1.36	4.0
1988	11.7	12.2	11.7	1.05	0.6
1993	16.1	19.9	16.4	1.21	3.5
1994	10.0	11.5	9.9	1.16	1.6
1995	13.8	17.0	13.9	1.22	3.1
Historical Mean	15.5	15.8	15.8	1.00	0.0

Seeded period:

YEAR	Control	Target	Predicted	Ratio	Increase
1976	15.7	15.6	16.0	0.98	-0.4
1977	6.2	9.3	5.8	1.59	3.5
1978	17.4	21.1	17.8	1.18	3.3
1979	18.9	18.0	19.4	0.93	-1.4
1980	19.0	24.4	19.5	1.25	4.8
1981	9.3	12.5	9.2	1.36	3.3
1982	21.4	19.6	22.1	0.89	-2.5
1989	13.9	9.9	14.1	0.70	-4.2
1990	10.7	12.4	10.7	1.16	1.7
1991	10.2	10.5	10.1	1.05	0.5

YEAR	Control	Target	Predicted	Ratio	Increase
1992	8.7	10.3	8.5	1.21	1.8
1996	14.5	12.8	14.7	0.87	-1.9
1997	14.8	17.9	15.0	1.19	2.9
1998	14.8	23.4	15.0	1.56	8.4
1999	10.1	8.8	10.0	0.88	-1.2
2000	11.2	15.9	11.2	1.42	4.7
2001	8.7	11.4	8.5	1.35	3.0
2002	11.2	11.0	11.2	0.98	-0.2
2003	8.5	9.6	8.3	1.16	1.3
2004	10.2	15.0	10.1	1.49	4.9
2005	18.0	20.2	18.5	1.09	1.7
2006	16.6	16.3	17.0	0.96	-0.6
2007*	6.8	7.2	6.4	1.11	0.7
2008	14.3	17.5	14.4	1.21	3.1
2009	12.6	13.9	12.6	1.10	1.2
2010	12.2	13.0	12.2	1.06	0.8
2011	16.0	21.9	16.3	1.34	5.5
2012*	8.2	7.2	7.9	0.91	-0.7
2013	7.9	10.0	7.7	1.30	2.3
2014	10.1	8.3	9.9	0.83	-1.7
2015*	4.1	1.5	3.6	0.43	-2.0
2016	13.6	12.0	13.8	0.87	-1.8
2017*	12.9	13.8	13.0	1.06	0.8
2018	8.3	5.3	8.1	0.66	-2.8
2019	19.3	21.4	19.8	1.08	1.6
Seeded Mean	13.1	14.5	13.1	**1.10**	**1.3**

* Not included in mean due to early-season snowmelt

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.766963
R Square	0.588233
Adjusted R Square	0.572982
Standard Error	3.975414
Observations	29

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	-0.80605	2.774503	-0.29052	0.773637	-6.49886
X Variable 1	1.068717	0.172081	6.210555	1.22E-06	0.715637

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