THE CONDUCT AND EVALUATION OF A CLOUD SEEDING PROGRAM FOR THE UPPER GUNNISON RIVER BASIN, COLORADO DURING THE 2011-2012 WINTER SEASON

Prepared for

Dos Rios Water System
East River Regional Sanitation District
Gunnison County
Gunnison County Stockgrowers Association
Town of Mt. Crested Butte
Skyland Metropolitan District
Upper Gunnison River Water Conservancy District

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Report No. WM 12-3
Project No. 11-294

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1.0 INTRODUCTION

North American Weather Consultants (NAWC) again conducted a winter cloud seeding program for the upper Gunnison River Basin from November 15, 2011 through April 15, 2012. This was the tenth season for the program, which initially included only those drainages above 9,000 feet MSL in Gunnison County during the first season (2002-2003). At the request of the sponsors, it was expanded to include watersheds above 9,000 feet that had their headwaters in two adjoining counties to the south (Hinsdale and Saguache). The Colorado Water Conservation Board (CWCB) granted a five-year permit to NAWC for the addition to the earlier target area in the fall of 2003. The first of the two CWCB cloud seeding permits issued for the Gunnison County program expired on April 15, 2007. A second permit was approved in Novemher 2007, covering both of the target areas, for the subsequent five-year period.

The 2011-2012 program was the ninth seeded season for the expanded target area. The CWCB also provided grant funds to those operating cloud seeding programs in Colorado for the past six winter seasons. A grant to the Upper Gunnison River program was authorized by the CWCB for this past winter season. Financial support was also provided through an agreement between the CWCB and the three Lower Colorado River Basin states.

There were 20 cloud seeding generator sites available for operations this past season. There were 14 seeded storm events occurred during the operational season. The following sections descrihe this season's operations and evaluation of effectiveness in more detail.

A technical paper summarizing this program was published in the Weather Modification Association's *Journal of Weather Modification,* Volume 43, in April 2011. The title of this peer reviewed paper is "A Winter Operational Cloud Seeding Program: Upper Gunnison River Basin."

2.0 PROJECT DESIGN

2.1 Background

The operational procedures utilized for the Upper Gunnison River cloud seeding program are the same as those that have proven effective in more than 30 years of cloud seeding in the mountains of Utah and elsewhere in the mountainous west. Results from these operational programs have consistently indicated increases in wintertime precipitation and snowpack in the target areas (e.g., Griffith, et al, 1991; 1997; 2009).

2.2 Seedability Criteria

NAWC follows a seeding decision making policy called selective seeding, which is the most efficient and cost-effective method, and provides the most beneficial results. Selective seeding means that seeding is conducted only during specific time periods, and in specific locations, where it is likely to be effective. This decision is based on several criteria, which determine the seedability of the storm. These criteria deal with key characteristics of the atmosphere (temperature, stability, wind flow, and moisture content) both in and below the clouds, and are presented in Table 2-1. Use of this focused seeding methodology has yielded consistently favorable results at very attractive benefit/cost ratios in a numher of NAWC projects conducted in the mountainous western states.

2.3 Suspension Criteria

As required in the cloud seeding permit granted by the Colorado Water Conservation Board, seeding operations shall not be undertaken, or shall be suspended, if:

- There is any emergency that affects public welfare in the region.

- The National Weather Service (NWS) forecasts a storm to produce unusually heavy precipitation that could contribute to avalanches or unusually severe weather conditions in the project area.

- The Colorado Avalanche Center issues an Extreme avalanche forecast warning for avalanche areas located in the target area (note, see modifications to this suspension criterion below).

- The National Weather Service forecasts a warm winter storm (freezing level above 8000 feet) with the possibility of considerable rain at the higher elevations that might lead to local flooding.

- When potential flood conditions exist in or around any of the project areas the Permit Holder shall consult with the NWS Flood Forecast services. If the NWS determines any of the following warnings or forecasts are in effect:

  1. Flash flood warnings hy the NWS.
  2. Forecasts of excessive runoff issued hy a river basin forecast center
  3. Quantitative precipitation forecasts issued by the NWS, which would produce excessive runoff in or around the project area.

In addition, seeding is to be suspended at any time the snowpack water equivalents at selected target SNOTEL sites exceed: 175% of average on Dec. 1st, 170% of average on Jan. 1st, 160% of average on Feb. 1st, 150% of average on Mar. 1st and 140% of average on Apr. 1st when two or more SNOTEL sites located in the target area exceed these amounts. A provision is made wherehy seeding can continue in a portion of the target area that is below the suspension criteria, using generators not expected to impact the SNOTEL sites that exceed the suspension criteria. Appendix A contains the suspension criteria in the weather modification permit.

Previous discussions with the CWCB concerning the avalanche suspension criteria led to a change in these criteria during the 2007-2008 winter season. This change was tied to special daily forecasts issued to the Colorado Department of Transportation (CDOT) by the Colorado Avalanche Information Center (CAIC). An agreement in principle was reached on December 7, 2007 that these forecasts, which focus on the more populated areas near or in the target area, could be used in place of the general forecasts issued by the CAIC which primarily focus on back-country areas. Seeding operations were to be suspended when the CAIC issued a "high" category rating. These revised suspension criteria have been used in subsequent seasons.

Table 2-1
NAWC Winter Cloud Seeding Criteria

1) CLOUD BASES ARE BELOW THE MOUNTAIN BARRIER CREST.

2) LOW-LEVEL WIND DIRECTIONS AND SPEEDS THAT 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 IS -5 C (23 F) OR COLDER.

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

2.4 Equipment and Project Set-Up

The target area for the 2011-2012 winter season was the same as that of the past several seasons. The operational period was November 15, 2011 through April 15, 2012. Figure 2.1 shows the seeding target areas and ground Cloud Nuclei Generator (CNG) sites. Table 2-2 lists the names, latitude and longitude and elevation information for the available CNG sites.

Figure 2.2 is a photo of a ground-based CNG, similar to those used in the Upper Gunnison River program. The cloud seeding equipment at each site consists of a cloud seeding generator unit and a propane gas supply. The seeding solution contains two percent (by weight) silver iodide (AgI), the active seeding agent, complexed with very small amounts of sodium iodide and para-dichlorobenzene in solution with acetone. Dr. William Finnegan of the Desert Research Institute published a paper (Finnegan, 1999) indicating that this formulation is superior to those that produce pure silver iodide particles. The modified particles act as ice-forming nuclei much more quickly, and the formulation produces somewhat larger numbers of effective nuclei at warmer temperatures (e.g. about -5 to -10C), both highly desirable characteristics.

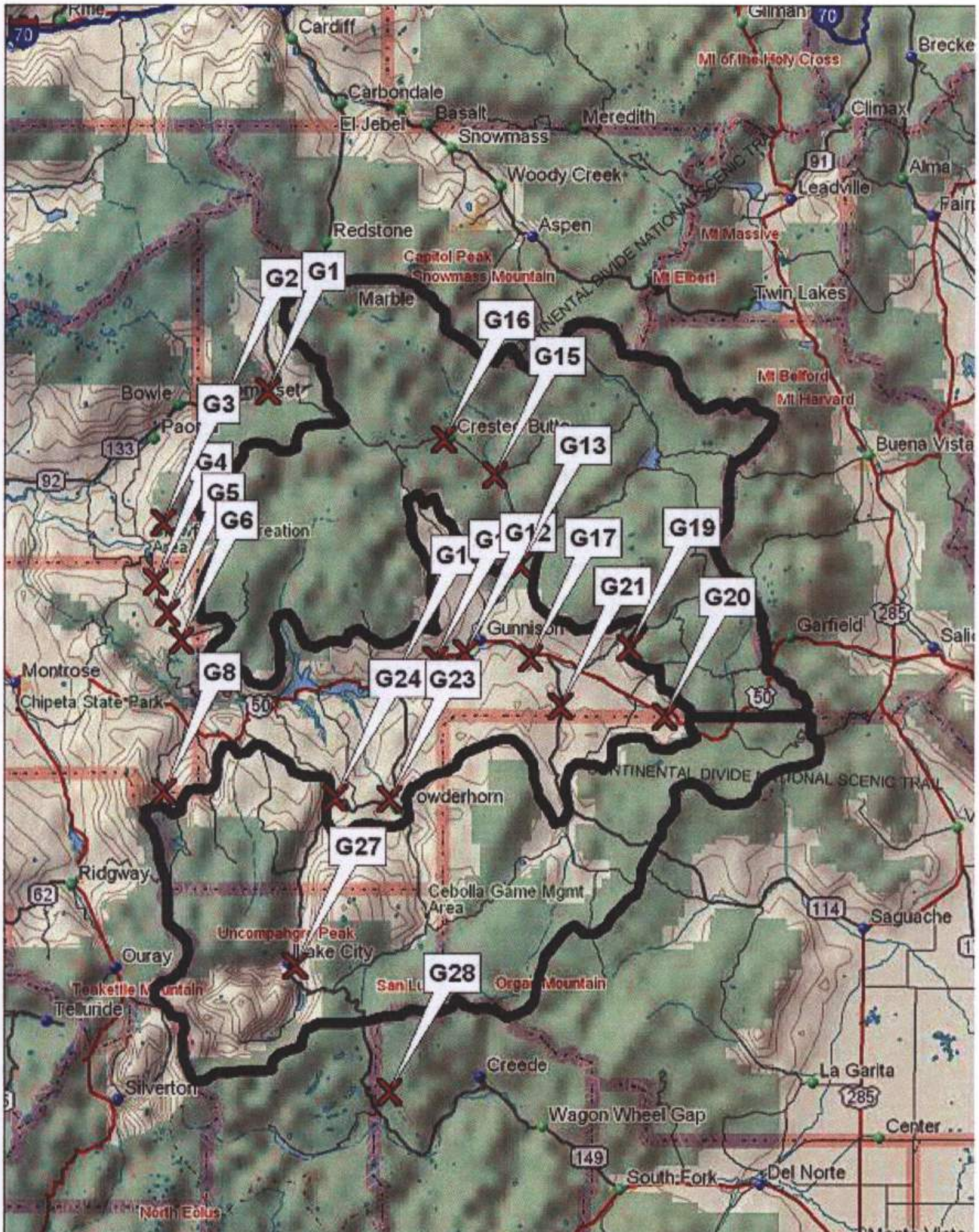


Figure 2.1   Seeding target area and generator locations

Table 2-2. Cloud Seeding Generator Locations

Site No.	Site Name	Latitude	Longitude	Elevation
G1	Somerset	38°56.26'	107°22.54'	6225'
G2	Paonia	38°50.15'	107°33.72'	6370'
G3	Crawford	38°43.57'	107°34.18'	6853'
G4	McLaughlin Ranch	38°38.26'	107°35.50'	6856'
G5	Maher	38°35.29'	107°33.85'	7435'
G6	Crawford South	38°32.65'	107°32.29'	7920'
G8	Cimmaron	38°17.67'	107°34.85'	8727'
G10	Lakeside Resort	38°29.39'	107°06.13'	7653'
G11	Blue Mesa East	38°31.06	107°01.05	7570'
G13	Three Rivers Resort	38°39.99'	106°50.72'	8065'
G15	Crested Butte East	38°48.59'	106°53.94'	8681'
G16	Crested Butte West	38°50.53'	106°56.27'	8940'
G17	Gunnison East	38°31.07'	106°49.45'	7825'
G19	Ohio City	38°33.99'	106°36.17'	8603'
G20	Coyote Hill	39°25.54'	106°33.04'	8166'
G21	Cochetopa	38°26.54'	106°45.66'	8017'
G22	Nine Mile	38°21.39'	107°07.07'	8860'
G23	Powderhorn	38°17.58'	107°06.78'	8033'
G24	Rivergate Ranch	38°17.63'	107°13.11'	7958'
G27	Lake City	38°01.64'	107°18.76'	8710'
G28	Santa Maria Res.	37°49.33'	107°06.61'	9666'

Figure 2.2 Photo of a Cloud Nuclei Generator (CNG)

2.5 Operations Center and Personnel

NAWC maintains a fully equipped operations center at its Sandy, Utah headquarters. Real-time weather information is acquired using the internet, supporting decisions regarding where and when to seed. Information acquired online includes hourly weather reports, rawinsonde (weather balloon) observations, surface and upper-air charts (both current and forecast), weather cameras, weather radar and satellite images, and forecasts from the National Weather Service, as well as numerous other products. All NAWC meteorologists also have computers in their residences so that weather conditions can be monitored from residences in addition to monitoring in the office environment.

The project meteorologist in charge of the operations utilizes this information to make informed cloud seeding decisions, as well as for documenting weather information and seeding activities for future reference. Figures 2.3-2.5 show examples of weather information and computer model output, which was utilized to make seeding decisions, during the 2011-2012 season. Figure 2.3 is an example of predictions of the plume transport from several ground generators during a storm on December 14, 2011. These predictions can be generated in real time using the National Oceanic and Atmospheric Administration's HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model. This model can be utilized by the project meteorologist to predict seeding plume transport during specific storm conditions which can assist in selecting which generators should be turned on and which generators should be turned off.

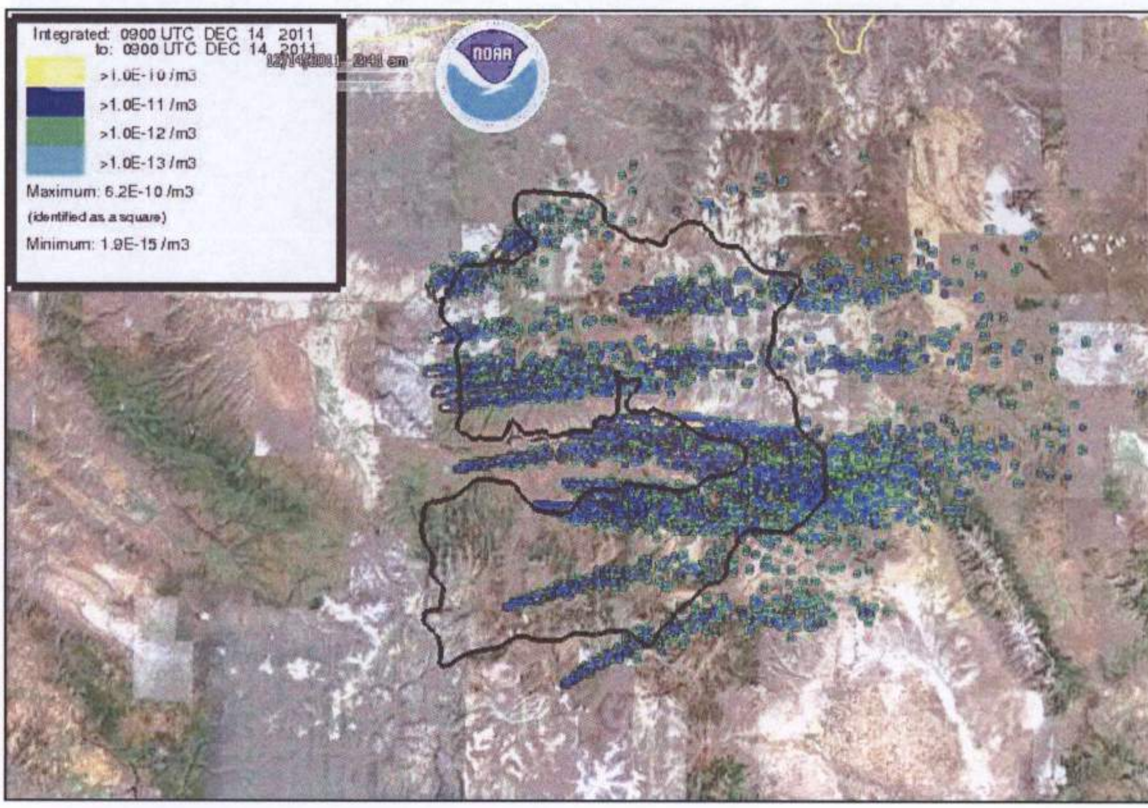


Figure 2.3 **HYSPLIT model forecast of seeding plume dispersion on December 14, 2011.**

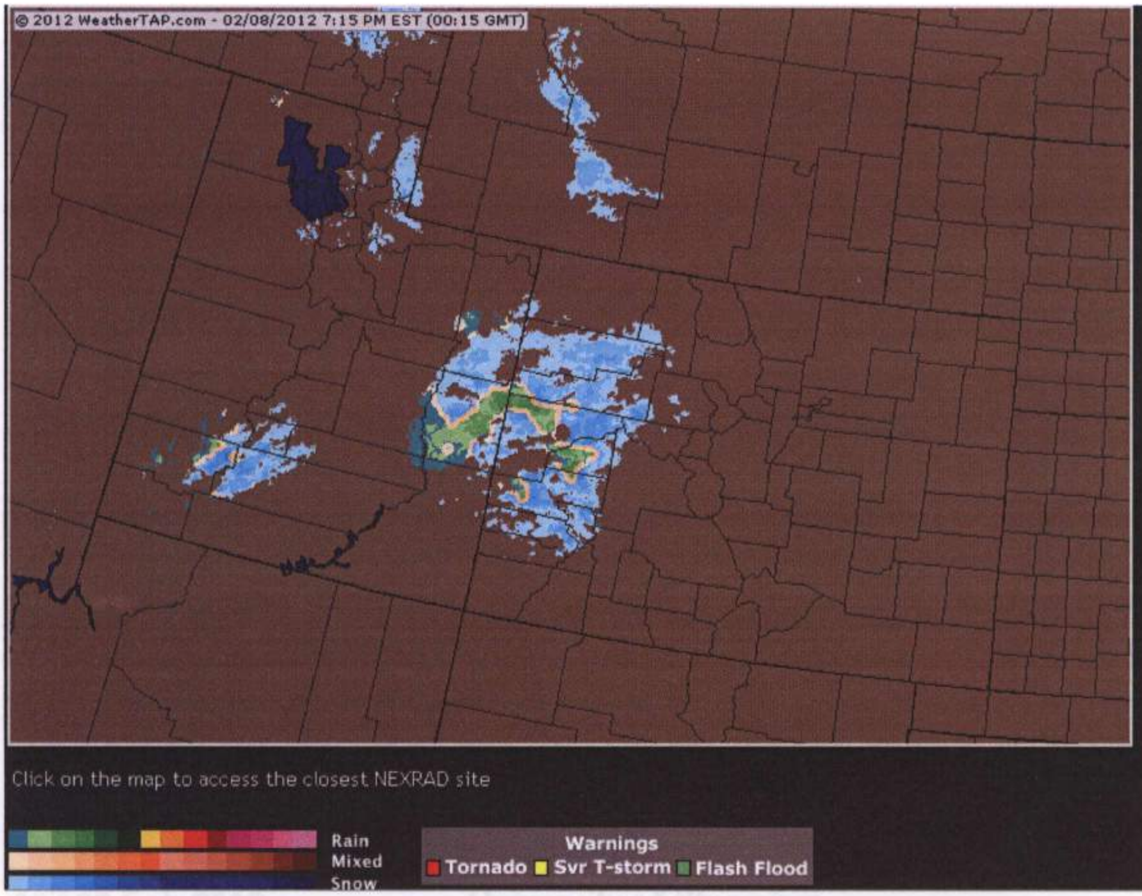


Figure 2.4 Regional radar at 1715 MST on February 8, 2012, near the beginning of a seeded storm event.

