THE CONDUCT AND EVALUATION OF A CLOUD SEEDING PROGRAM FOR THE GUNNISON RIVER BASIN, COLORADO DURING THE 2008-2009 WINTER SEASON

Prepared for

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

By

Don A. Griffith, CCM
T. Warren Weston
David P. Yorty
Mark E. Solak

North American Weather Consultants, Inc.
8180 South Highland Dr., Suite B-2
Sandy, UT 84093

Report No. WM 09-9
Project No. 08-236

August 2009

WATER CONSERVATION BOARD
1313 SHERMAN STREET, ROOM 721
DENVER, CO 80203

Buyer: MAGGIE VAN CLEEF
Phone Number: 303-866-3292
Agency Contact: STEVEN SHULL
Phone Number: 303 866 3441

DATE: 09-25-09

IMPORTANT
The PO# and Line # must appear on all invoices, packing slips, cartons and correspondence

ACC: 09-24-09

PURCHASE ORDER
STATE OF COLORADO

P.O. # OE PDA 10000000022 **Page#** 01

State Award #

BID #

FEIN 846000770 F **Phone:** - -
Vendor Contact:
Purchase Requisition #:

VENDOR
GUNNISON COUNTY
GUNNISON COUNTY FINANCE DEPT
200 E VIRGINIA
GUNNISON CO 81230

Invoice in Triplicate To:
DIVISION OF WATER CONSERVATION
1313 SHERMAN STREET, ROOM 721
DENVER, CO 80203

Payment will be made by this agency

Ship To:
DIVISION OF WATER CONSERVATION
1313 SHERMAN STREET, ROOM 721
DENVER, CO 80203

INSTRUCTIONS TO VENDOR:

1. If for any reason, delivery of this order is delayed beyond the delivery/installation date shown, please notify the agency contact named at the top left. (Right of cancellation is reserved in instances in which timely delivery is not made.)
2. All chemicals, equipment and materials must conform to the standards required by OSHA.
3. NOTE: Additional terms and conditions on reverse side.

Delivery/Installation Date: 10-01-09
F.O.B. DESTINATION STATE PAYS NO FREIGHT

SPECIAL INSTRUCTIONS:

LINE ITEM	COMMODITY/ITEM CODE	UNIT OF MEASUREMENT	QUANTITY	UNIT COST	TOTAL ITEM COST
001	91843000000 CLOUD SEEDING GRANT- REIMBURSEMENT FOR INCREASED CLOUD SEEDING FOR THE GUNNISON BASIN.				$40,000.00

DOCUMENT TOTAL = $40,000.00

THIS PO IS ISSUED IN ACCORDANCE WITH STATE AND FEDERAL REGULATIONS
This PO is effective on the date signed by the authorized individual.
EPSPO FAA

FOR THE STATE OF COLORADO

Authorized Signature 9/25/09
Date

DP-01 (R-02/06)

Gunnison County
COLORADO

Finance Department

PHONE 970.641.2203 FAX 970.641.7643

3-27-09 $40K
Please issue P.O. to Gunnison County for a cloud seeding grant for winter 08-09 Joe B

February 2, 2009

Joe Busto, Flood Plain Information Officer
Colorado Water Conservation Board
Centennial Building, Room 721
1313 Sherman Street
Denver, CO 80203

RE: Request for Weather Modification Grant Funds

Dear Mr. Busto:

As the coordinating entity for the Gunnison Weather Modification Program we are very appreciative of the grant funds received from the Colorado Water Conservation Board (CWCB). Once again we are requesting CWCB to issue a Purchase Order in the amount of $40,000 for the 2008-2009 cloud seeding season. The CWCB allocated $19,000 from these funds to cost share the Upper Gunnison River program. The Colorado River Lower Basin States (Arizona, California and Nevada) allocated funds to supplement cloud seeding operations in Colorado for the 2008-2009 winter season (Lower Basin Parties). Of the funds allocated, $21,000 was allocated to cost share on the Upper Gunnison River program.

Our program is truly a coordinated approach with the following partners:

> Upper Gunnison River Water Conservation District; City of Gunnison; Gunnison Stock Growers Association; Crested Butte South Water and Sanitation East River Water and Sanitation; Mt. Crested Butte Water and Sanitation Town of Crested Butte; Gunnison County; and Dos Rios Water Users.

Gunnison County is appreciative of this assistance provided by the CWCB and commends the CWCB for recognizing the importance of these snow-pack augmentation programs to the State. Enclosed you will find the Statement of Work. Please do not hesitate to contact me if you have any questions regarding our program, 970/641-7671 or jwyman@gunnisoncounty.org.

Sincerely,

Jane Wyman

Jane Wyman
Weather Modification Coordinator
Gunnison County

STATEMENT OF WORK FOR THE UPPER GUNNISON RIVER WINTER CLOUD SEEDING PROGRAM
2008-09 WINTER SEASON

Gunnison Counties' weather modification contractor, North American Weather Consultants, Inc. (NAWC), is contracted to provide cloud seeding services on this program. NAWC has a valid cloud seeding permit issued for this program by the Colorado Water Conservation Board. The target areas are those drainages above 9,000 feet that are tributary to the upper Gunnison River (defined as Blue Mesa Reservoir and above). The program has been contracted to run from December 1, 2008 through April 15, 2009. NAWC has established cloud seeding criteria to assess each storm passing through the area to determine if there are portions of the storm or in some cases where the entire storm is considered susceptible to cloud seeding. Operations are then conducted considering targeting of the effects of seeding while monitoring whether there should be any suspensions of seeding activities according to previously established criteria (e.g. avalanche warnings, excessive snowpack).