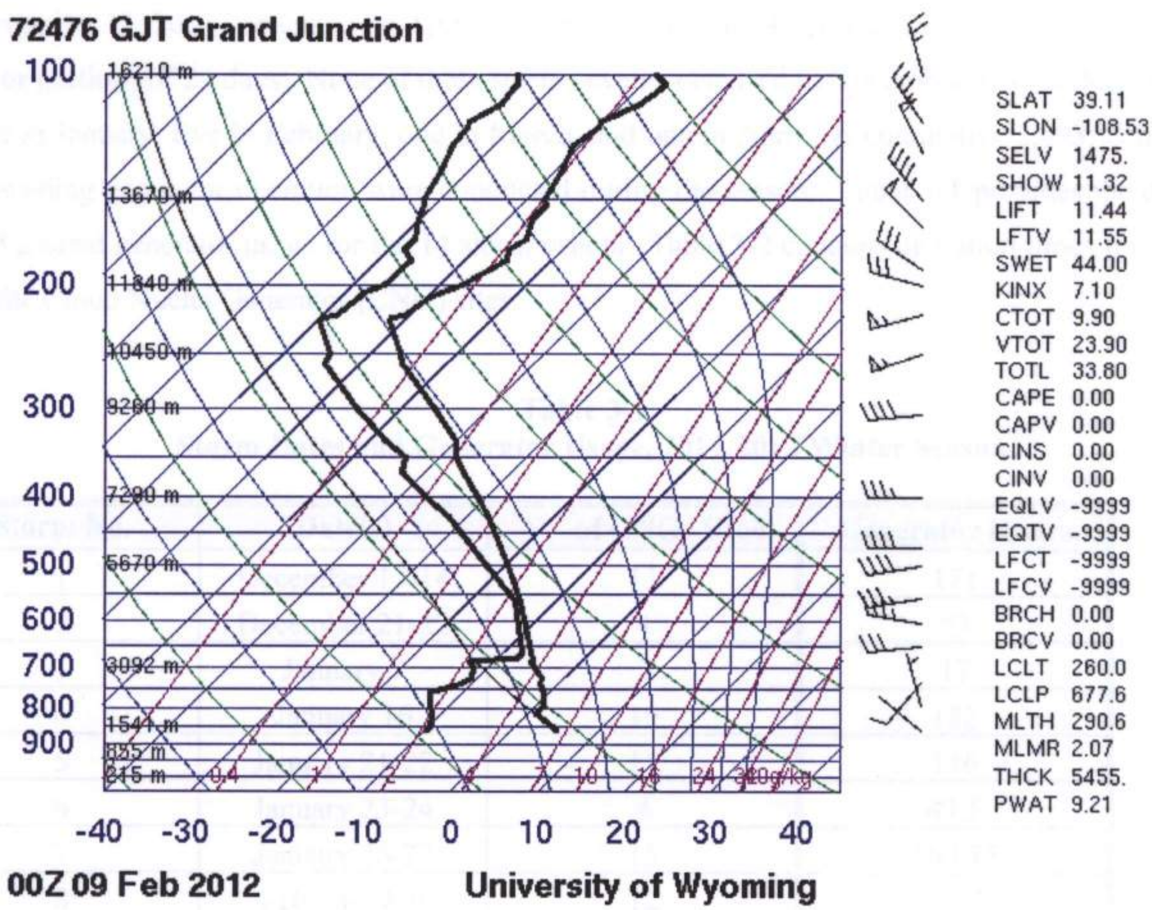


Figure 2.5 **Vertical atmospheric sounding from February 8, 2012 1700 MST weather balloon release in Grand Junction. Thick black traces represent temperature (right) and dew point (left). The black flags on the right hand side are wind vectors (direction and speed) at each level.**

Table 3-2a.
Generator Hours for Upper Gunnison River Program, 2011-2012, Storms 1-8

Storm	1	2	3	4	5	6	7	8
Date	Dec 13-14	Dec 21-22	Jan 7	Jan 16	Jan 21-22	Jan 23-24	Jan 26-27	Feb 8-9
SITE								
G1				14	4			
G2	12.5		8.5	5.5	11		11	16
G3	12.75			9.25	11		11.25	16
G4				9.5	10.75			14
G5				9.5	9.5		11.25	15
G6	14.75			9.5			11	16
G8				9				16
G10	14.75			9.25	11		11	
G11	5			13.75			3	
G13	14.5	14		9.25	10.75		10.75	
G15	14			9.75			14.5	14
G16			8.5	7.75			15	15
G17	12.75			9	12			
G19				9	12		11.5	
G20	14.5			9.5	12	12	10.5	
G21	14.25			9.5			6	8
G23	14.75	14		9.75		12	11	14.75
G24		14		8.75		11.5	11	15
G27	14.5	11		10.5	12	12	12	14
G28	12							
Storm Total	**171**	**53**	**17**	**182**	**116**	**47.5**	**160.75**	**173.75**
Accum Total	**171**	**224**	**241**	**423**	**539**	**586.5**	**747.25**	**921**

Table 3-2b.
Generator Hours for Upper Gunnison River Program, 2011-2012, Storms 9-14

Storm	9	10	11	12	13	14	
Date	Feb 12-13	Feb 13-14	Feb 19-20	Feb 27-28	Mar 1	Apr 14-15	Site Total
SITE							
G1			5	4.5	5	7.25	39.75
G2	20		18	12.75	10.75		126
G3	19.5	3	18.25	11.75	10.5		123.25
G4	23	15	13.5	5.25	10		101
G5	18	19	18.25	11	10.75		122.25
G6	19.25	19.5	18.25	11	8		127.25
G8		4.5	18	13.5			61
G10	16.5		18	9.5		26.5	116
G11						27	48.75
G13	21		17	13.5	10.75		121.5
G15	23.5	23.5		9.5	7	28	143.75
G16	4.75	24	18.25	9.5	6.75		109.5
G17	21		14		7.75	6.5	83
G19	19.75		14.25	15.5	9.75	29	120.75
G20			12.75	10.25	7.75	6.25	95.5
G21	17.5			10.25	8	23	96.5
G23	16		18	12			122.25
G24	16		18	5		27.5	126.75
G27	7.75	2	16.25	20	9	27	168
G28	5	5		19			41
Storm Total	**268.5**	**115.5**	**255.75**	**203.75**	**121.75**	**207.5**	
Accum Total	**1189.5**	**1305**	**1560.75**	**1764.5**	**1886.25**	**2093.75**	

Snowfall for this season was well below average throughout the target area. As of April 1, 2012, SNOTEL sites in the upper Gunnison River Basin reported snowpack water content ranging from 41% of average, to 86% of average. The average for the Gunnison Basin was 60% of normal April 1st snow water content. Water year precipitation was also below average, ranging from 58% to 95% with the Gunnison Basin average at 78% on April 1st. A water supply forecast was issued by the Colorado River Basin Forecast Center on May 1, 2012. A couple of quotes from this report helps put the 2012 water year in Colorado in perspective.

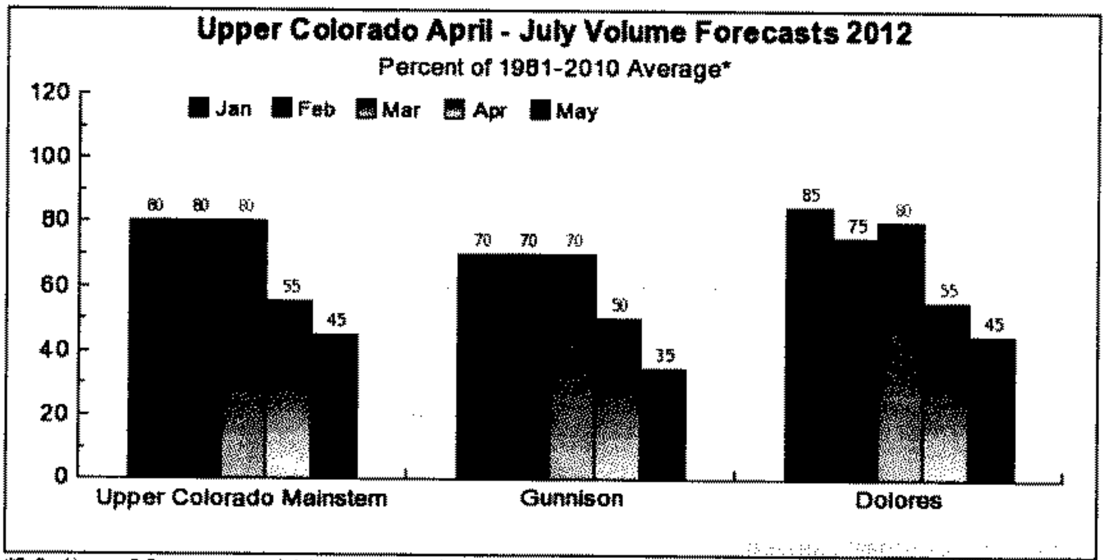
Snow:

"May 1st snow water equivalent was near just 20 percent of average in the basin as a whole. In a normal year snow continues to accumulate through March and into the middle of April at higher elevations, but this year snow melt began by the last half of March. Most SNOTEL sites below 10,500 feet in the basin do not have any snow left, and many of those melted out at the earliest time in their 30-year history".

Streamflow:

"There were again large drops in the forecast runoff volumes from what was issued last month. Most of the May through July forecasts are for volumes that would be the 2nd or 3rd lowest on record if they occurred. Current May through July streamflow volume forecasts range between 25 and 50 percent of average with a median value of 40 percent. Current April through July streamflow volume forecasts range between 35 and 55 percent of average with a median value of 45 pereent".

Figure 3.1, taken from this report, illustrates the dramatic drop in April-July Streamflow forecasts including those for the Gunnison River Basin. The entire water supply forecast is provided in Appendix B. Figures 3.2 through 3.7 provide monthly precipitation, expressed as percent of normal, for the upper Colorado River area for the months of November through April. These plots, which were prepared by the NWS Colorado Basin River Forecast Center, indicate that precipitation in the Gunnison River Basin was near normal in November, well above normal in Deeember, below normal in January, near normal in February and March and above normal in April.



*Median of forecasts within each basin.