Twenty ground-based, manually operated silver iodide generators have been installed for this winter's program. There are 4,500 generator hours budgeted for this program for a total estimated expenditure of $99,000.

Funding participants and seeding hour and percent of program funding allocations are as follows:

Participants	Funding	% Total Funds	Funded Seeding
Local supporters	$59,000	59.60 %	2,681.8 hours
CWCB	$19,000	19.19 %	863.6 hours
Lower Colo. River Basin	$21,000	21.21 %	954.6 hours
TOTALS	$99,000	100.00 %	4,500 hours

8180 South Highland Drive, Suite B-2
Sandy, Utah 84093
Telephone 801-942-9005
Facsimile 801-942-9007
E-Mail nawc@nawcinc.com

North American Weather Consultants, Inc.

Air Quality, Applied Meteorology, Meteorological Research, Weather Modification

August 24, 2009

Joe Busto
Colorado Water Conservation Board
1313 Sherman Street, Room 721
Denver, CO 80203

Dear Joe:

I have enclosed four copies of NAWC report number WM 09-9 entitled "The Conduct and Evaluation of a Cloud Seeding Program for the Gunnison River Basin, Colorado during the 2008-2009 Winter Season." I believe this seeding program is effective. Estimates of the effects of seeding are averaging about 10 - 15%. An estimate of the additional streamflow into Blue Mesa produced by a 10 - 15% increase in April 1st snow water content indicates increases in April through July streamflow that may be attributable to the cloud seeding program in an average year 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 estimated cost of the additional streamflow attributed to the cloud seeding program is roughly in the range of $0.62 to $0.93 per acre-foot.

Please let me know if you have any questions about this report.

Sincerely,

Don A. Griffith, CCM
President

enclosures

THE CONDUCT AND EVALUATION OF A CLOUD SEEDING PROGRAM FOR THE GUNNISON RIVER BASIN, COLORADO DURING THE 2008-2009 WINTER SEASON

Prepared for

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
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Report No. WM 09-9
Project No. 08-236

August 2009

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THE CONDUCT AND EVALUATION
OF A WINTER CLOUD SEEDING PROGRAM
FOR THE UPPER GUNNISON RIVER, COLORADO
2008-2009 WINTER SEASON

Report No. WM 09-9

Project No. 08-236

1.0 INTRODUCTION

North American Weather Consultants (NAWC) conducted a winter cloud seeding program for the upper Gunnison River from December 1, 2008 through April 15, 2009. This was the seventh season for this program. The program initially included only those drainages above 9000 feet MSL in Gunnison County during the first season (2002-2003). At the request of the sponsors, it was expanded to include watersheds 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 November 2007, covering both of the target area, that is valid for a five-year period.

The 2008-2009 program was the sixth seeded season for the expanded target area. The CWCB also provided grant funds to those operating cloud seeding programs in Colorado for the past five winter seasons. A grant to the Upper Gunnison River program was authorized by the CWCB for this past winter season. Additional funds to supplement this program were provided last winter through an agreement between the three Lower Basin Colorado River Compact States (Arizona, Colorado, and Nevada) and the CWCB.

There were 22 cloud seeding generator sites available for operations this past season. Twenty-two seeded storm events occurred during the operational season. The following sections describe this season's operations and evaluation of effectiveness in more detail.

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 has followed 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 the nature 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 number 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.

- The National Weather Service forecasts a warm winter storm (freezing level > 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, 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.

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, 175% 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 whereby 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 principal 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 same suspension criteria were used in the conduct of the 2008-2009 program

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 2008-2009 winter season was the same as that of the past several seasons. The operational period was December 1, 2008 through April 15, 2009. 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. The sites are the same as last season, except for the loss of site G26 (Ridgeway). NAWC attempted to find a new operator there, but was not successful. A site was located in the Somerset area, but unfortunately was not used due to lack of a good contact there. A better arrangement will be sought for next season for operation of the Somerset site. 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 three percent (by weight) silver iodide (AgI), the active seeding agent, complexed with very small portions of sodium iodide and para-dichlorobenzene in solution with acetone. Dr. William Finnegan of the Desert Research Institute published a paper (Finnegan, 1999) suggesting 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.