Figure 3.1 Upper Colorado April – July Percent of Normal Streamflow Forecasts

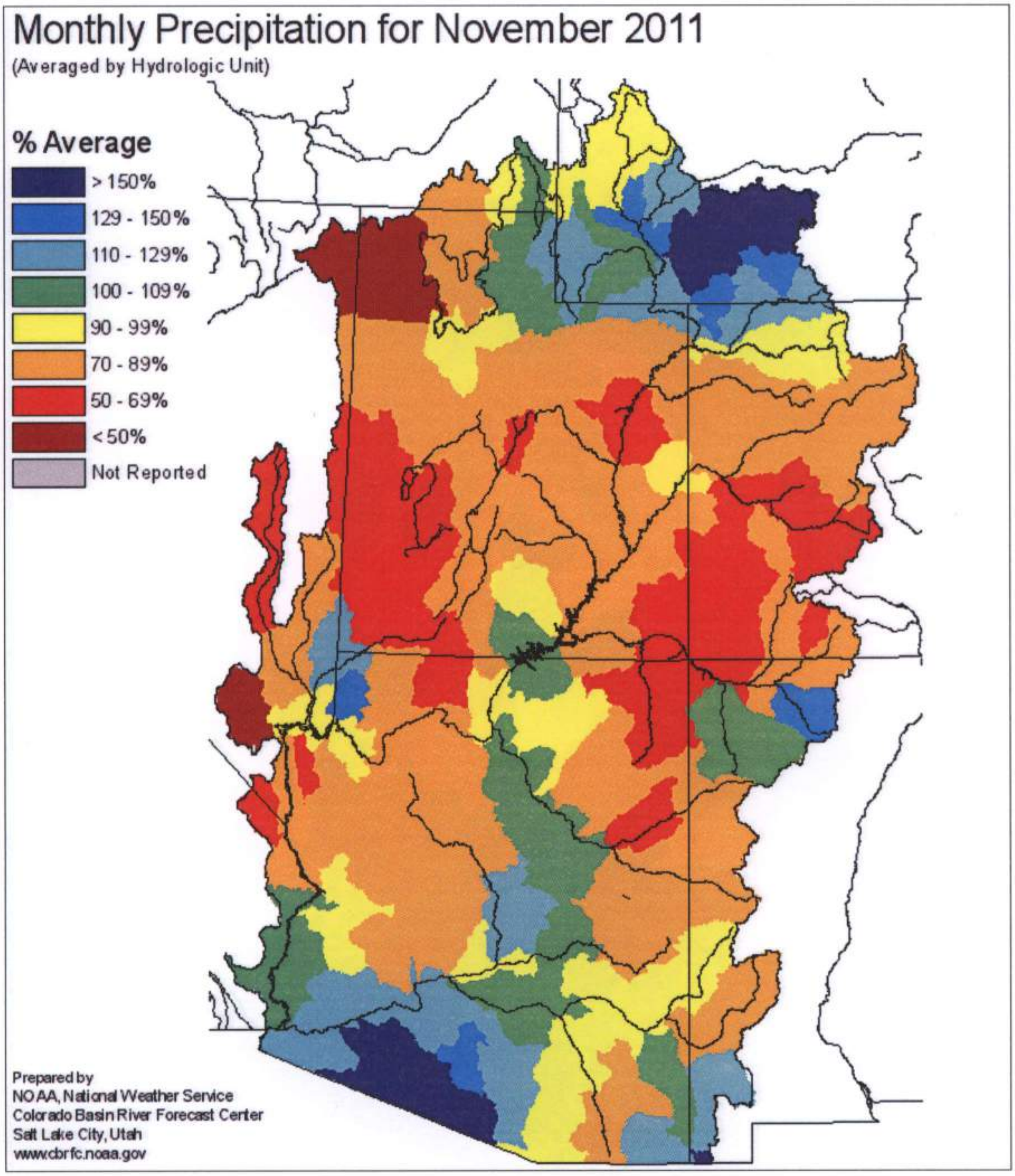


Figure 3.2 November 2011 precipitation

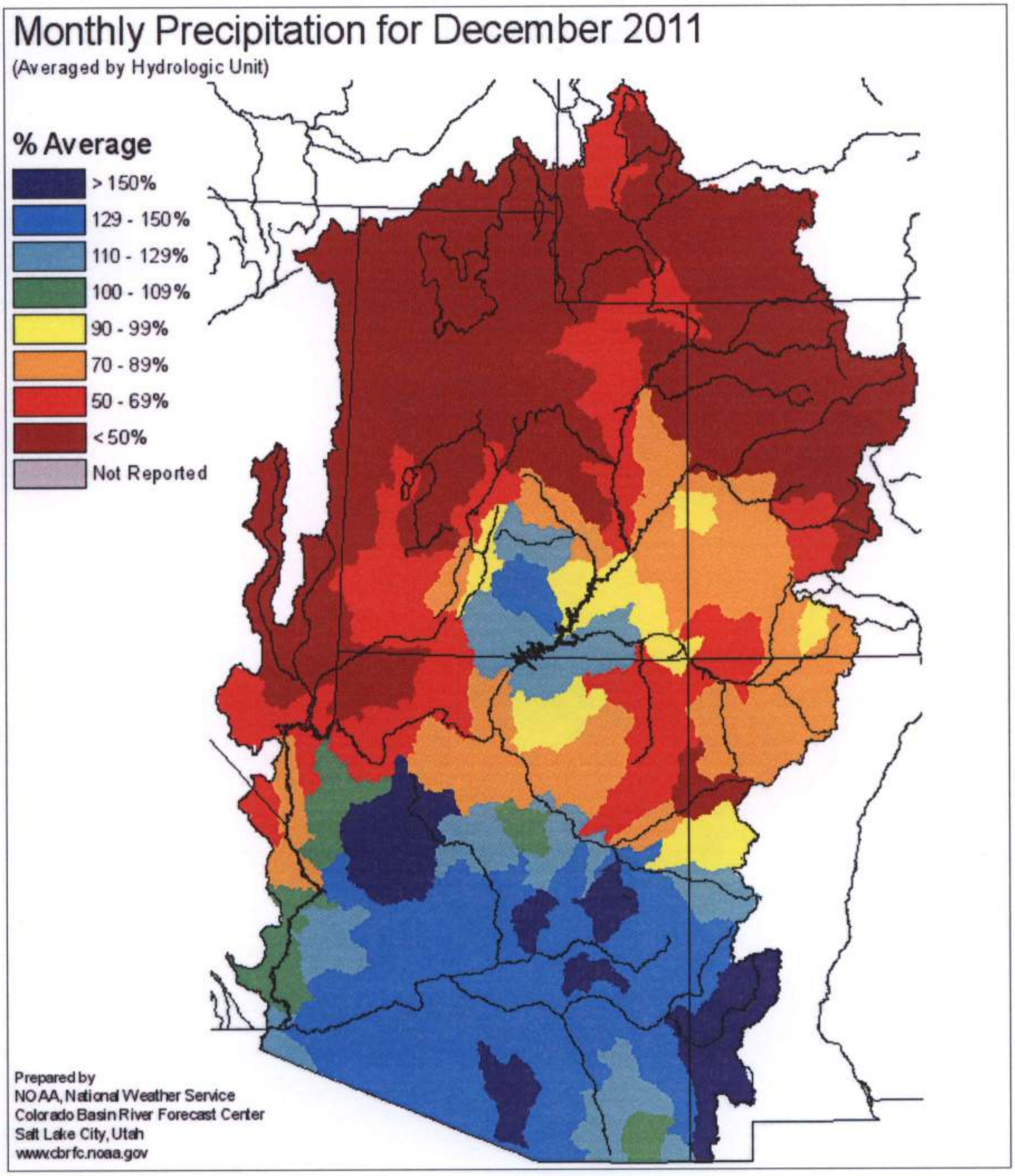


Figure 3.3 December 2011 precipitation

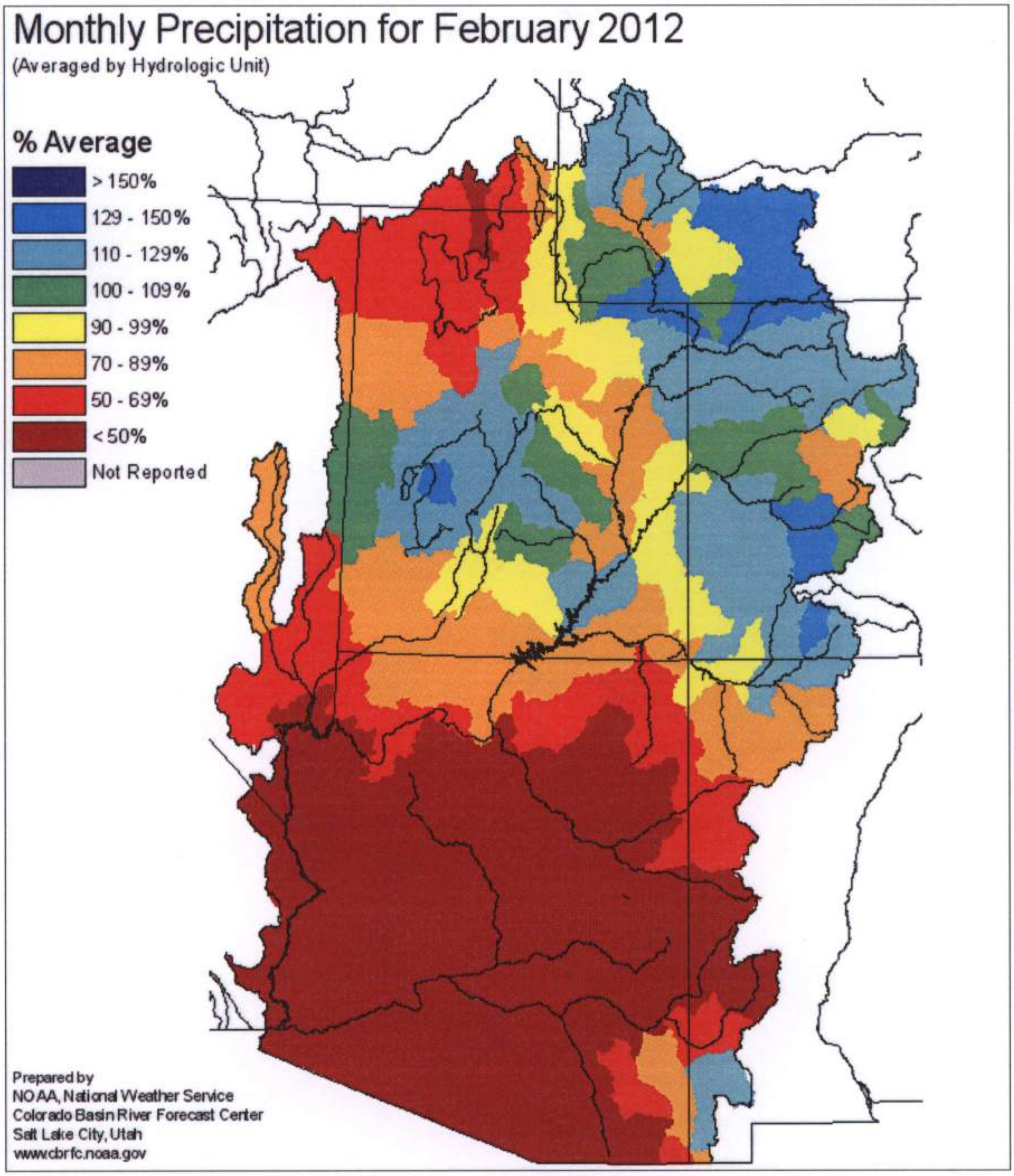


Figure 3.5 February 2012 precipitation

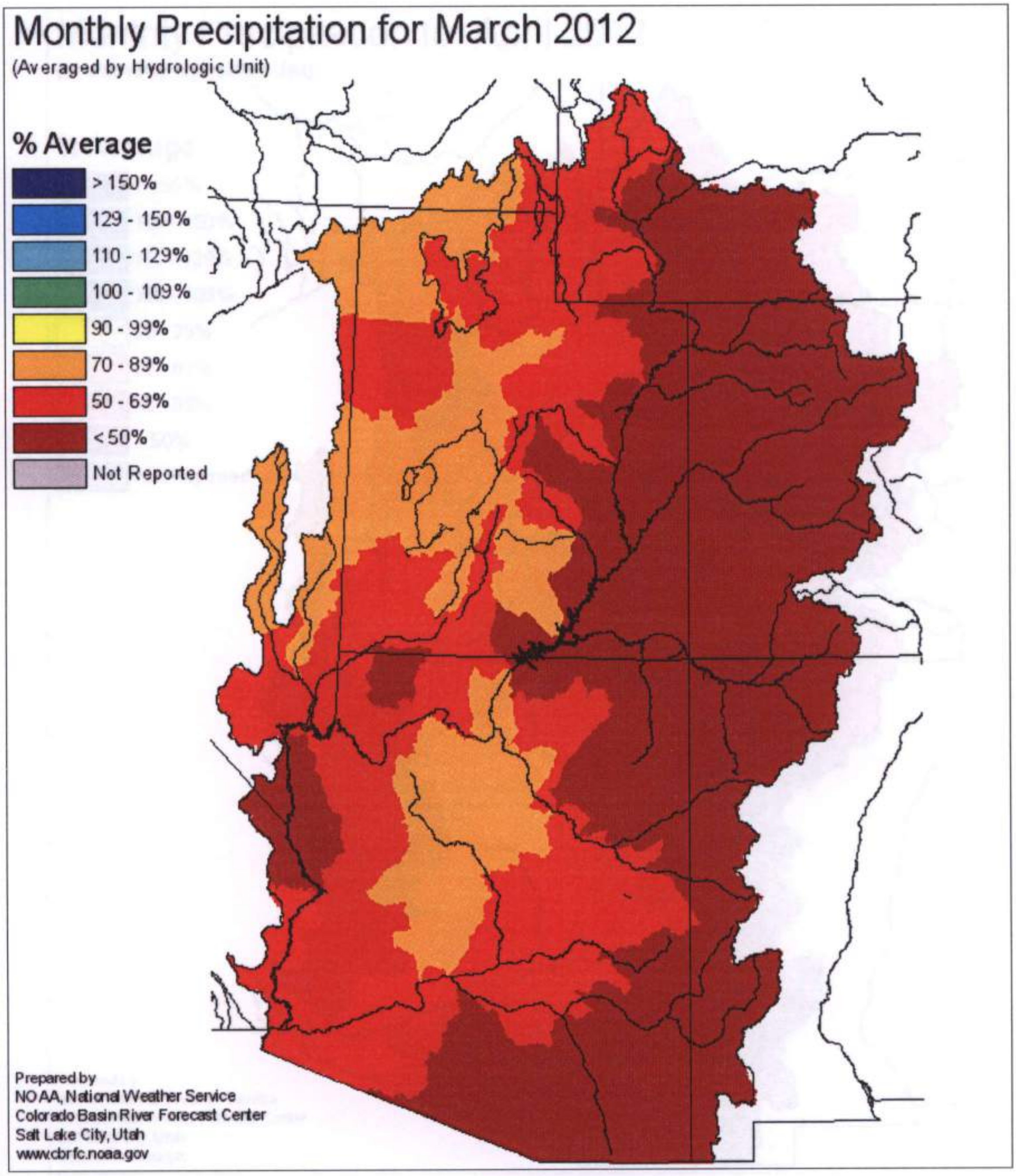


Figure 3.6 March 2012 precipitation

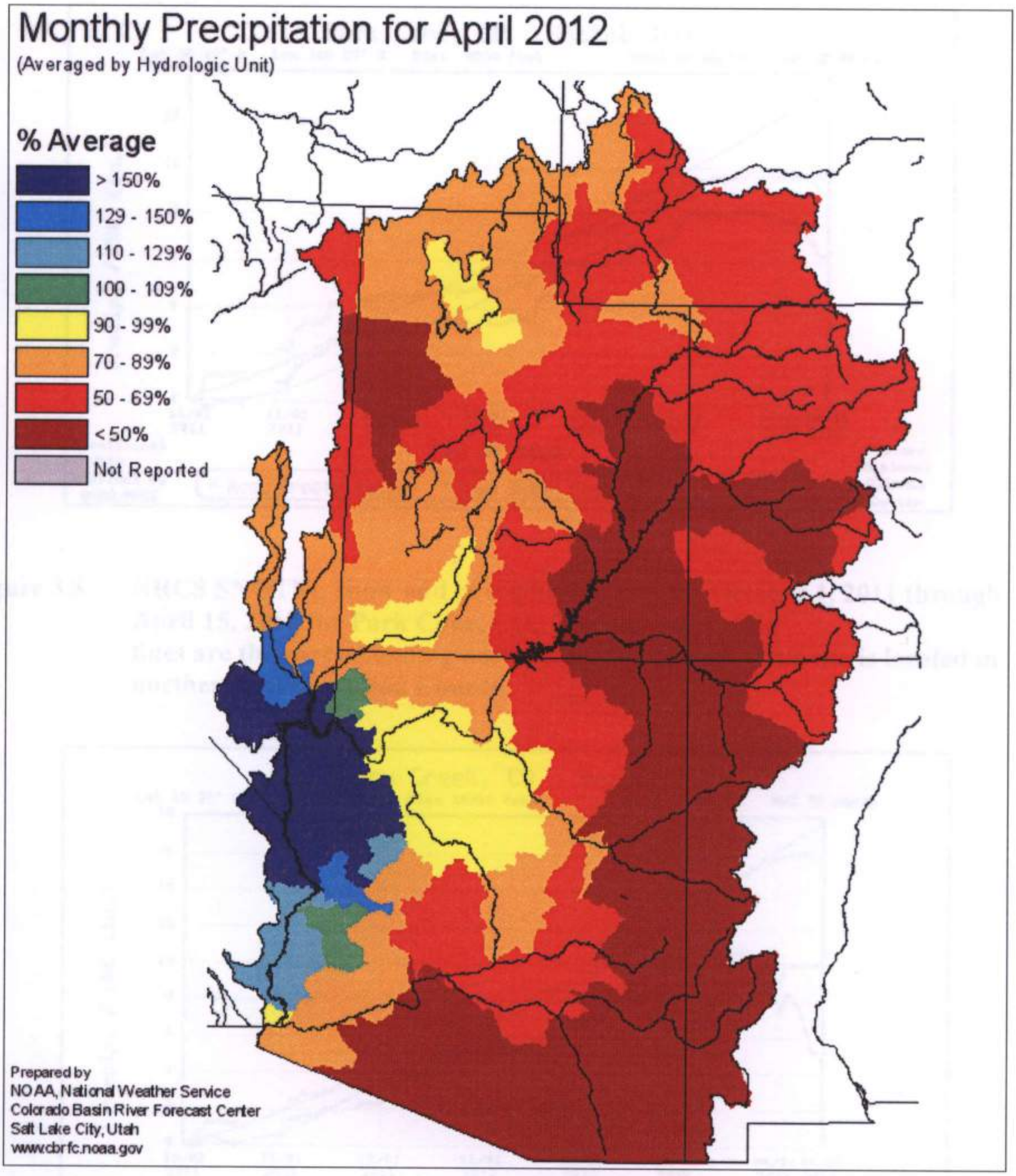


Figure 3.7 April 2012 precipitation

Figures 3.8 through 3.10 provide snow water equivalent and precipitation data for three NRCS SNOTEL sites located within the cloud seeding target area. Figure 3.11 provides the April 1st snow water content percent of normal for all of the Colorado River Basins.

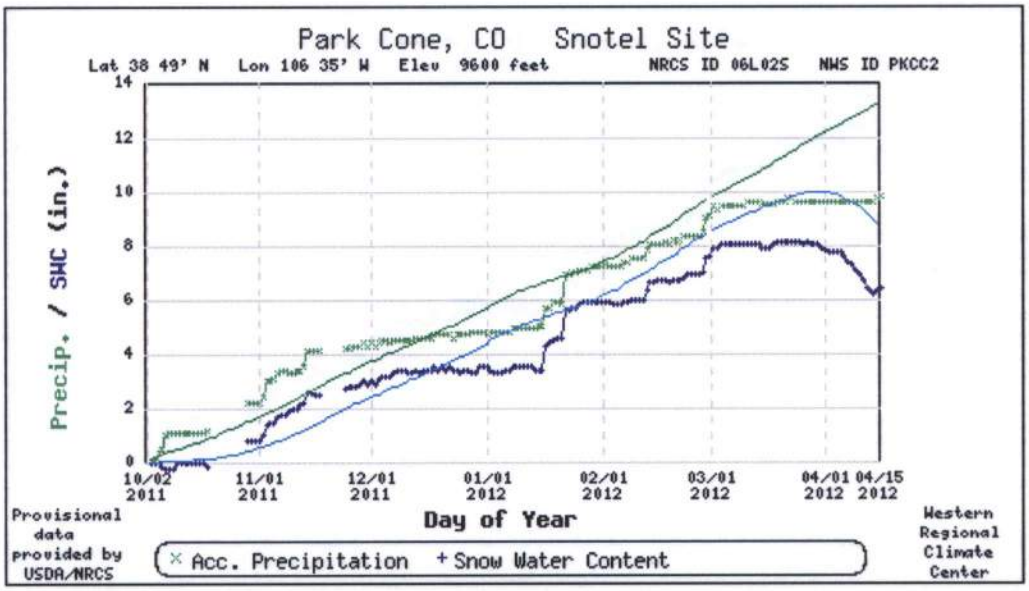


Figure 3.8 **NRCS SNOTEL snow and precipitation plot for October 1, 2011 through April 15, 2012 for Park Cone, CO. The smoother, thin lines are the corresponding normals for the period. This site is located in northeastern Gunnison County.**

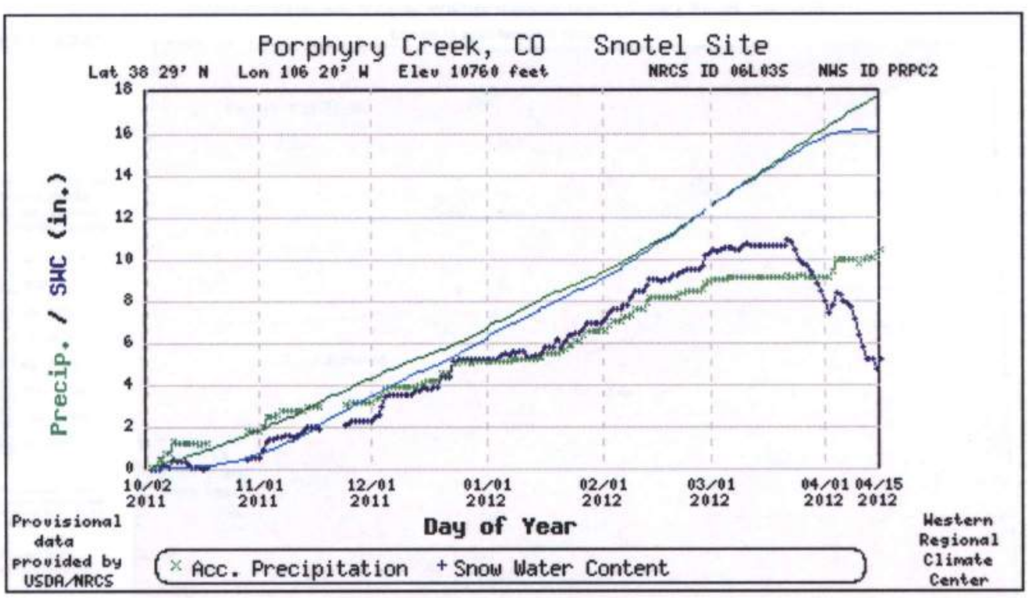


Figure 3.9 **NRCS SNOTEL snow and precipitation plot for October 1, 2011 through April 15, 2012 for Porphyry Creek, CO. The smoother, thin lines are the corresponding normals for the period. This site is located in the eastern portion of Gunnison County.**

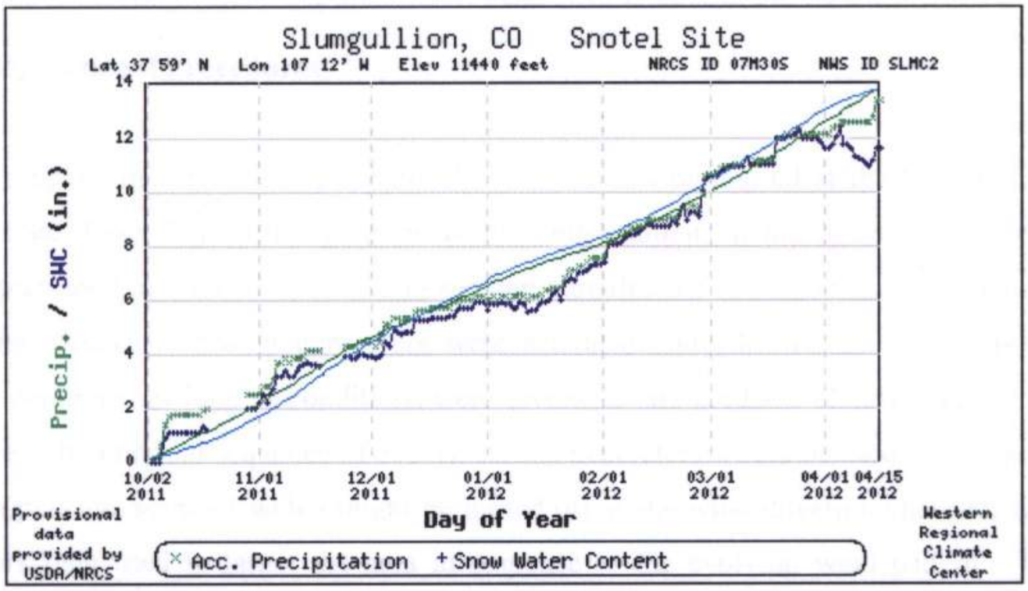


Figure 3.10 NRCS SNOTEL snow and precipitation plot for October 1, 2011 through April 15, 2012 for Slumgullion, CO, in the southern portion of the target area. The smoother, thin lines are the corresponding normals for the period.

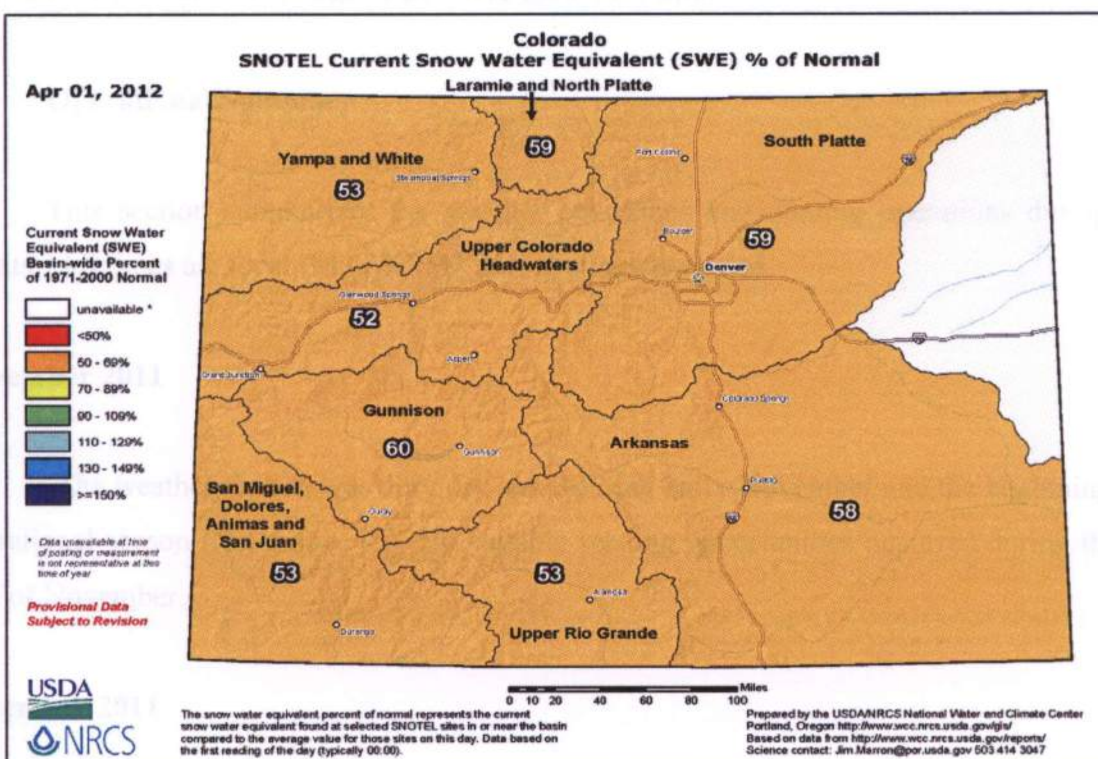


Figure 3.11 Colorado River Basins April 1st snow water content percent of normal

3.1 Operational Procedures

In operational practice, an approaching storm was monitored at the NAWC operations center in Salt Lake City, utilizing online weather information. If the storm met the seedability criteria presented in Table 2-1, and if no seeding curtailments or suspensions were in effect, an appropriate array of seeding generators were activated and adjusted as conditions required. Seeding continued as long as conditions were favorable and seedable clouds remained over the target area. In a normal sequence of events, certain generators would be used in the early period of storm passage, some of which might be turned off as the wind direction changed, with other generators then used to target the area in response to the evolving wind pattern. The wind direction during productive storm periods in the Upper Gunnison River Target Area usually favors a westerly or southwesterly direction (in meteorology wind direction is reported in terms of the direction from which the wind is blowing), so that the generator sites on the west/southwest side of the target areas were used most often.

3.2 Operational Summary

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

November 2011

The weather pattern was very dry since during early November and the beginning of the operational season (November 15). No suitable seeding opportunities occurred during the latter half of November.

December 2011

A persistent ridge of high-pressure maintained generally drier than average weather conditions over much of the western U.S. during the first half of the month, which in turn limited seeding opportunities in the target area. Two storms did finally present seedable conditions over the target area.