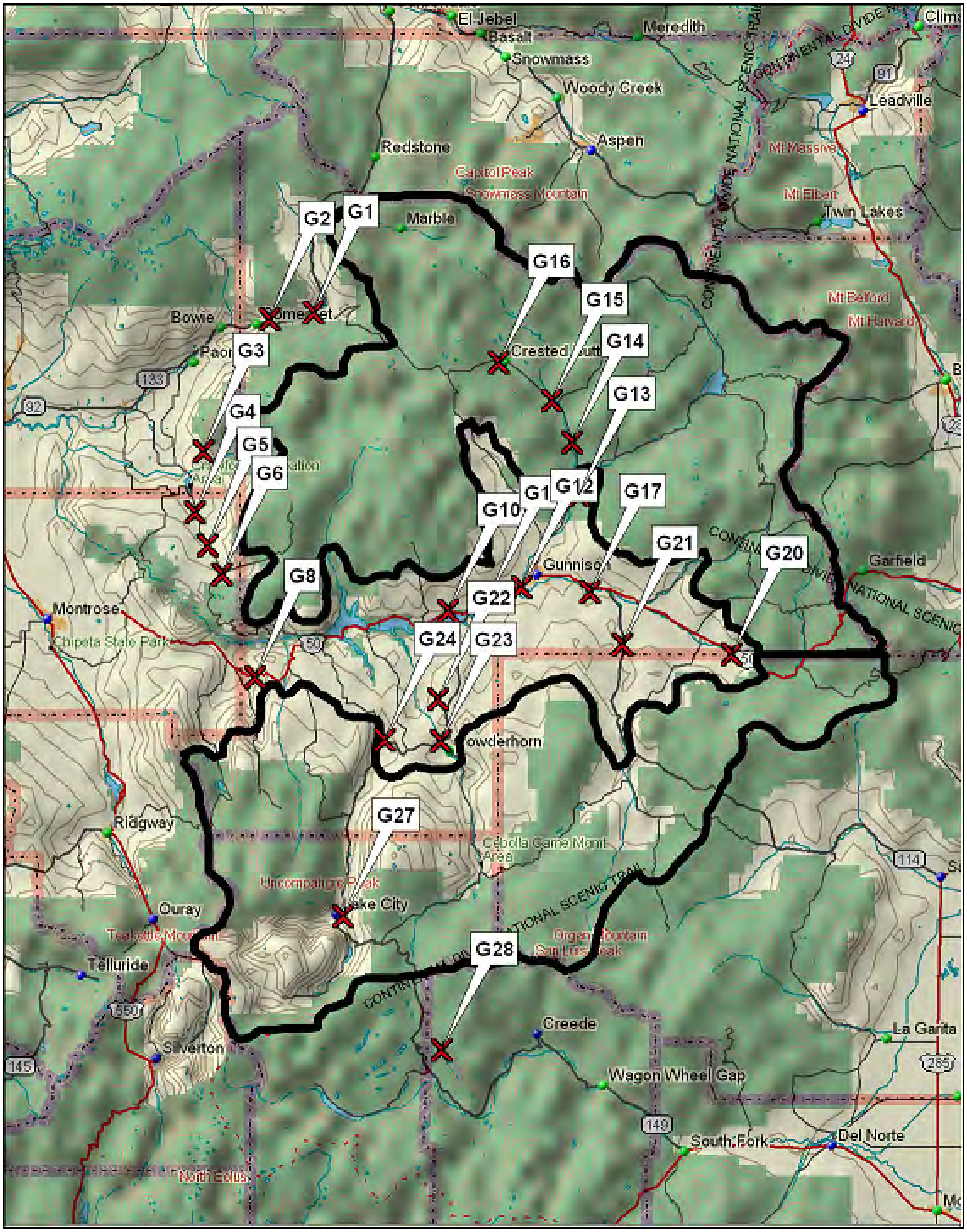

Figure 2.1 Seeding target area and generator locations

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°23.26'	107°29.37'	7544'
G10	Lakeside Resort	38°29.39'	107°06.13'	7653'
G11	Blue Mesa East	38°31.06	107°01.05	7570'
G12	Gunnison West	38°31.60'	106°57.45'	7669'
G13	Three Rivers Resort	38°39.99'	106°50.72'	8065'
G14	Rory Judy Ranch	38°44.80'	106°50.60'	8435'
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'
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, allowing decisions to be made regarding where and when to seed. Information acquired online includes hourly weather reports, radiosonde (weather balloon) observations, surface and upper-air charts (both current and forecast), weather radar and satellite images, and forecasts from the National Weather Service, as well as numerous other products. 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 acquired online, which was utilized to make seeding decisions, during the 2008-2009 season.

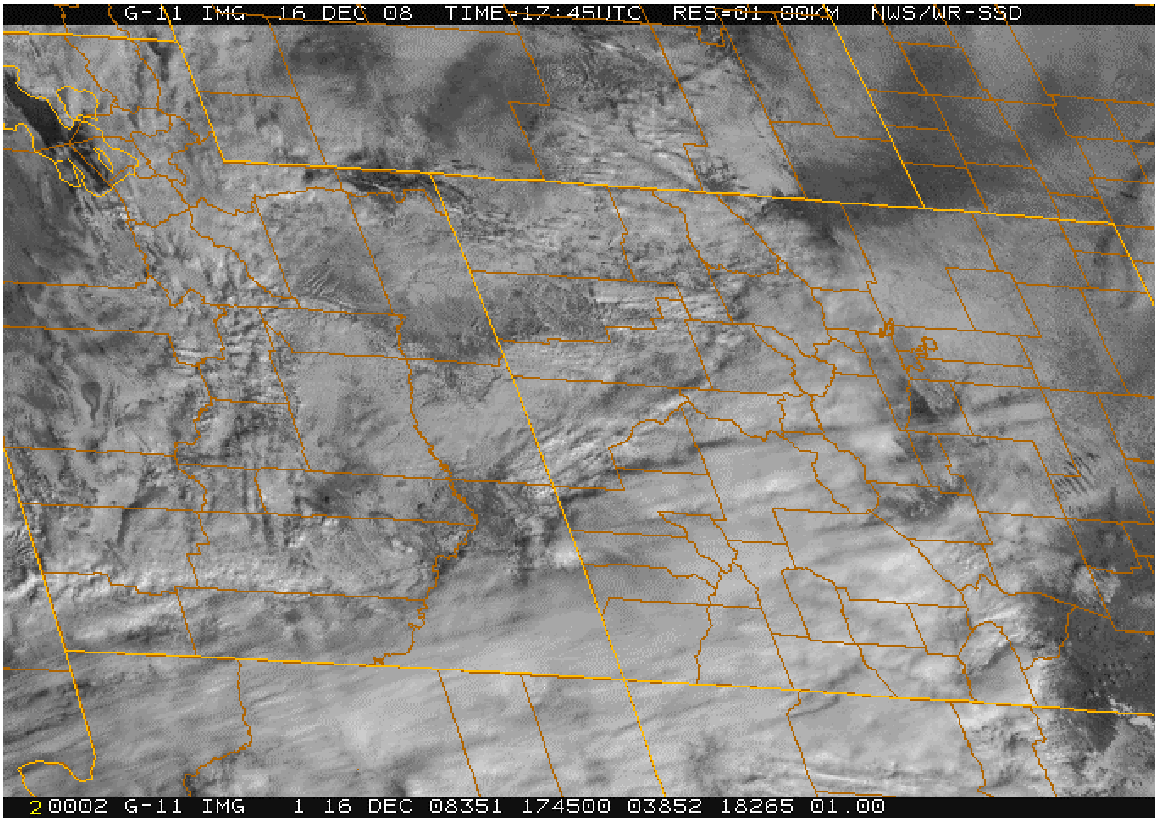

Figure 2.3 Satellite image of western Colorado at 1045 MST on December 15, 2008. This storm brought heavy snowfall area-wide and provided a seeding opportunity for the southern portion of the project area. The northern portion was suspended due to avalanche warnings.