A trough of low pressure moved out of California and into Colorado on December 13-14th (#1). The first part of the storm was very dry with very little moisture associated with the storm, but as a cold front reached the area later on the 13th, the airmass moistened up and seeding conditions turned favorahle. Generators were turned on around 1930 on the evening of the 13th and ran until about 1030 on the morning of the 14th when precipitation quickly ended as the storm moved to the east. Area SNOTEL stations recorded between 0.10"- 0.40" of water equivalent, and generator operators on the far western edge of the target area reported 5"-7" of snowfall overnight.

A weak upper level trough moved into the area on December 21-22nd (#2). This system developed some circulation as it moved into Utah and Colorado, but the upper level wind field developed an easterly component that caused some downsloping (descending air usually associated with drying conditions) over parts of the target area, wbich prevented the development of supercooled liquid water. Some seeding was conducted overnight from areas thought to be the most favorable, hut by the morning of the 22nd, conditions turned dry and seeding ended. Winds were easterly with 700-mh temperatures of -12 C. The storm continued to drop southward into the four-corners area and the target area received very little precipitation from this storm.

January 2012

The weather during January was generally fair during the first balf of the month as a split jet stream pattern continued over the Pacific Ocean. Split jet streams typically send storms to the north or south of Colorado. However, that pattern shifted to a more active pattern mid-month which allowed a few significant storms to move through the target area. Five storms presented favorable seeding conditions over parts of the target area.

A fast moving trough moved into northwest Colorado on January 7th (#3). Moisture was very limited with this storm, and winds were very northerly, which made seeding difficult. 700-mb temperatures dropped to -8 C and seeding was conducted from two locations on the far north side of the target area. Seeding began around 1330 and ran until 2130 before ending. Snowfall amounts were very light over most of the target area, with only 1-2" recorded over the far northern portion of the target area.

A cutoff area of low pressure that spent several days off the southern California coast finally opened up and lifted eastward passing over Colorado on January 16th (#4). Moderate to heavy snow developed over the area in the morning with 700-mb temperatures near -6 C and very light winds. Area-wide seeding began in the morning, as a cold front moved into the target area from the northwest. Heavy snow fell for several hours over portions of the target area. By 1900, 700-mb temperatures were below -15 C and were forecast to drop all the way down to -20 C by midnight, so seeding was discontinued due to the extreme cold temperatures falling outside NAWC's seeding criteria. This was a very productive storm with portions of the target area reporting anywhere from .50" to over 1.00" of water content.

A moist zonal flow was over the target area on January 21-22nd (#5) when an embedded cold front dropped into the area. 700-mb temperatures dropped from 0 C to -8 C behind the cold front. Several inches of snow had fallen during the warm portion of the storm. Seeding began immediately following the cold front as temperatures cooled into the effective seeding range. Seeding continued in northwesterly flow over the area overnight and ended early on the 22nd as conditions quickly dried out. SNOTEL stations in the target area recorded 0.25" of water content during the seeded period, and nearly 1.00" of water fell during the warm sector of the storm.

A storm split over California and a weak portion of that storm quickly moved through a portion of the target area on January 23-24rd (#6). The best dynamics of the storm remained over Arizona and New Mexico. The southern portion of the target area was seeded from generator location on the south side of the target area. Seeding began late on the 23rd and continued until early on the 24th. 700-mb temperatures were -8 C with northerly winds. Snowfall accumulations during this storm were light and SNOTEL stations recorded between 0.0"- 0.20" water content.

A quick moving cold front dropped into the area on the evening of January 26-27th (#7). 700-mb temperatures cooled from -4 C to -8 C behind the initial front, with west to northwest winds. Radar indicated a nice band of snowfall over the target area, and widespread seeding began late on the evening of the 26th and continued through the morning of the 27th. Precipitation totals ranged from very light to nearly .50" over portions of the target area.

February 2012

February brought near normal precipitation and snowfall to the target areas. Several of the storm events during February provided excellent seeding opportunities. There were five seeded storm events during February.

Showers developed over the target area on February 12-13th (#9) ahead of an impressive storm pulling out of UT and moving into Colorado. 700-mb temperatures were initially -5 C but gradually cooled to -8 C as the upper trough settled into the area. Widespread seeding began by 1500 on the 12th in southwesterly flow and continued overnight into the 13th as snow continued and the winds gradually turned more westerly. By the morning of the 13th, all seeding ended except around the Crested Butte area where convective showers lingered. Seeding continued in that area continued through the evening as another shortwave trough moved into the area. Additionally, sites on the western edge of the target area were activated. Area SNOTEL sites recorded between 0.25"- 0.50" of snow water content during this storm period. The convective nature of the clouds with this system made this one of the best seeding opportunities of the season.

The storm that affected the area on the 13th was centered over northwest Arizona that spread a plume of moisture over the four-corners area on the morning of February 14th (#10). Some seeding had continued from the 13th and additional sites were added in southwesterly flow on the 14th. 700-mb temperatures remained steady between -6 C and -8 C. By 1530, showers became very sparse and seeding was discontinued. Snow water content totals ranged from very light up to 0.25".

A shortwave trough moved into western Colorado on the evening of February 19-20th (#11). Satellite and radar showed a nice band of precipitation accompanied the front as it moved into the area. Initially, 700-mb temperatures were too warm for effective seeding, but cooled to -6 C under post frontal conditions and continued to drop through the night as the cold core of the upper trough moved into the area. Seeding was conducted from nearly all available sites overnight and into the 20th, as forecast models indicated a very favorahle westerly flow would persist through the night. By daylight on the 20th, 700-mb temperatures had dropped below -15 C, and seeding ended. The highest precipitation totals occurred on the western edge of the target area. Storm totals ranged from 0.1"- 0.40" of snow water content. Generator operators in the western portion of the area reported 6"-8" of snowfall.

A complex storm system moved into the area over February 27-28th (#12). Heavy precipitation developed over tbe southern portions of the target area during the day on the 27th, but 700-mh temperatures were much too warm to conduct seeding. The Slumgullion SNOTEL site reported over 1.00" of snow water content during the warm sector of the storm. Overnight, temperatures aloft dipped to -6 C and a few generator sites were activated as the storm moved into the area and winds became more westerly. By the morning of the 28th, the best seeding conditions were over the northern portion of the target area as indicated by radar and satellite. Conditions were very favorable during the afternoon hours as the clouds became more convective in nature. Seeding was conducted from nearly all available sites. By 2100, the storm clouds were moving eastward so seeding ended. Area SNOTEL sites reported between 0.50" and 1.50" of water content from this storm.

March 2012

Despite a decent storm at the beginning of the month, the weather pattern during March was generally dry and mild. A weak storm mid-month was considered not seedable due to high cloud bases and wann temperatures. There was one seeded storm event in March. Well above average temperatures resulted in many target area SNOTEL sites experiencing a loss of several inches of snow water content.

A storm moved into the area from the southwest on March 1st (#13). 700-mb temperatures were -10 C in southwesterly flow, and seeding was conducted from several sites area-wide as snow showers were scattered over the area. Again, clouds were fairly convective, resulting in favorable seeding conditions for much of the day. By 2100, the storm was well to the east of the area, and seeding ended as skies quickly cleared. SNOTEL reported mainly light totals, with ~0.25" or less reported at target area sites.

April 2012

Overall, precipitation during April was well below average and temperatures were above average. However, there was one storm that occurred on April 14-15 that provided favorable seeding conditions and brought some much needed precipitation to the target area.

A closed low moved over Colorado from the west which spread showers into the target area beginning on April 14th (#14). Low level winds were initially southerly, and 700-mb temperatures were -5 C. Seeding began from sites that favor southerly flow around 1530 on the 14th. As the low transitioned eastward into eastern Colorado and Kansas, winds shifted to north-northwest and additional sites were added to the seeding array on the morning of the 15th. Seeding continued through 1900 before the system pulled completely out of the area. Precipitation amounts ranged from 0.20" at Slumgullion to 1.10" at North Lost Trail and Schofield Pass SNOTEL.

4.0 EVALUATIONS OF SEEDING EFFECTIVENESS

The task of determining the effects of cloud seeding bas received considerable attention over the years. Evaluating the results of a cloud seeding program for a single season is rather difficult, and the results should be viewed with appropriate caution. The primary reason for this difficulty stems from the large natural variahility in the amounts of precipitation that occur in a given area from season to season, and between one area and another during a given season. Since cloud seeding is normally feasihle only when existing clouds are near to (or already are) producing precipitation, it is not usually obvious if, and how much, tbe precipitation was actually increased by seeding due to this large natural variability. The ability to detect a seeding effect becomes a function of the magnitude of the seeding increase and the numher of seeded events, compared with the natural variahility in the precipitation pattern. Larger seeding effects can be detected more readily and with a smaller number of seeded cases than are required to detect smaller increases.

Historically, tbe most significant seeding results have been observed in wintertime seeding programs in mountainous areas. However, the apparent differences due to seeding are relatively small, being of tbe order of a 5-15 percent seasonal increase. In part, this relatively small percentage increase accounts for the significant numher of seasons required to establish these results, often five years or more.

Despite the difficulties involved, some techniques are available for evaluation of the effects of operational seeding programs. These techniques are not as rigorous or scientifically desirable as is the randomization technique used in research, where typically about half the sample of storm events are randomly left unseeded. Most of NAWC's clients do not wish to reduce the potential benefits of a cloud seeding project by half in order to better document the effects of the cloud seeding project. The less rigorous techniques do, however, offer helpful indications of the long-term effects of seeding on operational programs.

A commonly employed technique, and tbe one utilized hy NAWC in this assessment, is the "target" and "control" comparison. This technique is one described by Dr. Arnett Dennis in bis book entitled "Weather Modification by Cloud Seeding" (1980). This technique is based on selection of a variable that would be affected by seeding (such as precipitation or snow water content). Records of the variable to be tested are acquired for an historical period of as many years duration as possible (ideally, 20 years or more). These records are partitioned into those located within the designated "target" area of the project and those in a nearby "control" area. Ideally the control sites should be selected in an area meteorologically similar area to the target, but one which would be unaffected by the seeding (or seeding from any other nearby projects). **The historical data (e.g., precipitation and/or snow water content) in both the target and control areas are taken from past years that have not been subject to cloud seeding activities.** These historical data are evaluated for the same seasonal period of time as that when the seeding was later conducted. The target and control sets of data for the unseeded seasons are used to develop an equation (typically a linear, but sometimes a multiple linear regression) that predicts the amount of target area precipitation, based on precipitation observed in the control area. This regression equation is then used during the seeded period, to estimate what the target area precipitation should have been without seeding, based on the control area precipitation. This allows a comparison to be made between the predicted target area precipitation and that, which actually occurred during the seeded period, to look for any differences potentially caused by the seeding activities.

This target and control technique works well where a good historical correlation can be found between target and control area precipitation. Generally, the closer the target and control areas are geographically, and the more similar they are in terms of elevation, the higher the correlation will be. Areas selected too close together, however, can be subject to contamination of the control area by the seeding activities. This can result in an underestimate of the seeding effect in the target area. For precipitation and snowpack assessments, a correlation coefficient (r) of 0.90 or greater would be considered excellent. A correlation coefficient of 0.90 would indicate that over 80 percent of the variance (r^2) in the historical data set would be explained by the regression equation used to predict the subject variable (expected precipitation or snowpack) in the seeded years. An equation indicating perfect correlation would have an r-value of 1.0.

Experience has shown that it is very difficult to provide a precise assessment of the effectiveness of cloud seeding over just a few seeded seasons. However, as the data sample size increases, it becomes possible to provide at least a semi-quantitative answer to the question of seeding effectiveness. This past winter season was the ninth seeded season (the first seeded season was only two and one half months long) for this program, so confidence in the indications of the average seasonal success of the seeding is improving.

Using the target-control comparison technique described above, mathematical relationships for the snowpack water content data were determined between a group of sites in the unseeded (control) areas and the sites in the seeded (target) area. From these data, predictor equations were developed, where the average value of the variable observed in the unseeded (control) areas was used to predict the average value of the variable in the seeded (target) area in the absence of seeding. A positive difference between the observed amount and the predicted amount in the seeded area (target) during seeded periods may indicate a positive result of seeding. A single-season negative difference may mathematically suggest that the seeding decreased the precipitation, but that would be a highly unlikely, if not impossible, occurrence. More likely, a negative difference would indicate that the regression equation did not have a sufficiently high correlation to provide an accurate prediction, especially for seasons with very low or very high snowpack amounts where the regression equation technique is typically less accurate.

Evaluations were previously conducted using precipitation data (November through March) in addition to April 1st snow water content. However, the precipitation data seemed particularly unreliable at the high-elevation sites of the target area, probably due to problems produced by high winds. Precipitation is measured in gages. Gage catch deficiency due to wind effects is well documented and can be extreme at higher wind velocities, particularly with snow. This is especially true for very exposed sites such as those above timberline. This was evidenced by total precipitation accumulations which were less than the existing snow water content in many cases, a situation which seemed to occur rather frequently in the seeded seasons. Previous NAWC reports have discussed this potential problem related to under-catch of snowfall in the precipitation gages, due to strong winds at the near- to above-timberline locations in the target area. Another possible difference between the precipitation and snow water content evaluations that may partially explain the different outcomes that were obtained is the length of the historical periods used to develop the regression equations. The precipitation evaluations were based upon a 15-season historical period, while the snow pack evaluations were based upon 20 seasons. Another difference is that nine target sites were used in the snow water content evaluations but only six in the precipitation evaluations. **Due to the above factors, the snow water evaluations are considered a more reliable indicator of the effects of cloud seeding in the target areas, and NAWC chose to include only those for the current season.**

There have been, and continue to be, several cloud seeding programs conducted in the State of Colorado. As a consequence, potential control areas that are unaffected by cloud seeding are somewhat limited. This is complicated by the fact that the best-correlated control sites are generally those closest to the target area, and most measurement sites in this part of the state have been subjected to "contamination" by numerous historical and current cloud seeding programs. This renders potentially affected sites of questionable value for use as statistical controls.

NAWC performed an evaluation of another cloud seeding project conducted during the 2002-2003 winter season in the Central Colorado Rockies, sponsored by Denver Water. One of the steps in the development of a target/control evaluation of that project was a comprehensive search of all available records of previous cloud seeding activities in Colorado. NAWC's report on that project (Solak, et al, 2002) provides a summary of these earlier seeding programs. This information was useful in the identification of possible control sites and non-seeded periods in the upper Gunnison target. Figure 4.1 is an updated map obtained from the website of the Colorado Water Conservation Board, showing the locations of seeding generators and target areas for cloud seeding projects conducted during the 2011-2012 winter season in Colorado. Similar programs have been conducted during the last few seasons. Data from the Denver Water study, as well as information regarding these other cloud seeding programs, were used to determine control areas for the Gunnison seeding program.

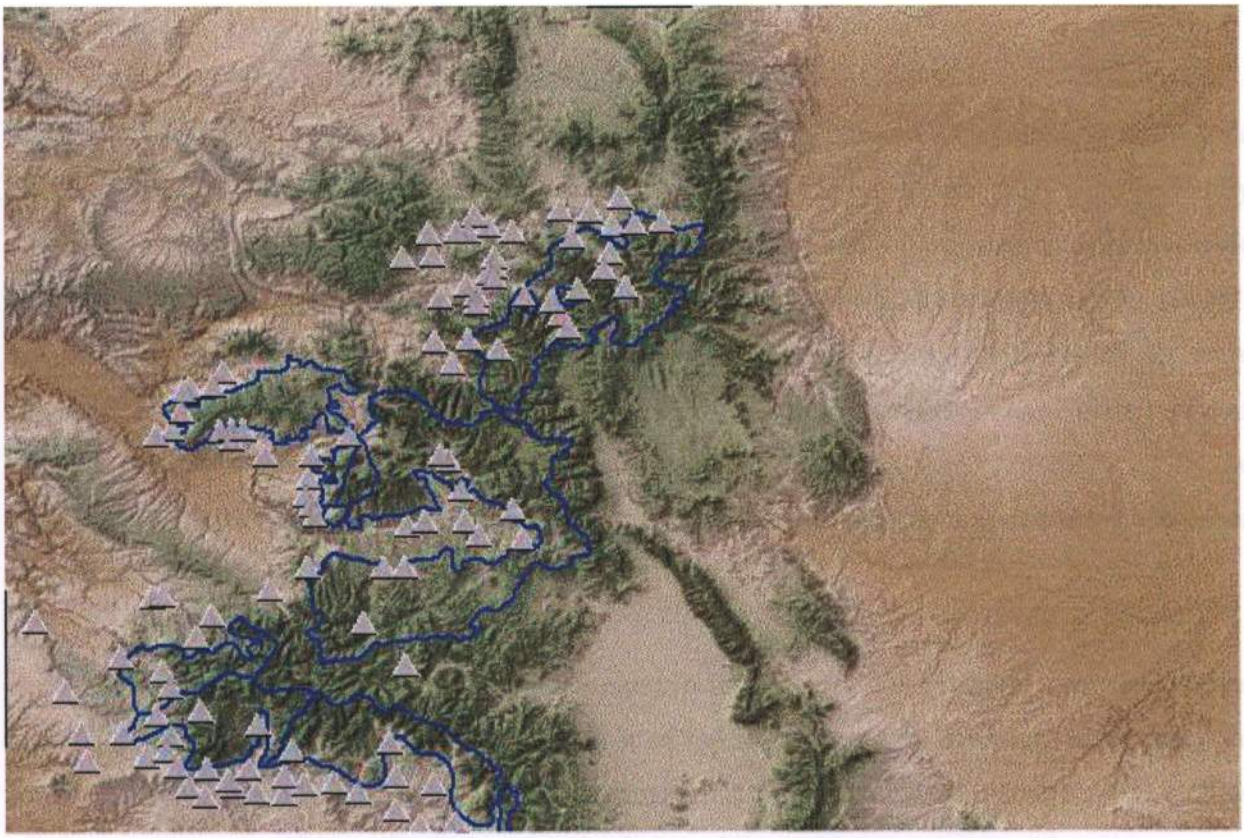


Figure 4.1 Map of 2011-2012 cloud seeding programs in Colorado (CWCB)

4.1 Snowpack (Water Equivalent) Analysis

The water content within the snowpack ultimately determines how much water will be available to replenish the water supply when the snowmelt occurs. Hydrologists routinely use snow water content measurements to generate forecasts of streamflow during the spring and early summer months. Colorado has excellent historical snowcourse and SNOTEL snow pillow data collected by the NRCS. Many of the same mountain reporting sites are available for both precipitation and snowpack measurements. Some limitations and pitfalls associated with snowpack measurements must be recognized when using snow water content to evaluate seeding effectiveness. For example, warm periods can occur between snowstorms. If a significant warm period occurs, some of the snow may melt. Thus, some of the snow water may not be recorded at the end of the month, even though some of the melted snow may have gone into the ground to recharge the soil moisture and ground water. This can also lead to a disparity between snow water measurements at higher elevations (where less snow will melt in warm weather) and those at lower elevations.

Another issue that can affect the indicated results of the snowpack evaluation is the date on which the manual snowcourse measurements are made. Those measurements are generally made near the end of the month. Since the advent of SNOTEL, daily measurements are available at many of the sites. However, prior to SNOTEL, and at those sites where snowcourses are still measured by visiting the site, the measurement is recorded on the day it was made. In some cases, because of scheduling issues or stormy weather, these measurements have been made as much as 10 days before or after the end of the month. This can lead to a disparity in the snowpack water content readings when comparing one group (such as a control) with another control or target group.

In order to address the potential differences in the types of observations discussed above, NAWC adopted the following procedure. Most of the snowpack data used in this analysis are from sites that were originally manual snowcourse sites but became automated SNOTEL sites after approximately 1980. NAWC recognized that this could present a problem because of potential systematic differences in method between the manual snowcourse and SNOTEL measurement techniques. The NRCS also recognized and addressed this potential problem. 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. NRCS personnel then developed correlations between the two types of measurements and applied a site-specific correction factor at each site that converted the previous monthly manual snowcourse 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 snowcourse data, while differences as great as 10-15% were found at some of the sites. Comparisons indicate that the SNOTEL observations were higher than the snowcourse observations at most target sites.