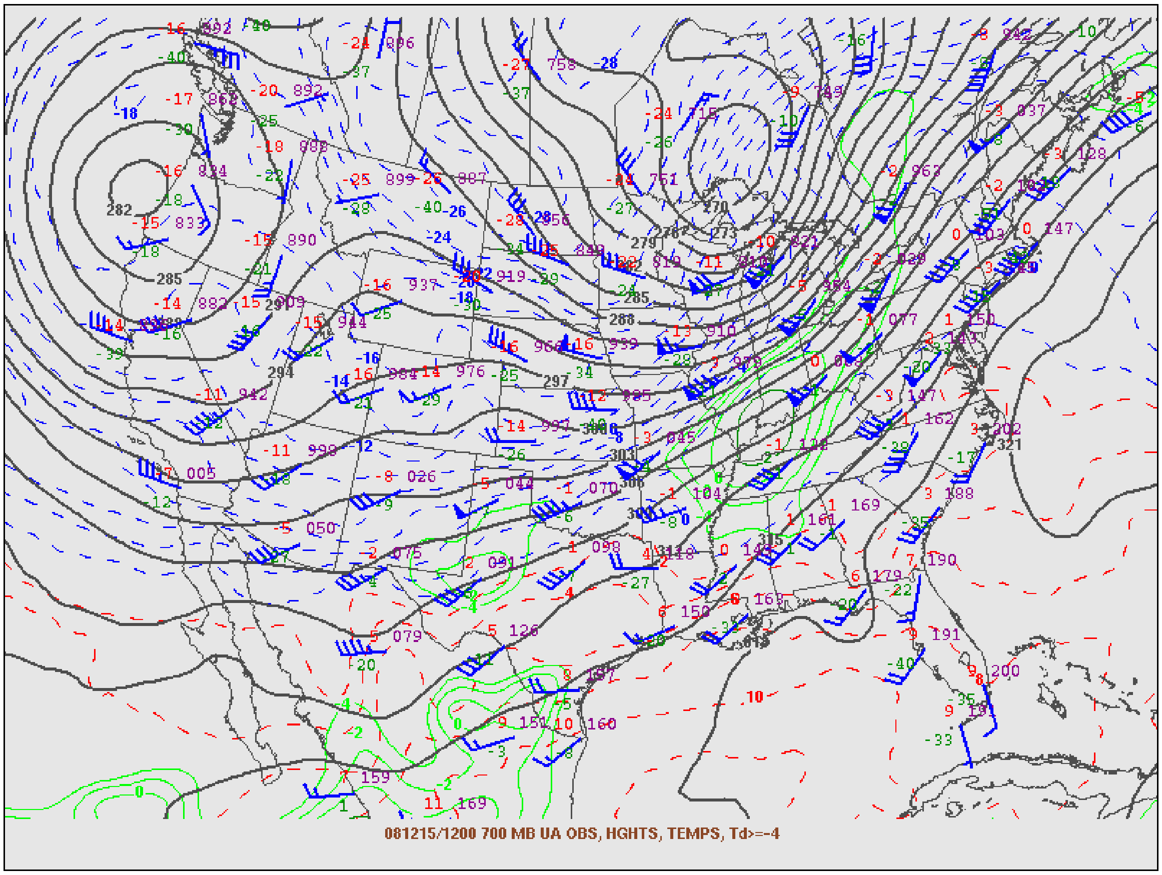

Figure 2.4 Map at 700-mb level, 12Z (0500 MST) on 12-15-08

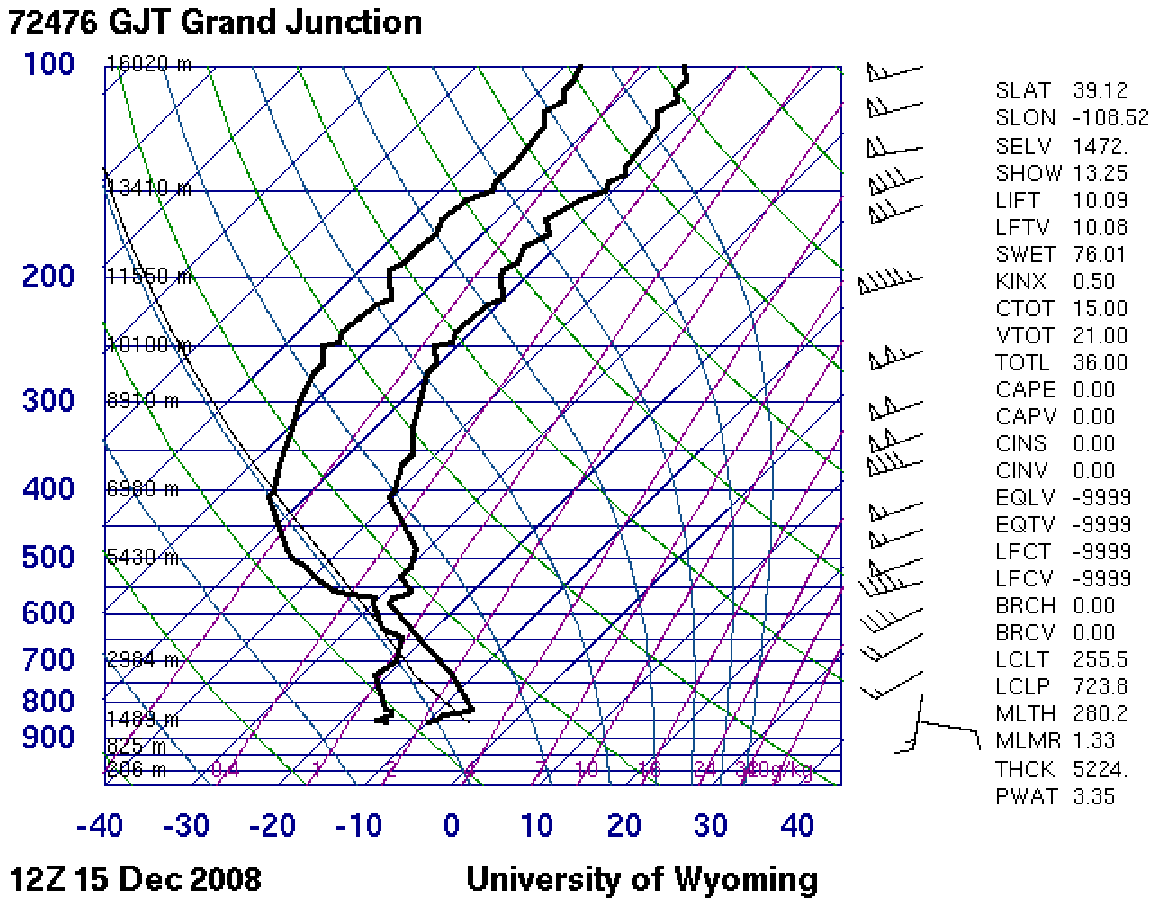

Figure 2.5 Upper-air sounding taken from Grand Junction on the morning of December 15, 2008. The right black line represents temperature, and the left black line is the dewpoint. Blue lines are pressure levels in millibars (horizontal) and temperature in degrees C (diagonal). Wind barbs on the right show wind speed and direction at various levels. The coincidence of the two lines (near the bottom) shows saturation of the atmosphere. The 700-mb temperature was near –15C, near the minimum threshold for seeding at that level. Winds are southwesterly at most levels except south to southeasterly near the surface.

3. 0 OPERATIONS

This season's cloud seeding program for Upper Gunnison River program began on December 1, 2008 and ended on April 15, 2009. A total of 22 storm events were seeded during all or portions of 36 days. Seven of these seeded events occurred in December, three in January, three in February, five in March, and four in April. A cumulative 2867.75 hours of seeding generator operation were conducted during the season, resulting in the release of approximately 34,413 grams of silver iodide. Table 3-1 shows the dates and ground generator usage for the 22 storm events, and Table 3-2 contains operation times for each of the Cloud Nuclei Generator (CNG) sites.

Table 3-1
Storm Dates and Generator Usage, 2008-2009 Winter Season

Storm No.	Date(s)	No. of CNGs Used	Generator Hours
1	December 2-3	9	93
2	December 8-9	8	118.75
3	December 13-14	7	128.5
4	December 15-16	3	51
5	December 18	16	167.25
6	December 22-23	16	286.5
7	December 25-26	10	194.5
8	January 3	12	117.5
9	January 9	1	7.5
10	January 26-27	10	189
11	February 9-10	7	139.75
12	February 12-13	14	156.5
13	February 14	7	68.25
14	March 7	4	34.75
15	March 9-10	9	89.25
16	March 22-23	12	285.75
17	March 25-26	11	159.5
18	March 29-30	5	57
19	April 1	10	40.75
20	April 3	16	291.75
21	April 11-12	8	92.5
22	April 15	9	98.5
Total	---	---	2867.75

Table 3-2a.
Generator Hours for Upper Gunnison River Program, 2008-2009, Storms 1-8

Storm	1	2	3	4	5	6	7	8
Date	Dec 2-3	Dec 8-9	Dec 13-14	Dec 15-16	Dec 18	Dec 22-23	Dec 25-26	Jan 3
SITE								
G1								
G2	10.5	6						10.5
G3	10.5	12			2.5	16.75		9.5
G4	10.5				3.5			9
G5	10.5				5.5	17		10
G6	10.5		14.75		13	10		10
G8	10.25	14.25	15		12.5		18.75	
G10					10	19.25	28	9.5
G11						19.5	15.25	9.5
G12					12.25	19.5		
G13	10		15.5		10.75	19.25	4	10.25
G14			39	21	9	18.75	26.75	10.25
G15				8	9.5	18		
G16								
G17			15.5		9.5	19.5		
G19								
G20		15	15.75		10.5	19	9.75	9.5
G21					11.25	19.5	16.5	7.75
G22		14				13	27.5	
G23	10	20			11.5	20.5	118	
G24	10.25	20.5			26	19.5	30	
G26								
G27		17	13			17.5		11.75
G28				22	10			
G29								
Storm Total	**93.0**	**118.75**	**128.5**	**51.0**	**167.25**	**286.5**	**194.5**	**117.5**
Accum Total	**93**	**211.75**	**340.25**	**391.25**	**558.5**	**845**	**1039.5**	**1157**

Table 3-2b.
Generator Hours for Upper Gunnison River Program, 2008-2009, Storms 9-15

Storm	9	10	11	12	13	14	15
Date	Jan 9	Jan 26	Feb 9-10	Feb 12-13	Feb 14	Mar 7	Mar 9-10
SITE							
G1							
G2				11.5			9
G3				12			10
G4		16.5		10			10
G5		20.5		11.25			10
G6		14.25			7.5		
G8		18.25	19.5	12			
G10					8		9.75
G11		20	20	11.5	18		
G12		18.25	19.75	9.5			
G13		20.25		11.5	8	8.5	
G14		20.25	20.75		10.75	8	
G15		21					
G16							
G17		19.75	19.5	11.5			
G19							
G20			20.5	11.25	8		
G21				12	8		
G22				10.5			9.75
G23				10.5			10.25
G24	7.5		19.75	11.5			10.25
G26							
G27						9.75	10.25
G28						8.5	
G29							
Storm Total	7.5	189.0	139.75	156.5	68.25	34.75	89.25
Accum Total	1164.5	1353.5	1493.25	1649.75	1718	1752.75	1842

Table 3-2c.
Generator hours for Upper Gunnison River Program, 2008-2009, Storms 16-22

Storm	16	17	18	19	20	21	22	
Date	Mar 22-23	Mar 25-26	Mar 29-30	Apr 1	Apr 3	Apr 11-12	Apr 15	Site Total
SITE								
G1								
G2	17.75	18.5	12.5	4.5	24			249.5
G3	21		13.5		20			127.75
G4		19	4.5	4.25	22			109.25
G5	19		13.5		21			138.25
G6	15.5	19	13	4.25	9.5			141.25
G8	24							154.5
G10		18.75		4.25	19	11.5	11	149
G11								113.75
G12	23	10.5		6	20.5	12	11.5	162.75
G13	35	10.25		4.25	20.5	11.5	11.25	210.75
G14	24.5				21.75		9	239.75
G15	34.5	9.5		4.25	9.5			114.25
G16								9.5
G17					19.75	12	11.5	138.5
G19								0
G20	23	10.25		2.75	21.25	11		217
G21	24	11		3.25	15.75		11.5	140.5
G22		21.75			14.75		11.25	122.5
G23				3	19	11.5	10.25	244.5
G24		11				11.5	11	188.75
G26								0
G27	24.5				13.5	11.5		128.75
G28								40.5
G29								0
Storm Total	**285.75**	**159.5**	**57.0**	**40.75**	**291.75**	**92.5**	**98.25**	
Accum Total	**2127.75**	**2287.25**	**2344.25**	**2385**	**2676.75**	**2769.25**	**2867.75**	

Snowfall for this season was well above normal early in the year, but gradually decreased later in the season and by April 1 was very near normal percentages. As of April 1, SNOTEL sites in the Gunnison Basin reported snowpack ranging from 89% of average, to 122% of average. The average for the Gunnison Basin was 101% of normal April 1st snow water content. Water year precipitation was similar, although less variable, ranging from 89% to 110%. Figures 3.1 through 3.5 show monthly precipitation expressed as percent of normal for the upper Colorado River area for the months of December, January, February, March, and April. These plots, which were prepared by the NWS Colorado Basin River Forecast Center, indicate that precipitation in the Gunnison River Basin was much below normal in November, much above normal in December, January, and February and below normal in March and April. Data published by the Colorado NRCS provides specific Gunnison Basin monthly precipitation percent of normal values as follows:

- November 2008 50%
- December 195%
- January 2009 200%
- February 150%
- March 73%
- April 97%

Figures 3.6 through 3.8 provide snow water equivalent and precipitation data for three NRCS SNOTEL sites located within the cloud seeding target area. Figure 3.9 provides a time series graph of the April 1 snow water content percent of normal for the Upper Gunnison Basin from 1968-2009. Figure 3.10 provides the April 1st snow water content percent of normals for all of the Colorado River Basins. This figure indicates that some of the larger winter storm periods favored southern Colorado.