After careful consideration, NAWC decided to use the NRCS estimated data in place of a mixture of manual snowcourse and SNOTEL measurements. We believe that using these NRCS estimates can at least help account for the inherent systematic hias between data obtained using the snowcourse and SNOTEL measurement systems, although some question exists regarding how well the mathematical adjustments at some sites really work.

April 1 snowpack readings are widely used to approximate the maximum snow accumulation for the winter season in most western mountain ranges. Most streamflow and reservoir storage forecasts are made on the basis of the April 1 snowpack data.

4.1.1 Regression Equation Development

Some earlier weather modification research programs have indicated that the precipitation can he modified in areas downwind of the intended target areas. Analyses of some of these programs have indicated increases in precipitation in these downwind areas out to distances of 50-100 miles. NAWC conducted an analysis of tbe potential downwind effects of cloud seeding, utilizing a long-term program that has been conducted in central and southern Utah (Solak, et al, 2003). Historical regression equations were developed for that study to examine the possihle existence of downwind effects. Figure 4.2, taken from the study, shows the ratios of actual over predicted precipitation for several sites in southeast Utah and southwest Colorado. This figure (4.2) indicates possible positive downwind effects from the Utah program out to locations near the Utah/Colorado horder, a distance of approximately 100 miles from the location of the seeding generator network. The downwind study therefore suggests that if we wish to consider any precipitation gage sites in eastern Utah as control sites for the Gunnison project, tbey should be only those near the eastern border of Utah, to avoid incorporating sites that have been contaminated by the seeding in central and southern Utah. More general guidance gleaned from the study is that areas up to approximately 100 miles downwind of current or historic cloud seeding programs in Colorado may also be contaminated, limiting their usefulness as control areas. For example, it would be a tempting area to look for control sites in southwestern Colorado since they would be close to the target area and would probably be well correlated. However, since winds during storms that impact the target areas in southwestern Colorado are frequently blowing from the southwest, the potential exists for impacts on stations in this area outside the designated boundaries of cloud seeding programs being conducted in that region. As a consequence, we did not consider any snow course sites in that particular area as control sites for the Gunnison project.

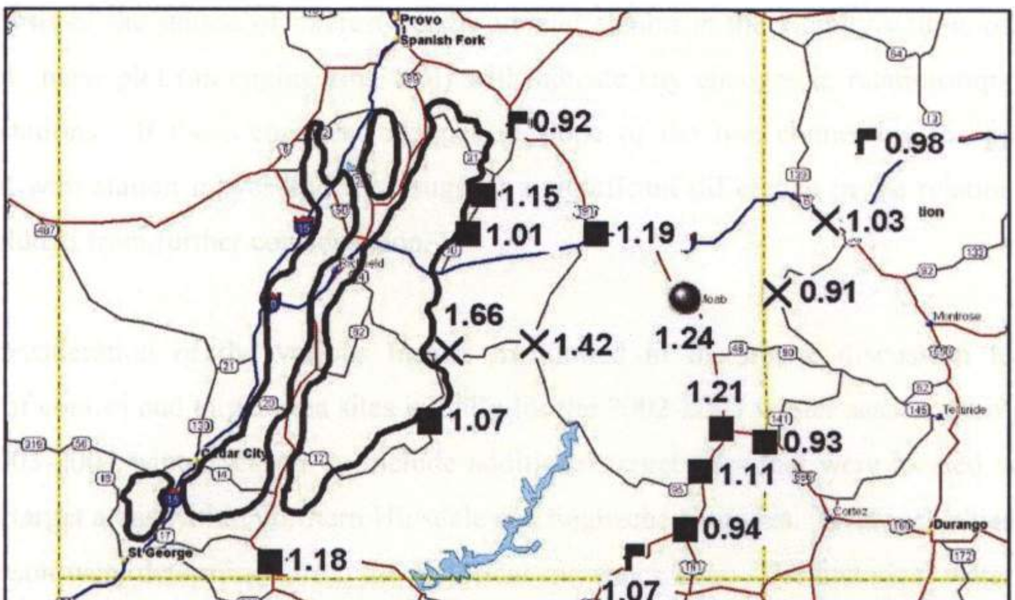


Figure 4.2 Ratios of actual/predicted downwind precipitation from Utah study

Potential contamination of <u>target area</u> sites from other cloud seeding programs is a consideration, just as it is in selecting control sites. Unfortunately, our geographic range is very limited compared to that for control sites since the target area is fixed. Normally one attempts to use all available target sites unless data quality problems exist. The Gunnison County project is in a peculiar situation in that a cloud seeding program has been conducted over the Grand Mesa and at times over the West Elk Mountains for a significant number of winter seasons (31 prior to the 2002-2003 winter season). We, therefore, were forced to accept the possibility of contamination affecting our evaluations.

An additional consideration in the selection of control sites for the development of an historical target/control relationship is that of data quality. A potential control site may be rejected due to poor data quality, which usually manifests itself in missing data. While data quality may appear to be satisfactory, another consideration is whether the station has been moved during its history. If a significant move that could adversely affect data continuity or quality is indicated in the station records, then to assess the situation we may perform a double mass analysis of the station of interest versus another station in the vicinity with good records. The double mass plot (an engineering tool) will indicate any changes in relationships between pairs of stations. If these changes (changes in slope of the line connecting the points) are coincident with station moves and they suggest a significant difference in the relationship, the site is excluded from further consideration.

Consideration of the various factors mentioned in the above discussion led to the selection of control and target area sites initially for the 2002-2003 winter season, then modified for the 2003-2004 winter season, to include additional target sites that were located within the expanded target areas within northern Hinsdale and Saguache Counties. Average values for each winter season were determined from the historical snowpack data. The historical water years of 1971-76, 1978, 1983-84, 1986-92, and 1997-2000 were used in the April 1st snowpack (water equivalent) evaluation, a total of 20 seasons. A total of nine target area snow water content observation sites were available. Six sites were selected as controls, based on obtaining high correlations with the target sites. Control and target area site names, elevations and locations are provided in Tables 4-1 and 4-2. The locations of these sites are provided in Figure 4.3, in which the numbers and letters correspond to those found in Tables 4-1 and 4-2.

Linear and multiple linear regression equations were developed for the snowpack analyses. Both types of evaluations included McClure Pass, a site on the edge of the target area, as a target site. Elevations for the control area sites averaged ~9200 feet MSL, while those in the target area averaged ~9800 feet, favorably similar for the statistical comparisons.

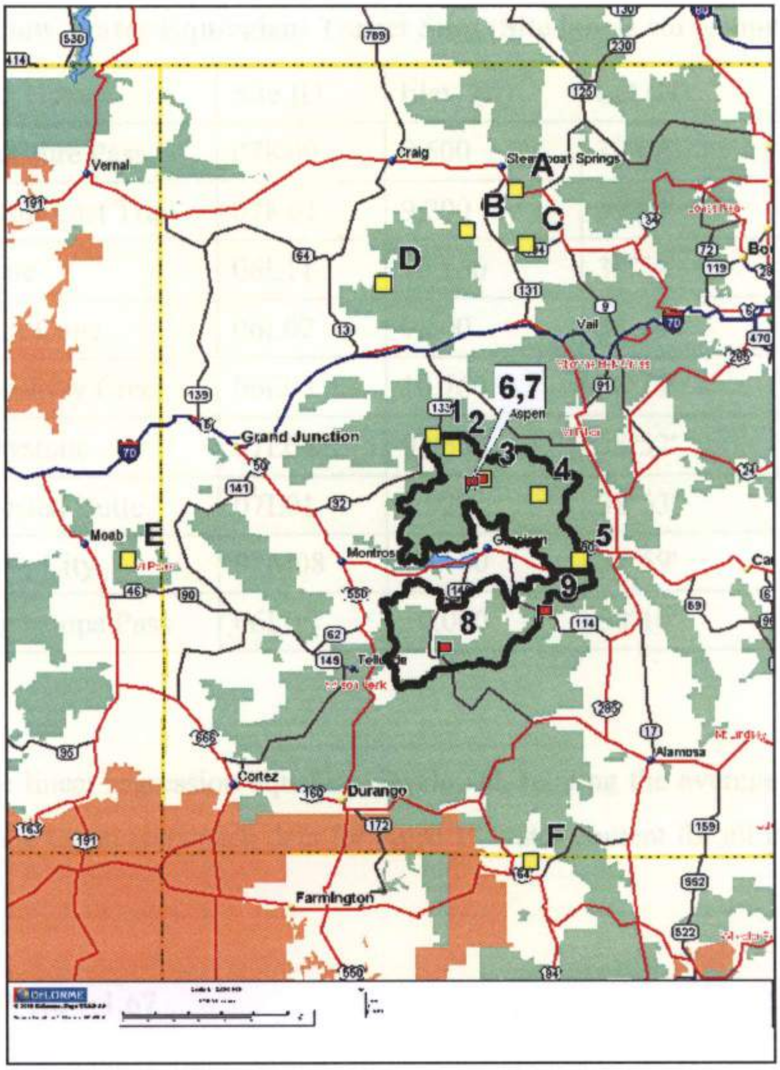


Figure 4.3 Snowpack target sites (1-9) and control sites (A-F)

Table 4-1 Snow Water Equivalent Control Sites (Site labels correspond to Fig. 4.3)

Site No.	Site Name	Site ID	Elev. (ft)	Lat (N)	Lon (W)
A	Rabbit Ears	06J09	9,400	40°22'	106°44'
B	Crosho	07J04	9,100	40°10'	107°03'
C	Lynx Pass	06J06	8,880	40°05'	106°40'
D	Burro Mtn	07K02	9,400	39°53'	107°36'
E	LaSal Mtn, UT	09L03	9,850	38°29'	109°16'
F	Chamita, NM	06N03	8,400	36°57'	106°39'

Table 4-2 Snow Water Equivalent Target Sites (Site labels correspond to Fig. 4.3)

Site No.	Site Name	Site ID	Elev. (ft)	Lat (N)	Lon (W)
1	McClure Pass	07K09	9,500	39°08'	107°17'
2	North Lost Trail	07K01	9,200	39°04'	107°09'
3	Butte	06L11	10,160	38°54'	106°57'
4	Park Cone	06L02	9,600	38°49'	106°35'
5	Porphyry Creek	06L03	10,760	38°29'	106°20'
6	Keystone	07L04	9,960	38°52'	107°02'
7	Crested Butte	07L01	8,920	38°53'	107°00'
8	Lake City	07M08	10,160	37°59'	107°15'
9	Cochetopa Pass	06L06	10,000	38°10'	106°36'

The simple linear regression equation developed, relating the average control snowpack data and the average target snowpack data for April 1st water content for all target si… following:

$$Yc = 0.75 * Xo + 1.67$$

the

target

where Yc is the calcula

was 6.42

is the 6-station control

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A multiple linear regr

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iches. The actual observed

the data from each control site is

6.42 inches. This yields an

allows a higher correlation (r-valu

he value predicted by the control

linear regression technique is as foll

ng effect (in percentage) is obtained

Table 4-2 Snow Water Equivalent Target Sites (Site labels correspond to Fig. 4.3)

Site No.	Site Name	Site ID	Elev. (ft)	Lat (N)	Lon (W)
1	McClure Pass	07K09	9,500	39°08'	107°17'
2	North Lost Trail	07K01	9,200	39°04'	107°09'
3	Butte	06L11	10,160	38°54'	106°57'
4	Park Cone	06L02	9,600	38°49'	106°35'
5	Porphyry Creek	06L03	10,760	38°29'	106°20'
6	Keystone	07L04	9,960	38°52'	107°02'
7	Crested Butte	07L01	8,920	38°53'	107°00'
8	Lake City	07M08	10,160	37°59'	107°15'
9	Cochetopa Pass	06L06	10,000	38°10'	106°36'

The simple linear regression equation developed, relating the average control snowpack data and the average target snowpack data for April 1st water content for all target sites, was the following:

$$Yc = 0.75 * Xo + 1.67 \qquad (1)$$

where Yc is the calculated average snow water content (inches) for the 9-station target, and Xo is the 6-station control average observed April 1st snow water content. The r-value for this equation was 0.86, suggesting that 74% of the target/control variation is explained by the regression equation.

A multiple linear regression equation was also developed using the same data. The primary difference between the two mathematical methods is that, with the multiple regressions, the data from each control site is related independently to the target area average. This normally allows a higher correlation (r-value) to be obtained. The equation developed for the multiple linear regression technique is as follows:

$$Yc = 0.08*X_1 + 0.51*X_2 + 0.34*X_3 - 0.50*X_4 - 0.03*X_5 + 0.23 * X_6 + 3.01 \quad (2)$$

where X_1 is Rabhit Ears SNOTEL, X_2 is Crosho, X_3 is Burro Mountain, X_4 is Lynx Pass, X_5 is LaSal Mountain (Utah), X_6 is Chamita (New Mcxico), and Yc is the 9-station predicted target area average. The r-value for equation (2) is 0.89, suggesting that 79% of the target/control variation is explained hy the equation.

It is important to note that the control and target sites and the resulting regression equations werc developed after thc second season of operations (to includc sites in the expanded target area) and have remained thc same since that time. This approach renders NAWC's evaluations of seeding effects of an *a priori* (e.g., from before) nature. In other words, NAWC cannot change target or control stations each scason in order to indicate positive results.

4.1.2 Evaluation Results

As in previous seasons, thc April 1 snow water contents fgor the individual sites were averaged for the eontrol and target groups. April 1, 2012 average snow water content for the control group was 4.47 inehes. When this observed amount was entered into equation (1), the simple regression, the predicted (most probable) average natural snow water content in the target area was 5.04 inches. The aetual observed April 1st average water eontent in the target was 6.42 inches. This yielded a ratio of 1.27 for the season, whieh is 27% more than the value predicted using equation (1) (the simple linear regression technique).

When the ohserved individual control area site snow water content amounts for April 1, 2012 were entered into equation (2) (the multiple linear regression technique), the predicted average April 1st snow water content in the target area was 4.67 inches. The actual ohserved April 1st average water content for this target group was 6.42 inches. This yields an observed/predicted ratio of 1.38, which is 38% more than the value predicted by the control stations and equation (2). The estimated seasonal seeding effect (in pereentage) is obtained using equation (3):

$$SE = 100 * (Yo - Ye)/Ye \quad (3)$$

Unfortunately, a closer inspection of the snowpack data this year revealed that there was an anomalously large amount of snow melt (and/or sublimation) prior to April 1, although the impact of this melting was extremely variable from site to site. Some sites (especially a couple of the control sites) experienced snowpack reductions of 70% or more prior to April 1st, while on the other end of the spectrum, other sites experienced only minor reductions in snowpack or (in one case) a slight increase between March 1 and April 1. Table 4-3 shows a comparison of the March 1 and April 1 snowpack this season for each target and control site, highlighting this dilemma. Such a large amount of early snowmelt, depending heavily on individual site sun exposure and other factors, renders the April 1st snowpack data very unreliable for this season in terms of attempting to estimate the seeding impacts. Although the individual results for this season were presented (and appear very favorable at face value), we have decided to exclude this season's results from the longer-term average in the evaluation due to the unusual degree of early season snowmelt and/or sublimation. Figures 4.4 and 4.5 are seasonal graphs of snow water content and precipitation for Crosho (a control site) and Park Cone (a target site), showing the wide variability in the amount of early-season snow. As shown in Table 4-3, these sites are at a fairly similar elevation. This degree of variability in pre-April 1st snowmelt is what makes analysis of the data particularly troublesome for purposes of the seeding effects evaluation this season.

Table 4-3 Site comparisons at March 1 vs. April 1, 2012 snow water content

Site No.	Control Sites	Elev. (ft)	Mar 1 SWE	Apr 1 SWE
A	Rabbit Ears	9,400	14.1	10.4
B	Crosho	9,100	8.9	1.7
C	Lynx Pass	8,880	7.8	4.9
D	Burro Mtn	9,400	10.2	6.9
E	LaSal Mtn, UT	9,850	8.8	1.7
F	Chamita, NM	8,400	8.3	0.2

Site No.	Target Sites	Elev. (ft)	Mar 1 SWE	Apr 1 SWE
1	McClure Pass	9,500	11.7	8.2
2	North Lost Trail	9,200	11.9	8.7
3	Butte	10,160	7.7	6.5
4	Park Cone	9,600	7.6	7.8
5	Porphyry Creek	10,760	10.2	8.0
6	Keystone	9,960	9.4	4.4
7	Crested Butte	8,920	7.6	6.0
8	Lake City	10,160	5.7	5.1
9	Cochetopa Pass	10,000	3.6	3.1

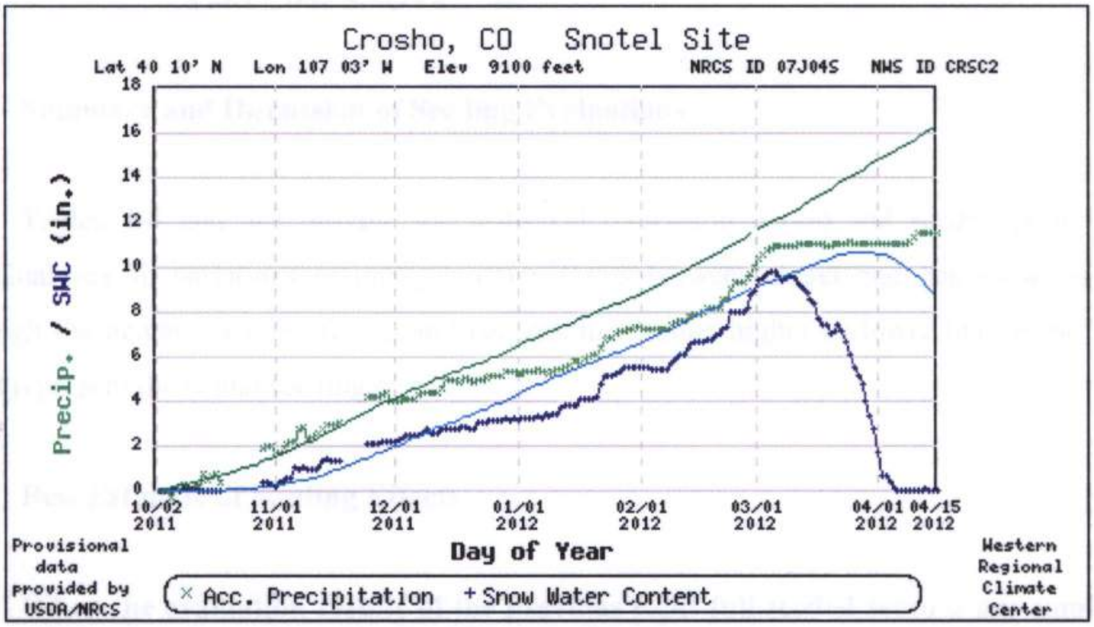


Figure 4.4 Seasonal precipitation (green) and snow water content (blue) at the Crosho SNOTEL site

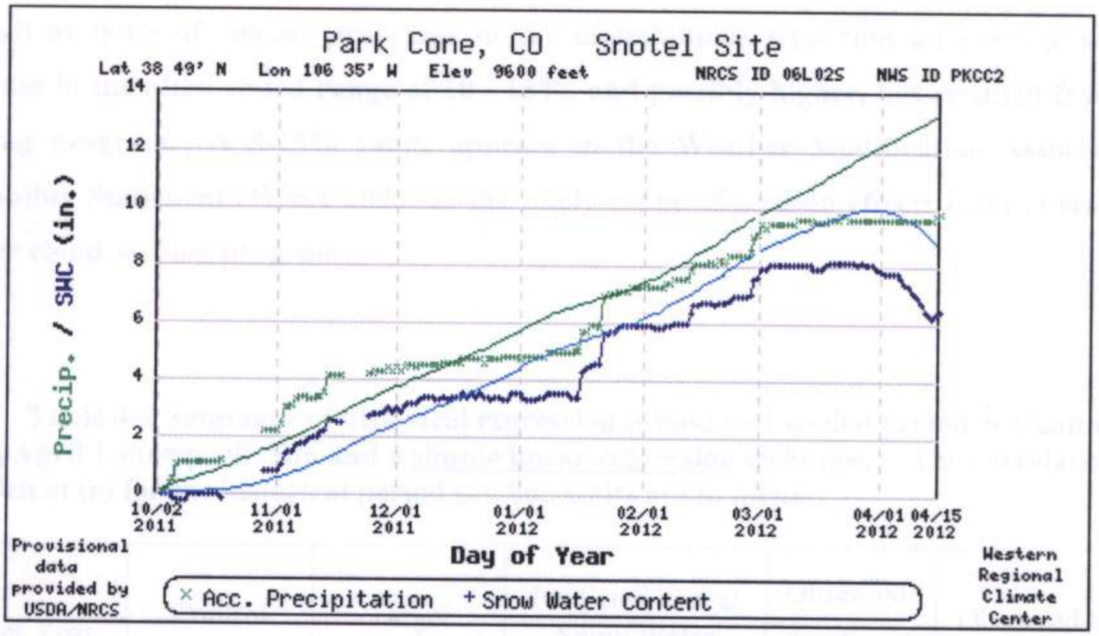


Figure 4.5 Seasonal precipitation (green) and snow water content (blue) at the Park Cone SNOTEL site

4.2 Summary and Discussion of Seeding Evaluations

Tables 4-4 and 4-5 provide the historical regression period and seeded period data. Individual season variations in precipitation patterns between target and control areas often outweigh the actual seeding effects, and can result in ratios higher or lower than those which would represent the actual seeding effect.