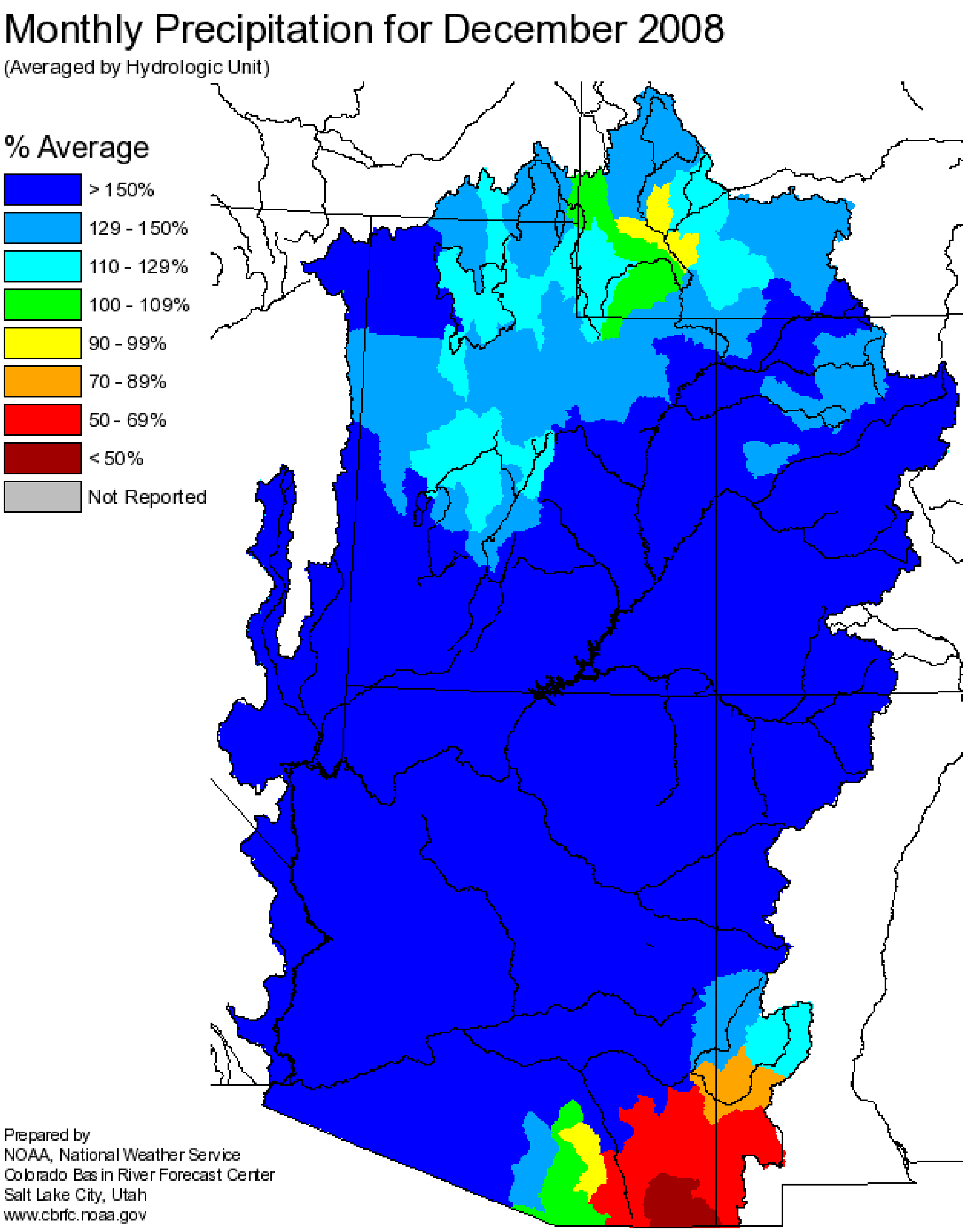

Figure 3.1 December 2008 precipitation

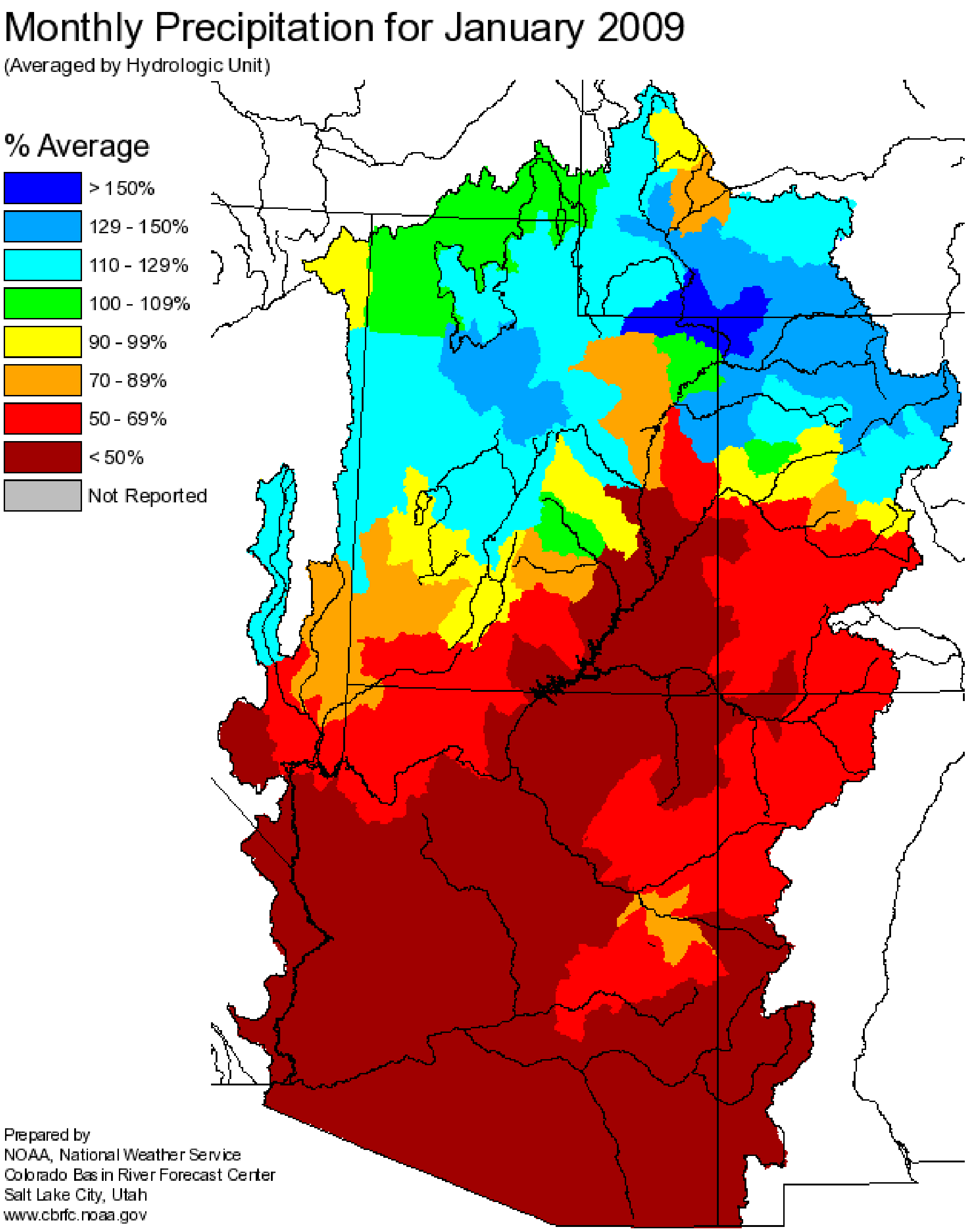