Best Estimate of Seeding Effects

When the evaluation results of the previous eight <u>full</u> seeded seasons are combined, the average indicated increases are 14% and 19% (for single and multiple regressions, respectively) for April 1st snow water content (Tables 4-3 and 4-4). The 2012 data have been excluded from this combined result, as discussed in Section 4.2. Even the eight-season combined results may be skewed by natural variability in snowpack accumulation, and thus these numbers may be imprecise. For example, the 1.43 and 1.47 ratios (for the linear and multi-linear evaluations) for water year 2008 are unrealistically high, which has the effect of raising the 8-year average values. However, it is estimated from these evaluations

as well as those of similar programs in the mountainous west that an average seeding increase in the often-stated range of 10 - 15%, and possibly higher, has resulted from this seeding program. A 5-15% range appears in the Weather Modification Association's Capability Statement (WMA 2005) as the likely range of seeding effects from operational winter cloud seeding programs.

Table 4-4 Summary of historical regression period and seeded period evaluations using April 1 snowpack data and a simple linear regression technique. The correlation coefficient (r) for the historical period is 0.86. Units are in inches.

Water Year	Control Average	Target Average	Predicted Target Snow Water Content	Observed/ Predicted Ratio	Observed Minus Predicted Precip.
1971	17.9	13.0	15.2	0.85	-2.2
1972	12.2	11.3	10.8	1.04	0.4
1973	16.6	14.5	14.2	1.02	0.3
1974	16.4	14.0	14.0	1.00	-0.0
1975	20.5	18.4	17.1	1.08	1.3
1976	14.5	13.5	12.6	1.07	0.9
1978	23.1	17.8	19.1	0.93	-1.3
1983	19.5	14.2	16.4	0.87	-2.2
1984	20.8	20.4	17.4	1.17	3.0
1986	16.2	15.1	13.9	1.09	1.2
1987	13.1	13.0	11.5	1.13	1.5
1988	16.2	11.2	13.9	0.81	-2.7
1989	12.1	12.5	10.8	1.16	1.7
1990	10.7	7.5	9.7	0.77	-2.2
1991	15.7	12.4	13.5	0.91	-1.2
1992	15.0	11.8	13.0	0.91	-1.2
1997	17.4	17.0	14.8	1.15	2.2
1998	14.5	12.6	12.6	1.00	-0.0
1999	8.4	8.1	8.0	1.02	0.1
2000	14.6	12.9	12.7	1.02	0.2
2003*	**13.8**	**NA**	**12.1**	**NA**	**NA**
2004	**8.3**	**9.0**	**7.9**	**1.14**	**1.1**
2005	**15.2**	**16.4**	**13.1**	**1.25**	**3.3**
2006	**16.6**	**13.7**	**14.2**	**0.96**	**-0.5**
2007	**9.2**	**9.3**	**8.6**	**1.08**	**0.7**

Water Year	Control Average	Target Average	Predicted Target Snow Water Content	Observed/ Predicted Ratio	Observed Minus Predicted Precip.
2008	**17.1**	**20.8**	**14.6**	**1.43**	**6.2**
2009	**15.2**	**14.4**	**13.1**	**1.10**	**1.4**
2010	**12.9**	**12.1**	**11.4**	**1.07**	**0.8**
2011	**18.8**	**16.6**	**15.9**	**1.05**	**0.8**
2012*	**4.5**	**6.4**	**5.0**	**1.27**	**1.38**
Mean	**14.2**	**14.1**	**12.3**	**1.14**	**1.7**

* Data excluded from the mean long-term evaluation results (2003 seeding was only conducted during February and March; 2012 data excluded due to early snowmelt).

Table 4-5 Summary of historical regression period and seeded period evaluations using April 1 snowpack data and a <u>multiple linear regression</u> technique. The correlation coefficient (r) for the historical period is 0.89. Units are in inches.

Water Year	X_1	X_2	X_3	X_4	X_5	X_6	Target Average	Predicted Target Snow Water Content	Observed/ Predicted Ratio	Observed Minus Predicted Precip.
1971	37.3	16.3	24.7	17.4	11.6	0.0	13.0	13.6	0.95	-0.6
1972	25.6	14.3	12.7	12.5	7.4	0.5	11.3	10.3	1.10	1.0
1973	22.6	12.6	20.3	12.8	16.6	14.6	14.5	14.6	1.00	-0.1
1974	33.0	15.4	16.1	13.5	13.0	7.4	14.0	13.5	1.04	0.5
1975	30.8	16.5	23.9	18.1	14.4	19.2	18.4	16.9	1.09	1.5
1976	18.7	13.4	20.6	14.7	10.6	9.0	13.5	12.7	1.07	0.8
1978	39.6	20.2	27.7	18.1	19.6	13.3	17.8	19.3	0.92	-1.5
1983	31.5	12.6	22.3	13.1	24.0	13.6	14.2	15.4	0.92	-1.2
1984	35.3	16.8	24.0	15.1	20.6	13.2	20.4	17.4	1.17	3.0
1986	25.0	13.4	26.0	13.2	12.3	7.1	15.1	15.3	0.99	-0.2
1987	18.1	9.2	15.9	9.4	16.8	8.9	13.0	11.4	1.14	1.6
1988	25.3	15.5	20.1	14.4	12.5	9.4	11.2	14.3	0.78	-3.1
1989	24.6	9.9	16.9	11.3	7.3	2.7	12.5	10.5	1.19	2.0
1990	24.6	10.4	10.2	11.0	4.7	3.2	7.5	8.8	0.85	-1.3
1991	25.3	10.9	19.0	11.7	14.4	12.9	12.4	13.7	0.90	-1.4
1992	22.9	8.8	20.0	10.7	15.8	12.0	11.8	13.0	0.91	-1.2
1997	36.6	12.6	25.0	12.3	10.1	7.7	17.0	16.2	1.05	0.9
1998	26.8	8.7	21.3	10.8	12.9	6.6	12.6	12.5	1.00	0.0
1999	22.9	7.0	12.4	8.1	0.0	0.0	8.1	8.6	0.95	-0.4
2000	30.8	12.8	16.1	10.4	11.9	5.4	12.9	13.1	0.98	-0.3
2003*	**25.3**	**14.8**	**14.1**	**10.8**	**10.5**	**7.2**	**NA**	**NA**	**NA**	**NA**
2004	**20.7**	**6.8**	**10.2**	**6.8**	**4.4**	**0.6**	**9.0**	**8.2**	**1.10**	**0.8**
2005	**21.8**	**9.5**	**15.0**	**10.6**	**19.1**	**15.3**	**16.4**	**12.3**	**1.33**	**4.1**

Water Year	X_1	X_2	X_3	X_4	X_5	X_6	Target Average	Predicted Target Snow Water Content	Observed/ Predicted Ratio	Observed Minus Predicted Precip.
2006	**35.5**	**16.1**	**18.0**	**14.2**	**11.7**	**4.2**	**13.7**	**13.7**	**1.00**	**0.0**
2007	**21.4**	**7.0**	**11.0**	**10.7**	**4.3**	**0.9**	**9.3**	**6.7**	**1.38**	**2.5**
2008	**32.0**	**15.4**	**16.6**	**14.9**	**11.2**	**12.7**	**20.8**	**14.2**	**1.47**	**6.6**
2009	**30.4**	**14.5**	**15.9**	**13.6**	**9.9**	**6.6**	**14.4**	**12.6**	**1.14**	**1.8**
2010	**14.7**	**9.6**	**13.9**	**8.6**	**17.0**	**13.3**	**12.1**	**12.0**	**1.01**	**0.1**
2011	**40.7**	**18.7**	**19.5**	**17.1**	**12.2**	**4.7**	**16.6**	**14.6**	**1.14**	**2.1**
2012*	**11.4**	**1.7**	**6.9**	**4.9**	**1.7**	**0.2**	**6.42**	**4.67**	**1.38**	**1.8**
Mean	**27.2**	**12.2**	**15.0**	**12.1**	**11.2**	**7.3**	**14.1**	**11.8**	**1.19**	**2.3**

* Data excluded from the mean long-term evaluation results (2003 seeding was only conducted during February and March; 2012 data excluded due to early snowmelt).

4.3 Estimates of the Effects of Seeding on April - July Streamflow

NAWC performed a snowpack/streamflow analysis in 2010 for the upper Gunnsion River Basin, using streamflow data from the Gunnison River near the town of Gunnison (USGS station #09114500). This station does have one upstream impoundment that could impact these data (Taylor Park Reservoir). First, the monthly mean streamflow data (in cubic feet per second) were obtained and converted to **April – July** totals (in acre-feet). The target area April 1 snowpack data (for sites used in the regular snowpack seeding evaluation) were used to establish snowpack/streamflow relationships. NAWC used both the linear and multiple linear regression techniques, to obtain estimated streamflow increases corresponding to snowpack increases of 10% and 15%. **These increases were applied to an "average April - July" period based on the regression period, which includes 30 seasons (1971-2000).**

The linear regression technique for estimating streamflow increases showed only a fairly good correlation with the target area snowpack sites, with an r value of 0.81. The multiple linear regression had a much better correlation with an r value of 0.92, meaning that some of the target sites were much better correlated with the Gunnison River streamflow than others. The results of the linear evaluation showed April – July streamflow increases of 11.6% (40,933 AF) and 17.3% (61,400 AF), based on snowpack increases of 10% and 15%, respectively. The multiple linear evaluation yielded higher streamflow increases of 13.2% (46,727 AF) and 19.8% (70,090 AF), for 10% and 15% snowpack increases, respectively.

In summary, these results imply April – July streamflow increases of approximately 11.6% – 13.2% for a 10% snow water increase in an average runoff year. Streamflow increases of about 17.3% – 19.8% are indicated for a 15% increase in snow water content in an average runoff year. For a 10% increase in April 1 snowpack, this corresponds to an increase of approximately 41,000 to 47,000 acre-feet in the Gunnison River (near Gunnison). For a 15% increase in April 1 snowpack, an increase of approximately 61,000 to 70,000 acre-feet is suggested. The estimates from the multiple linear regression equation are considered to be more accurate than those from the linear regression equation since the correlation coefficients are considerably higher for the multiple linear equations and the historic base period is thought to be sufficiently long for reasonable mathematical stability of the technique. The streamflow increases attributed to cloud seeding are generally expected to be higher (percentage–wise) in dry years and lower in wet years.

NAWC's evaluation for the eight seeded full winter seasons suggest an average increase in April 1st snow water contents of greater than 15% which may he on the high side due to the abnormal 2007-2008 winter. The 10 – 15% estimates used in the above are probahly in the proper range of effects.

The ahove increases in streamflow are of interest, hut no doubt underestimate the total amount of additional streamflow into Blue Mesa that may be attrihuted to the cloud seeding program. This is because additional runoff flows into Blue Mesa from other streams below the gaging station in Gunnison (e.g., the Lake Fork). The seeding program targets a number, if not all, of those streams.

NAWC located some additional data on a Bureau of Reclamation web site that provides calculated inflows to Blue Mesa on a daily hasis. That information was acquired for the same historical period used in the analysis described in the above (water years 1971-2000). The data were converted into **April through July** runoff amounts. As in the above analysis, the runoff amounts were correlated with April 1st snow water content values at the same target SNOTEL sites. Linear and multiple linear regression equations were developed.

The linear regression technique showed only a fairly good correlation with the target area snowpack sites, with an r-value of 0.82. The multiple linear regression had a much better correlation with an r-value of 0.92, meaning that some of the target sites were much better correlated with the calculated Blue Mesa inflow than others. **The results of the linear evaluation showed April – July streamflow increases of 11.7% (79,602 AF) and 17.5% (119,403 AF), based on snowpack increases of 10% and 15%, respectively. The multiple linear evaluation yielded higher increases of 14.1% (96,218 AF) and 21.1% (144,327 AF), for 10% and 15% snowpack increases, respectively.** These results are quite similar, in terms of percentages, to the results obtained for the Gunnison River flows measured in the city of Gunnison.

Some may ask how higher percentage increases in runoff than in snow water contents can occur. When the relationship between snowfall and hydrology is carefully considered, this is actually an expected outcome of such analyses. Perhaps one way to consider this is the fact that there will be a certain amount of water required from the snowpack to recharge the upper soil mantle before significant runoff begins. Once this requirement is met, the efficiency of conversion of snow water content to surface runoff (the basin efficiency) is much higher. The underlying assumption is that the soil recharge will be met by the amount of natural snow that accumulates in the target area. If cloud seeding can add an incremental increase in snowfall, then this increase is almost entirely converted into additional streamflow and likely results in a greater increase (in percentage terms) for streamflow than the percentage increase in snowpack.

To determine how estimated increases in streamflow might fluctuate depending upon whether a given season was below or above normal, we looked at the analysis for the inflow to Blue Mesa and then used the regression equations to estimate the additional **April through July** streamflow in a 75% of normal and a 125% of normal winter season based upon target area April 1st snow water contents. We again applied the assumed 10% and 15% increases in snow water content to these below and above normal seasons.

The results from 10% and 15% increases in the 75% of normal season were estimated increases of 12.3% (59,702 acre feet) and 18.5% (89,552 acre feet), respectively, using the linear regression equation. Likewise, the results from 10% and 15% increases in the 75% of normal season were estimated increases of 16.3% (72,163 acre feet) and 24.5% (108,235 acre feet), respectively, using the multiple linear regression equation.

Information for the 125% of normal season with 10% and 15% increases in April – July streamflow resulted in estimated increases of 11.3% (99,502 acre feet) and 16.9% (149,254 acre feet), respectively, using the linear regression equation. Likewise, the results from 10% and 15% increases in the 125% of normal season were estimated increases of 13.0% (120,272 acre feet) and 19.5% (180,409 acre feet), respectively, using the multiple linear regression equation.

Tables 4-6 and 4-7 summarize the results of the estimated increases in inflow to Blue Mesa under the varying assumptions for the linear regression equation and the multiple linear equations, respectively.

Table 4-6 Estimated Increases of April – July Streamflow Into Blue Mesa Reservoir, Based on Linear Regression Equation

Estimated Increases	75% of Average Winter season	**Average Winter Season**	125% of Average Winter Season
% Increase in Streamflow with 10% increase in Snow water	12.3%	**11.7%**	11.3%
% Increase in Streamflow with 15% increase in Snow water	18.5%	**17.5%**	16.9%
Increase in Streamflow (acre feet) with 10% increase in Snow water	59,702 ac ft	**79,602 ac ft**	99,502 ac ft
Increase in Streamflow (acre feet) with 15% increase in Snow water	89,552 ac ft	**119,403 ac ft**	149,254 ac ft

Table 4-7 Estimated Increases of April – July Streamflow Into Blue Mesa Reservoir, Based on Multiple Linear Regression Equation

Estimated Increases	75% of average Winter season	**Average Winter Season**	125% of Average Winter Season
% Increase in Streamflow with 10% increase in Snow water	16.3%	**14.1%**	13.0%
% Increase in Streamflow with 15% increase in Snow water	24.5%	**21.1%**	19.5%
Increase in Streamflow (acre feet) with 10% increase in Snow water	72,163 ac ft.	**96,218 ac ft**	120,272 ac ft
Increase in Streamflow (acre feet) with 15% increase in Snow water	108,235 ac ft	**144,327 ac ft**	180,409 ac ft

We regard the estimates obtained from the multiple regression equations to be more accurate than the linear regression equations due to higher correlation coefficients associated with the multiple regressions. The estimated increases in inflow to Blue Mesa are more representative of the areas providing inflow to Blue Mesa that are being targeted by the cloud seeding program. **As a consequence, the estimated increases in streamflow that may be attributable to the cloud seeding program in an average April – July period are thought to be in the range of 96,218 to 144,327 acre feet. The approximate cost of conducting the program is $90,000. Therefore, the cost of the additional streamflow attributed to the cloud seeding program (in 2010 dollars) is estimated to be in the range of $0.62 to $0.93 per acre-foot.** If the water users in the area were to quantify the value of this additional streamflow, a benefit/cost ratio could be estimated. For example, if the estimated additional streamflow is worth $10/acre-foot, then the estimated benefit to cost ratio would be 10.7 to 16.0/1. If this were the case, each dollar spent on the cloud seeding program would generate from $10.70 to $16.00 of benefit.

Appendix C contains the regression equation information.

5.0 SUMMARY AND RECOMMENDATIONS

A cloud seeding project was organized to benefit Gunnison County during a portion of the 2002-2003 winter season. North American Weather Consultants (NAWC) was selected as the contractor to perform that work. The seeding project has been continued for the ensuing winter seasons. The project target area was expanded for the second (2003-2004) season of operations to include tributaries that drain areas in the southern part of the upper Gunnison River Basin. A second cloud seeding permit, valid for a five-year period, was obtained from the Colorado Water Conservation Board to add the expanded area. A request for a new five-year cloud seeding permit, covering the areas previously permitted under two separate permits, was approved by the Colorado Water Conservation Board on November 16, 2007. Several local sponsors join together to obtain the funds required to organize and conduct this project. Sponsors have included: City of Gunnison, Crested Butte Mountain Resort, Crested Butte South Metropolitan District, Dos Rios Water System, East River Regional Sanitation District, Gunnison County, Gunnison County Stockgrowers Association, Mt. Crested Butte Water and Sanitation District, Town of Crested Butte, and the Upper Gunnison River Water Conservancy District. The operational seeding project has continued, to target the two permitted areas during the 2004-2005 through the 2011-2012 winter seasons. The 2011-2012 operational season is the subject of this report.

The State of Colorado, through the Colorado Water Conservation Board (CWCB) has provided grant funds to support operational cloud seeding programs. An agreement between the Colorado River lower basin states (Arizona, California and Nevada) and the CWCB provided some additional funds to augment the Upper Gunnison program for the 2011-2012 winter season.

Twenty ground-based, manually operated silver iodide generators were installed for the project this season. Fourteen storm periods were seeded during the operational period of November 15, 2011 through April 15, 2012. The first seeding opportunity occurred on December 13, with the final seeded event of the season on April 15. A total of 2,093.75 generator hours of seeding were conducted during the season.

Precipitation and snowpack were well below normal in most of the basin this season, with a split storm track resulting in dry conditions during much of the winter season. As of April 1, 2012, SNOTEL sites in the Gunnison Basin had snow water equivalent (SWE) averaging 60% of the normal (average) April 1 values. A water supply forecast was issued by the Colorado River Basin Forecast Center on May 1, 2012. A couple of quotes from this report helps put the 2012 water year in Colorado in perspective.

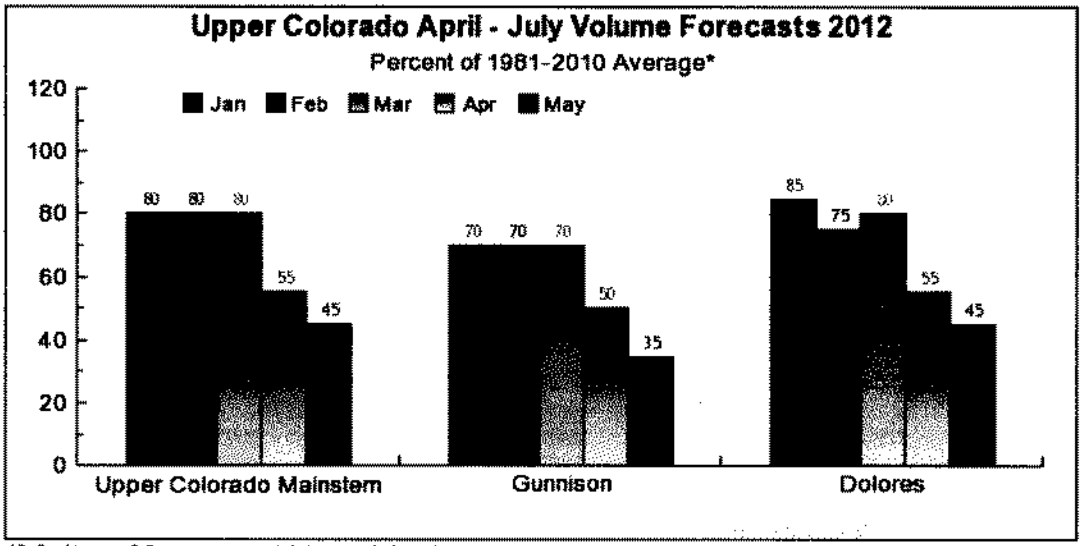
Snow:

"May 1st snow water equivalent was near just 20 percent of average in the basin as a whole. In a normal year snow continues to accumulate tbrough March and into the middle of April at higher elevations, but this year snow melt began by the last half of March. Most SNOTEL sites below 10,500 feet in the basin do not have any snow left, and many of those melted out at the earliest time in their 30 year history".

Streamflow:

"There were again large drops in the forecast runoff volumes from what was issued last month. Most of the May through July forecasts are for volumes that would be the 2nd or 3rd lowest on record if they occurred. Current May through July streamflow volume forecasts range between 25 and 50 percent of average with a median value of 40 percent. Current April through July streamflow volume forecasts range between 35 and 55 percent of average with a median value of 45 percent".

Figure 5.1, taken from this report, illustrates the dramatic drop in April-July streamflow forecasts, including those for the Gunnison River Basin, as the 2011 – 2012 water year progressed. The entire water supply forecast is provided in Appendix B.



*Median of forecasts within each basin.

Figure 5.1 Upper Colorado April – July Percent of Normal Streamflow Forecasts

5.1 Estimates of the Effects of Seeding on April 1st Snow Water Content

Evaluations of the potential effects of the seeding project on target area snowpack were conducted, utilizing the historical target/control approach. These evaluations considered only snow water content observations this season, due largely to problems with the high-elevation precipitation measurements discussed in previous reports. The source of the snow water content data was the SNOTEL data network operated by the National Resources Conservation Service (NRCS). April 1st snow water content values from SNOTEL or NRCS manually observed snow course sites were evaluated using both a simple linear regression (as used in previous seasonal reports), and a multiple linear regression technique. Nine snow water observation sites in the target area were correlated with six sites in non-seeded control areas. Historical periods were selected to exclude effects of earlier seeding projects that may have impacted the observations. Individual station records were examined for data quality. For the linear regression technique, data from potential control sites were averaged together in different groupings and correlated (using linear regression techniques) with the average values from the target sites to determine the best set of control stations, a set that provided a high correlation with the target and also provided some geographic "bracketing" of the target

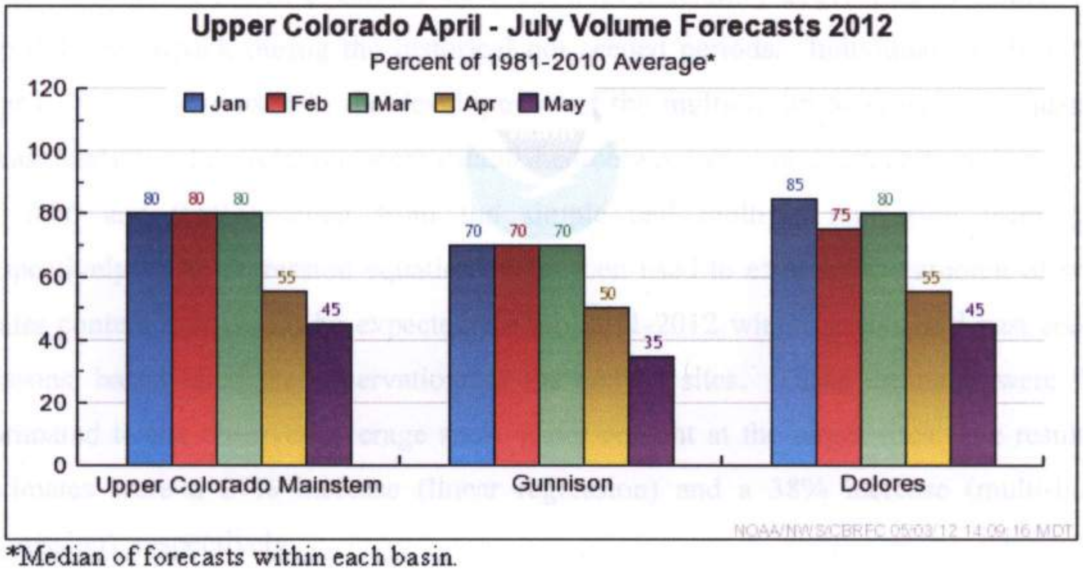


Figure 5.1 Upper Colorado April – July Percent of Normal Streamflow Forecasts

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As discussed in Section 4.2, an abnormally large amount of early-season snow melt (and/or sublimation) prior to April 1 made analysis of these snowpack data very unreliable for the purposes of estimating the seeding impacts for this season. NAWC feels the abnormal snowmelt pattern skewed these results. The prior eight-season averages for these evaluations suggest increases of 14% (simple linear regression) and 19% (multiple linear regression). We suspect that the very high estimated increases from the 2007-2008 season may be inflating these eight-year averages. We believe that the actual effects of the cloud seeding program are more likely in the 10 – 15 % range, consistent with results from similar long-term programs in the western U.S.

5.2 Estimates of the Effects of Seeding on April - July Streamflow

As described in detail in Section 4.5, NAWC performed a snowpack/streamflow analysis in 2010 for the upper Gunnison River Basin, using historical April 1 snowpack and April – July streamflow data. The streamflow data was obtained from a gage on the Gunnison River, near the town of Gunnison, as well as for additional inflow into Blue Mesa Reservoir which would not be accounted for by this gage. The relationship of each of these sets of streamflow data to April 1 snowpack data in the target area, was used to estimated total streamflow increases that would results from April 1 snowpack increases of 10% and 15% (which could reasonably be obtained due to cloud seeding). Both linear and multiple linear regression technique were used in this analysis, with good to very good correlations indicated between the snowpack and streamflow data sets.

Results of this analysis indicate that for a year with near-average snowpack, an increase of 10% in the April 1 snow water content yields April – July streamflow increases ranging from 11.6% to 14.1%. Similarly, a 15% increase in April 1 snow water equivalent would likely yield streamflow increases ranging from 17.3% to 21.1%. Further analyses showed that the streamflow increases due to cloud seeding would be larger (percentage-wise) in a drier year and somewhat lower in a wetter year, due to the essentially fixed requirement for soil moisture recharge before runoff begins.

In terms of absolute amounts, these estimated increases in streamflow that may be attributable to the cloud seeding program in an average April – July period are estimated to be in the range of 96,218 to 144,327 acre feet. The approximate cost of conducting the program is $90,000. Therefore, the cost of the additional streamflow attributed to the cloud seeding program (in 2010 dollars) is estimated to be in the range of $0.62 to $0.93 per acre-foot. If the water users in the area were to quantify the value of this additional streamflow, a benefit/cost ratio could be estimated. For example, if the estimated additional streamflow is worth $10/acre-foot, then the estimated benefit to cost ratio would be 10.7 to 16.0/1. If this were the case, each dollar spent on the cloud seeding program would generate from $10.70 to $16.00 of benefit.

5.3 Recommendations

The western United States is known for its frequent periods of drought. In addition, in many areas of the west, water supplies even in "normal" years do not meet the demand for water. The 2011 – 2012 water year is a good example of a significant drought impacting the Gunnison River Basin. It may be important to state that cloud seeding programs cannot overcome drought conditions but potentially can add some incremental increases during droughts that can be valuable. For example, if an area was destined to receive 50% of normal precipitation naturally during a drought period and a cloud seeding program produced a 10% increase then the precipitation would still be only 55% of normal (still a significant drought). **Some people seem to believe that conducting a cloud seeding program should guarantee at least normal precipitation. Unfortunately this is not the case.** Our approach as a company has consistently been one of recommending the application of cloud seeding technology on a consistent, year after year basis. Such an approach has the potential of increasing water supplies during drought periods (as well as in more normal times) due to increases in carryover soil moisture, underground aquifers and reservoir storage. Of course the conduct of seeding during drought periods has the potential to add some additional precipitation as stated previously although the amounts of increase will be less. To give an example, if we assume a 10% increase can be achieved in a normal year and in a 50% of normal year and there is 20" during a normal year and 10" in the drought year, then the same 10% increase would yield 2" of additional precipitation in the normal year but only 1" of additional precipitation during the drought year even though the percentage increase is the same.

Consequently, NAWC recommends that all our clients consider conducting cloud seeding projects on a routine basis each year. This has proven to be very effective water management approach in southern and central Utah, where operational cloud seeding has been conducted in 35 of the past 38 winter seasons, as well as in other areas of the western U.S. Contractual provisions can he made to temporarily suspend or terminate the cloud seeding projects in very high water years, when additional water may not be beneficial. We recommend this approach for several reasons:

- No one can accurately predict if precipitation during the coming winter season will be above or helow normal. Having a cloud seeding program already operational will take advantage of each seeding opportunity.

- Seeding in normal to above normal water years will result in a larger precipitation increase, which may provide additional, valuahle carryover storage in surface reservoirs or underground aquifers that can be drawn from during dry years.

- The continuity of conducting cloud seeding programs each year can lead to planned budgets for such programs, avoiding the potential difficulties of attempting to obtain emergency funding in the middle of a drought situation.

- Conducting cloud seeding programs only after drought conditions are encountered may mean fewer cloud seeding opportunities, leading to less additional precipitation being generated from a cloud seeding program.

We believe that the Upper Gunnison River cloud seeding program is meeting its stated objective of augmenting the precipitation in the target area, at an attractive benefit/cost ratio. It is recommended that the program be continued, to provide additional water for the increasing water demands in the areas served by the Upper Gunnison River.

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APPENDIX A

SEEDING SUSPENSION CRITERIA

As contained in NAWC's Weather Modification Permit No. 2007-03
From the State of Colorado dated November 16, 2007

Suspensions due to Snowpack:

The Permit Holder will suspend seeding operations if, at any time, the average of the snowpack snow water equivalent, at SNOTEL sites in and near the target area exceeds the thirty-year average defined by the following points:

A. 175% of average on December 1st
B. 170% of average on January 1st
C. 160% of average on February 1st
D. 150% of average on March 1st
E. 140% of average on April 1st

The NRCS Snow Survey Program operates a network of 100 SNOTEL sites in Colorado. The NRCS Snow Survey Program will map Colorado's snowpack suspension criteria via a daily online mapping of all SNOTEL sites in Colorado each year. The Permit Holder is required to check this mapping on a daily hasis during times of high snowpack.

One SNOTEL site that is nearing seeding thresholds but has not exceeded snowpack SWE suspension criteria will not suspend all of operations but will require the Permit Holder to notify the CWCB and all Project Sponsors about the conditions via email. If two SNOTEL sites in or near the target area are nearing snowpack suspension criteria then the Permit Holder will initiate discussions with tbe CWCB and Project Sponsors about suspending operations.

If two or more SNOTEL sites in a portion of the target area have exceeded the State snowpack suspension criteria then generators that reasonably affect those SNOTEL sites will be suspended until the NRCS daily mapping shows readings below the snowpack suspension criteria.

Suspensions due to Emergency Conditions:

The Permit Holder shall suspend seeding operations if there is any emergency that affects public welfare in the region. Seeding operations in that region will be suspended until the emergency conditions are no longer a threat to the public. Seeding suspensions are generally expected to occur due to one or more of the following conditions:

Avalanche Danger

The Permit Holder will not need to suspend operations at the High avalanche danger level but will send an email to the CWCB about specific areas of concern. When the avalanche category, determined by the CAIC, in a portion of the target area is rated EXTREME then seeding generators that reasonahly affect that area are suspended. The

Permit Holder will receive email forecasts from the CAIC at 7 am and 4 pm and will make operational decisions based on forecasts.

Flooding Potential

When the National Weather Service (NWS) forecasts a warm winter storm with a freezing level above 8,000 feet, with the possibility of considerable rain at higher elevations which might lead to local flooding, seeding will he suspended.

When potential flood conditions exist in or around any of the project areas, the Permit Holder shall consult with the NWS Flood Forecast Services, and if the NWS determines any of the following warnings or forecasts are in effect:

1. Flash flood warnings by the NWS
2. Forecasts of excessive runoff issued by a river basin forecast center
3. Quantitative precipitation forecasts issued by the NWS which would produce excessive runoff in or around the project area

APPENDIX B

UPPER COLORADO RIVER WATER SUPPLY OUTLOOK, MAY 1, 2012

(From the Colorado River Basin Forecast Center)

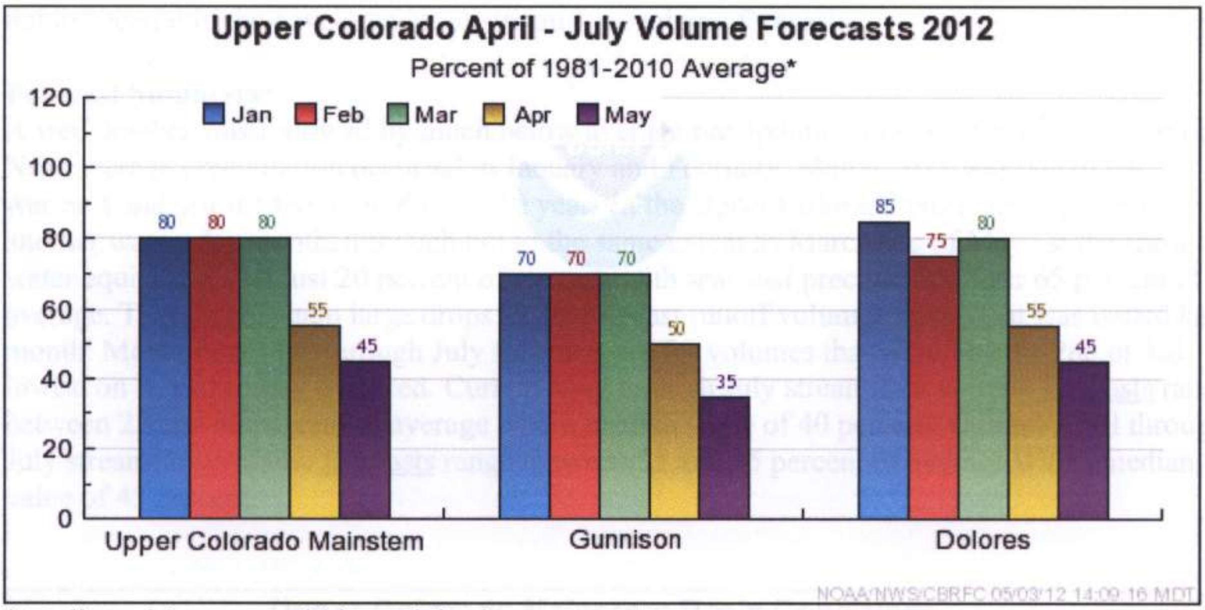
New 1981-2010 Averages being used this year.
Note: This publication is currently undergoing major revisions. The current publication will be replaced with a new publication based on stakeholder requirements and scientific advances. We expect to begin sharing details on this soon. If you have input on content, format, or publication frequency at any time, please contact us at cbrfc.webmasters@noaa.gov.

Upper Colorado Water Supply Outlook, May 1, 2012

Prepared by Brenda Alcorn, Greg Smith
NOAA, National Weather Service
Colorado Basin River Forecast Center
Salt Lake City, Utah
www.cbrfc.noaa.gov

Contents

Upper Colorado Summary



*Median of forecasts within each basin.

Upper Colorado Mainstem Basin Conditions

The following conditions influenced this month's forecasts:

Precipitation:
Seasonal October through April precipitation was near 65 percent of average in the Upper Colorado mainstem basin. April was another much below average precipitation month with 50 percent of average.

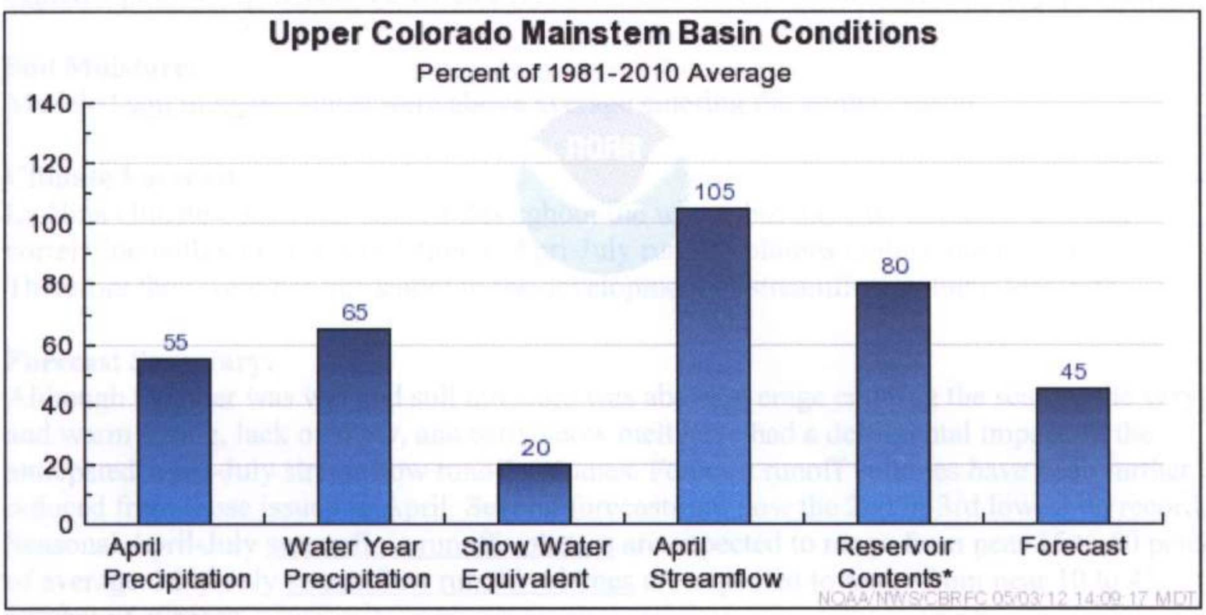
Snow:
May 1st snow water equivalent was near just 20 percent of average in the basin as a whole. In a normal year snow continues to accumulate through March and into the middle of April at higher elevations, but this year snow melt began by the last half of March. Most SNOTEL sites below 10,500 feet in the basin do not have any snow left, and many of those melted out at the earliest time in their 30 year history.
--- Upper Colorado basin snow water equivalent plot

Streamflow:
April streamflow was near to above average in the basin as a whole. However, some sites in the upper part of the basin had volumes greater than 150% of average.

Soil Moisture:
Modeled soil moisture states were above average heading into the winter.

Climate Forecasts:
La Nina climate conditions existed throughout the winter but these do not show a strong correlation with winter precipitation in the Upper Colorado mainstem basin, and therefore were not influential in the development of streamflow volume forecasts.

Forecast Summary:
A wet October was followed by much below average precipitation in November and December. Near average precipitation occurred in January and February. March 2012 was one of the warmest and driest March's in the last 30 years in the Upper Colorado basin and April was another warm, dry month, although not to the same extent as March. As of May 1st the snow water equivalent was just 20 percent of average with seasonal precipitation near 65 percent of average. There were again large drops in the forecast runoff volumes from what was issued last month. Most of the May through July forecasts are for volumes that would be the 2nd or 3rd lowest on record if they occurred. Current May through July streamflow volume forecasts range between 25 and 50 percent of average with a median value of 40 percent. Current April through July streamflow volume forecasts range between 35 and 55 percent of average with a median value of 45 percent.



* Percent usable capacity, not percent average contents.
Click for multi-month Graph.

Gunnison Basin Conditions

The following conditions influenced this month's forecasts:

Precipitation:
Seasonal October through April precipitation ranged from 60 to 85 percent of average in most of the Gunnison River Basin.

April was another warm and dry month in the Gunnison Basin with precipitation generally between 30 to 65 percent of average.

Snow:
The May 1st snow water equivalent for the Gunnison Basin was near 30 percent of average. However snow has melted out at several measuring sites. Where snow remains it ranged between 10 and 55 percent of average on May 1st.

All areas have experienced a very early snow melt as above average temperatures occurred in March and April. Some snow measuring sites that were void of snow in April or early May melted out a full 4 to 6 weeks earlier than average.

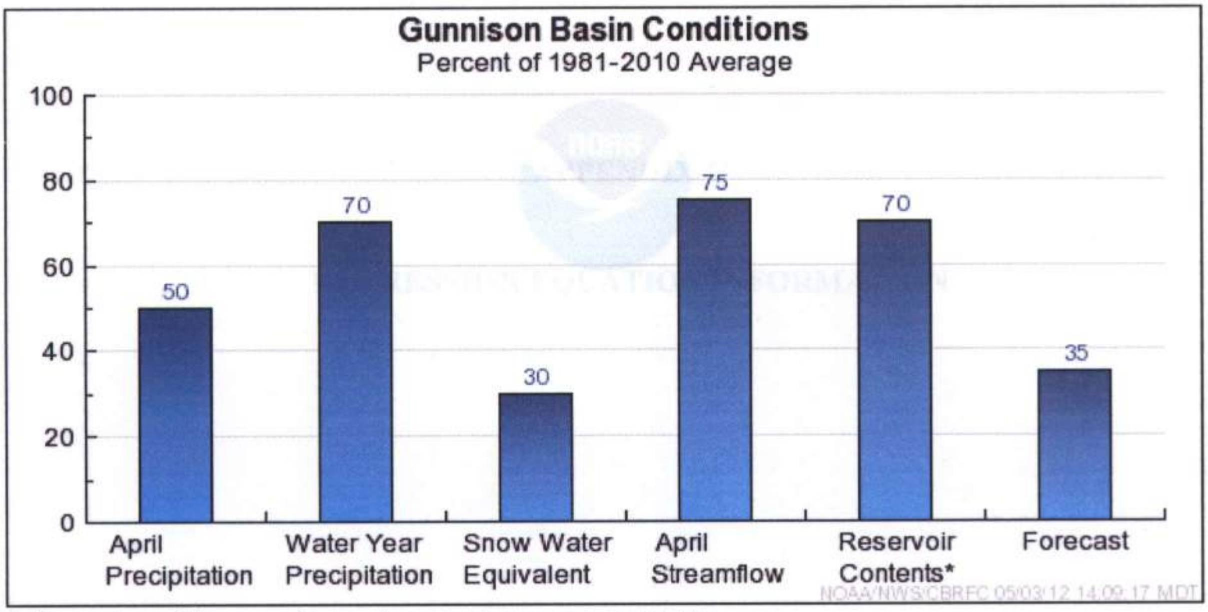
Gunnison Basin snow water equivalent plot

Streamflow:
Streamflow volumes for April were near or above average, ranging from 100 to 145 percent of average at higher elevation and headwater locations. At locations further downstream April streamflow ranged from 60 to 85 percent of average, most likely due to lack of snow that was depleted prior to April, and increased irrigation demands due to the warm and dry conditions.

Soil Moisture:
Modeled soil moisture states were above average entering the winter season.

Climate Forecasts:
La Nina climate conditions existed throughout the winter but these do not show a strong correlation with winter precipitation or Apri-July runoff volumes in the Gunnison Basin. Therefore they were not influential in the development of streamflow volume forecasts.

Forecast Summary:
Although October was wet and soil moisture was above average entering the season, the very dry and warm spring, lack of snow, and early snow melt have had a detrimental impact on the anticpated April-July streamflow runoff volumes. Forecast runoff volumes have been further reduced from those issued in April. Several forecasts are now the 2nd or 3rd lowest on record. Seasonal April-July streamflow runoff volumes are expected to range from near 15 to 50 percent of average. May-July streamflow runoff volumes are expected to range from near 10 to 45 percent of average.



* Percent usable capacity, not percent average contents.

Click for multi-month Graph.

APPENDIX C

REGRESSION EQUATION INFORMATION

April 1 Snowpack – Linear Regression:

Regression (non-seeded) period:

YEAR	XOBS	YOBS	YCALC	RATIO	EXCESS
1971	17.88	12.96	15.15	0.85	-2.20
1972	12.17	11.29	10.84	1.04	0.45
1973	16.58	14.52	14.17	1.02	0.35
1974	16.40	14.00	14.04	1.00	-0.04
1975	20.48	18.41	17.12	1.08	1.30
1976	14.50	13.53	12.80	1.07	0.93
1978	23.08	17.77	19.08	0.93	-1.31
1983	19.52	14.20	16.39	0.87	-2.19
1984	20.83	20.36	17.38	1.17	2.98
1986	18.17	15.09	13.86	1.09	1.23
1987	13.05	12.97	11.51	1.13	1.46
1988	16.20	11.21	13.89	0.81	-2.67
1989	12.12	12.51	10.81	1.16	1.70
1990	10.68	7.52	9.73	0.77	-2.20
1991	15.70	12.36	13.51	0.91	-1.15
1992	15.03	11.84	13.01	0.91	-1.16
1997	17.38	17.01	14.78	1.15	2.23
1998	14.52	12.57	12.82	1.00	-0.05
1999	8.40	8.13	8.00	1.02	0.13
2000	14.57	12.86	12.65	1.02	0.20
Mean	15.76	13.56	13.56	1.00	0.00

Seeded period:

YEAR	XOBS	YOBS	YCALC	RATIO	EXCESS
2003*	13.78	n/a	12.06	**n/a**	**n/a**
2004	8.25	8.98	7.89	**1.14**	**1.09**
2005	15.22	16.43	13.14	**1.25**	**3.29**
2006	18.62	13.68	14.20	**0.96**	**-0.52**
2007	9.22	9.29	8.62	**1.08**	**0.67**
2008	17.13	20.83	14.59	**1.43**	**6.24**
2009	15.15	13.11	13.09	**1.00**	**0.02**
2010	12.85	12.14	11.36	**1.07**	**0.79**
2011	18.82	16.63	15.86	**1.05**	**0.77**
2012*	4.47	6.42	5.04	**1.27**	**1.38**
Mean	14.16	14.05	12.34	**1.14**	**1.71**

SUMMARY OUTPUT

Regression Statistics

Multiple R	0.858423
R Square	0.736891
Adjusted R Square	0.722274
Standard Error	1.655331
Observations	20

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	1.668613	1.714526	0.973221	0.343341	-1.93347
X Variable 1	0.754053	0.106202	7.100188	1.28E-06	0.530931

* Data excluded from the mean long-term evaluation results (2003 seeding was only conducted during February and March; 2012 data excluded due to early snowmelt).

April 1 Snowpack – Multiple Linear Regression:

Regression (non-seeded) period:

YEAR	Rabbit Ears Pil	Crosho Pil	Burro Mtn Pil	Lynx Pass Pil	La Sal Mtn Pil, UT	Chamita Pil, NM	YOBS	YCALC	RATIO	EXCESS
1971	37.3	16.3	24.7	17.4	11.6	0.0	13.0	13.6	0.95	-0.6
1972	25.6	14.3	12.7	12.5	7.4	0.5	11.3	10.3	1.10	1.0
1973	22.6	12.6	20.3	12.8	16.6	14.6	14.5	14.6	1.00	-0.1
1974	33.0	15.4	16.1	13.5	13.0	7.4	14.0	13.5	1.04	0.5
1975	30.8	16.5	23.9	18.1	14.4	19.2	18.4	16.9	1.09	1.5
1976	18.7	13.4	20.6	14.7	10.6	9.0	13.5	12.7	1.07	0.8
1978	39.6	20.2	27.7	18.1	19.6	13.3	17.8	19.3	0.92	-1.5
1983	31.5	12.6	22.3	13.1	24.0	13.6	14.2	15.4	0.92	-1.2
1984	35.3	16.8	24.0	15.1	20.6	13.2	20.4	17.4	1.17	3.0
1986	25.0	13.4	26.0	13.2	12.3	7.1	15.1	15.3	0.99	-0.2
1987	18.1	9.2	15.9	9.4	16.8	8.9	13.0	11.4	1.14	1.6
1988	25.3	15.5	20.1	14.4	12.5	9.4	11.2	14.3	0.78	-3.1
1989	24.6	9.9	16.9	11.3	7.3	2.7	12.5	10.5	1.19	2.0
1990	24.6	10.4	10.2	11.0	4.7	3.2	7.5	8.8	0.85	-1.3
1991	25.3	10.9	19.0	11.7	14.4	12.9	12.4	13.7	0.90	-1.4
1992	22.9	8.8	20.0	10.7	15.8	12.0	11.8	13.0	0.91	-1.2
1997	36.6	12.6	25.0	12.3	10.1	7.7	17.0	16.2	1.05	0.9
1998	26.8	8.7	21.3	10.8	12.9	6.6	12.6	12.5	1.00	0.0
1999	22.9	7.0	12.4	8.1	0.0	0.0	8.1	8.6	0.95	-0.4
2000	30.8	12.8	16.1	10.4	11.9	5.4	12.9	13.1	0.98	-0.3
Mean	27.87	12.87	19.76	12.93	12.83	8.34	13.56	13.56	1.00	0.00

Seeded period:

YEAR	Rabbit Ears Pil	Crosho Pil	Burro Mtn Pil	Lynx Pass Pil	La Sal Mtn Pil, UT	Chamita Pil, NM	YOBS	YCALC	RATIO	EXCESS
2003*	25.3	14.8	14.1	10.8	10.5	7.2	n/a		**n/a**	**n/a**
2004	20.7	6.8	10.2	6.8	4.4	0.6	9.0	8.2	**1.10**	**0.8**
2005	21.8	9.5	15.0	10.6	19.1	15.3	16.4	12.3	**1.33**	**4.1**
2006	35.5	16.1	18.0	14.2	11.7	4.2	13.7	13.7	**1.00**	**0.0**
2007	21.4	7.0	11.0	10.7	4.3	0.9	9.3	6.7	**1.38**	**2.5**
2008	32.0	15.4	16.6	14.9	11.2	12.7	20.8	14.2	**1.47**	**6.6**
2009	30.4	14.5	15.9	13.6	9.9	6.6	13.1	12.6	**1.04**	**0.5**
2010	14.7	9.6	13.9	8.6	17.0	13.3	12.1	12.0	**1.01**	**0.1**
2011	40.7	18.7	19.5	17.1	12.2	4.7	16.63	14.56	**1.14**	**2.1**
2012*	11.4	1.7	6.9	4.9	1.7	0.2	6.42	4.67	**1.38**	**1.8**
Mean	27.2	12.2	15.0	12.1	11.2	7.3	14.1	11.8	**1.19**	**2.3**

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.889
R Square	0.79
Adjusted R Square	0.693
Standard Error	1.739
Observations	20

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*	*P-value*	*Lower 95%*
Intercept	3.006	2.2566	1.33	0.21	-1.87	7.8809	-1.87	7.8809	0.3433	-1.9335
X Variable 1	0.082	0.0997	0.82	0.43	-0.13	0.2975	-0.13	0.2975	1E-06	0.53093
X Variable 2	0.508	0.3447	1.47	0.16	-0.24	1.2523	-0.24	1.2523		
X Variable 3	0.337	0.1466	2.3	0.04	0.021	0.654	0.021	0.654		
X Variable 4	-0.5	0.4319	-1.2	0.27	-1.43	0.4321	-1.43	0.4321		
X Variable 5	-0.03	0.1306	-0.2	0.81	-0.31	0.2501	-0.31	0.2501		
X Variable 6	0.235	0.1272	1.84	0.09	-0.04	0.5092	-0.04	0.5092		

* Data excluded from the mean long-term evaluation results (2003 seeding was only conducted during February and March; 2012 data excluded due to early snowmelt).

April-July Streamflow at Gunnison vs Apr 1 Snowpack, Linear Regression: (Multiple Linear not shown due to size constraints)

Regression period: YEAR	Target SWE (in)	Apr-Jul AF	YCALC (AF)	RATIO	EXCESS (AF)	
1971	12.96	366362	319902	1.15	46461	
1972	11.29	248884	271672	0.92	-22788	
1973	14.52	331407	365238	0.91	-33831	
1974	14.00	260488	350126	0.74	-89638	
1975	18.41	339043	477775	0.71	-138731	
1978	13.53	234456	336622	0.70	-102166	
1977	5.58	77042	106404	0.72	-29361	
1978	17.77	384267	459128	0.84	-74858	
1979	20.34	485474	533722	0.91	-48248	
1980	21.49	471530	566839	0.83	-95310	
1981	7.44	127640	180421	0.80	-32782	
1982	17.40	341394	448515	0.76	-107121	
1983	14.20	388223	355914	1.09	32309	
1984	20.36	653809	534043	1.22	119766	
1985	16.10	508569	410898	1.24	97674	
1986	15.09	524606	381836	1.37	142970	
1987	12.97	368029	320223	1.15	47806	
1988	11.21	240090	269421	0.89	-29331	
1989	12.51	249930	307041	0.81	-57110	
1990	7.52	170084	162672	1.05	7412	
1991	12.36	313768	302539	1.04	11229	
1992	11.84	222167	287749	0.77	-65582	
1993	19.72	513207	515716	1.00	-2509	
1994	10.36	278284	244663	1.14	33621	
1995	17.73	687588	458161	1.50	229427	
1996	17.09	439248	439512	1.00	-264	
1997	17.01	560868	437282	1.28	123607	
1998	12.57	275883	308648	0.89	-32785	
1999	8.13	308662	180356	1.71	128306	
2000	12.86	258838	317008	0.82	-58170	
Mean	14.15	354328	354327	1.00	1	
Normal Year				Difference:	Ratio	
10% incr:	15.56		395261	40933.34	1.115524062	**11.6% incr**
15% incr:	18.27		415727	61400.01	1.173286093	**17.3% incr**
125% norm	17.68		456661			
10% incr	19.45		507827	51166.67	1.112045267	**11.2% incr**

15% incr	20.33	533411	76750.01	1.1680679	**16.8% incr**
75% norm	10.61	251994			
10% incr	11.67	282694	30700.00	1.121828295	**12.2% incr**
15% incr	12.20	298044	46050.00	1.182742443	**18.3% incr**

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.806981861
R Square	0.651219724
Adjusted R Square	0.638763286
Standard Error	88276.8109
Observations	30

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-55005.94661	58862	-1	0.35804	-175579	65567.18478
X Variable 1	28938.04483	4002	7	7.18E-08	20740	37136.25644

April-July Streamflow at Blue Mesa Gage vs Apr 1 Snowpack, Linear Regression:
(Multiple Linear not shown due to size constraints)

Regression period:

YEAR	Target SWE	Apr-Jul AF	YCALC	RATIO	EXCESS	
1971	12.96	679903.20	616130.89	1.10	63772.31	
1972	11.29	449324.81	522339.22	0.86	-73014.41	
1973	14.52	712404.69	704295.06	1.01	8109.63	
1974	14.00	520153.48	674907.00	0.77	-154753.54	
1975	18.41	793080.12	923142.28	0.86	-130062.16	
1976	13.53	454478.50	648645.33	0.70	-194166.83	
1977	5.58	162494.25	200946.44	0.81	-38452.19	
1978	17.77	758373.79	888876.17	0.86	-128502.38	
1979	20.34	880401.8	1031940.61	0.85	-151538.81	
1980	21.49	916550.89	1096344.22	0.84	-179793.33	
1981	7.44	258639.65	305993.11	0.85	-47353.46	
1982	17.40	684742.92	866242.00	0.79	-181499.08	
1983	14.20	840047.73	686162.00	1.22	153885.73	
1984	20.38	1373095.67	1032565.89	1.33	340529.78	
1985	16.10	991382.18	793084.50	1.25	198297.68	
1986	15.09	987730.75	736184.22	1.34	251546.53	
1987	12.97	750279.82	616756.17	1.22	133523.85	
1988	11.21	370690.03	517962.28	0.72	-147272.25	
1989	12.51	404552.68	591119.78	0.68	-186567.10	
1990	7.52	350746.79	310370.06	1.13	40376.73	
1991	12.36	571710.69	582365.89	0.98	-10655.20	
1992	11.84	444358.55	553603.11	0.80	-109244.56	
1993	19.72	941573.08	996925.06	0.94	-55351.97	
1994	10.36	486961.07	469815.89	1.04	17145.18	
1995	17.73	1206640.68	885000.33	1.36	321640.35	
1996	17.09	807417.67	848734.22	0.95	-41316.55	
1997	17.01	1015838.99	844357.28	1.20	171481.71	
1998	12.57	549040.65	594246.17	0.92	-45205.51	
1999	8.13	637058.82	344760.33	1.85	292298.49	
2000	12.86	492748.75	610503.39	0.81	-117754.64	
Mean	14.15	683080.76	683077.30	1.00	3.46	
Normal Year				Difference	Ratio	
10% incr:	15.56		762679.33	79602.03	1.116534439	**11.7% incr**
15% incr:	16.27		802480.34	119403.04	1.174801659	**17.5% incr**
125% norm	17.68		882082.37			
10% incr	19.45		981584.91	99502.54	1.112804133	**11.3% incr**
15% incr	20.33		1031336.18	149253.81	1.1892062	**16.9% incr**

75% norm	10.61	484072.22			
10% incr	11.67	543773.74	59701.52	1.123331849	**12.3% incr**
15% incr	12.20	573624.51	89552.28	1.184997774	**18.5% incr**

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.817266262
R Square	0.667924143
Adjusted R Square	0.656064291
Standard Error	165400.8433
Observations	30

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-112942.9698	110287.1351	-1.024081093	0.314563668	-338856.179	112970.239
X Variable 1	56275.24251	7498.828808	7.504537568	3.56865E-08	40914.57077	71635.91425

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