Figure 3.2 January 2009 precipitation

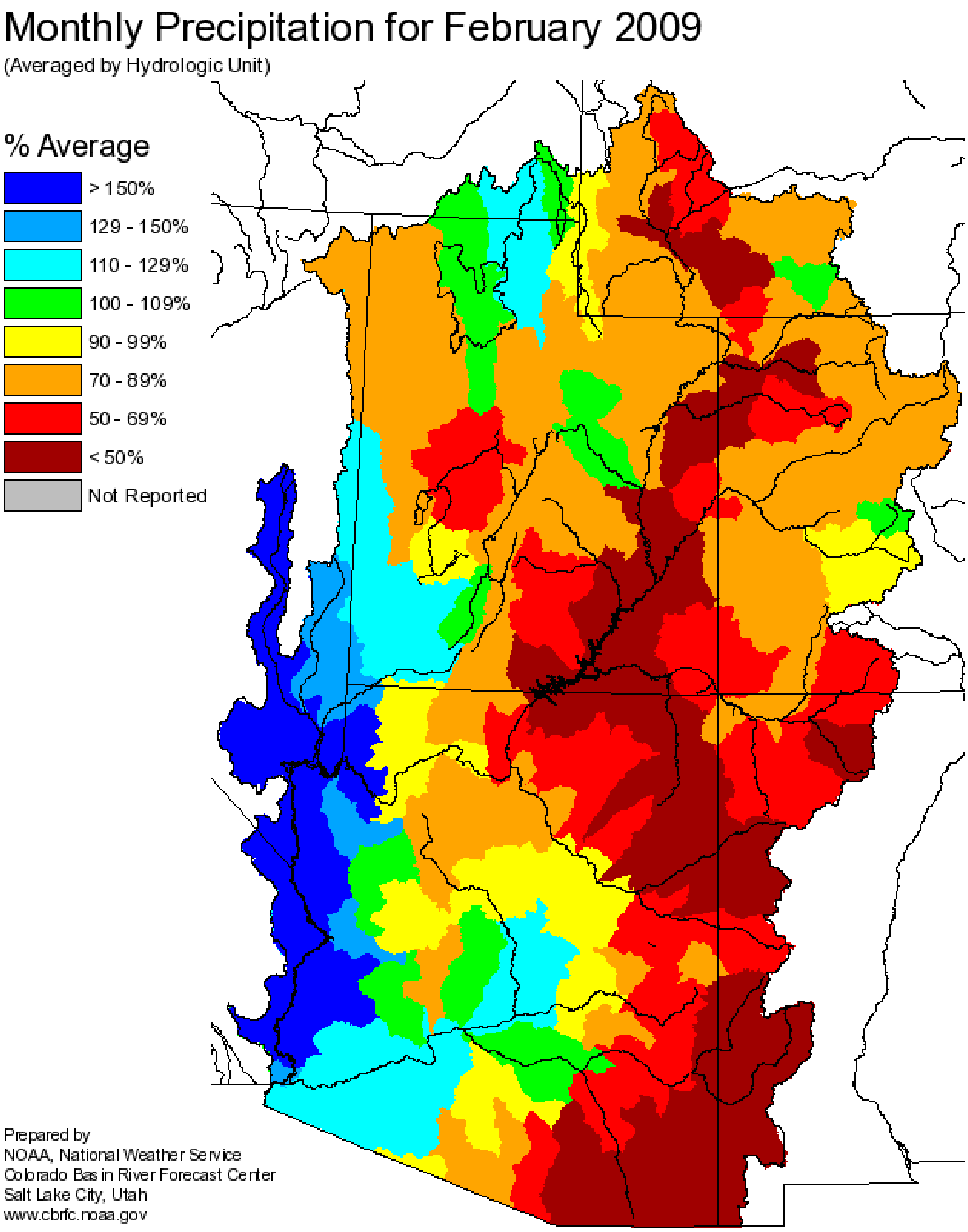

Figure 3.3 February 2009 precipitation

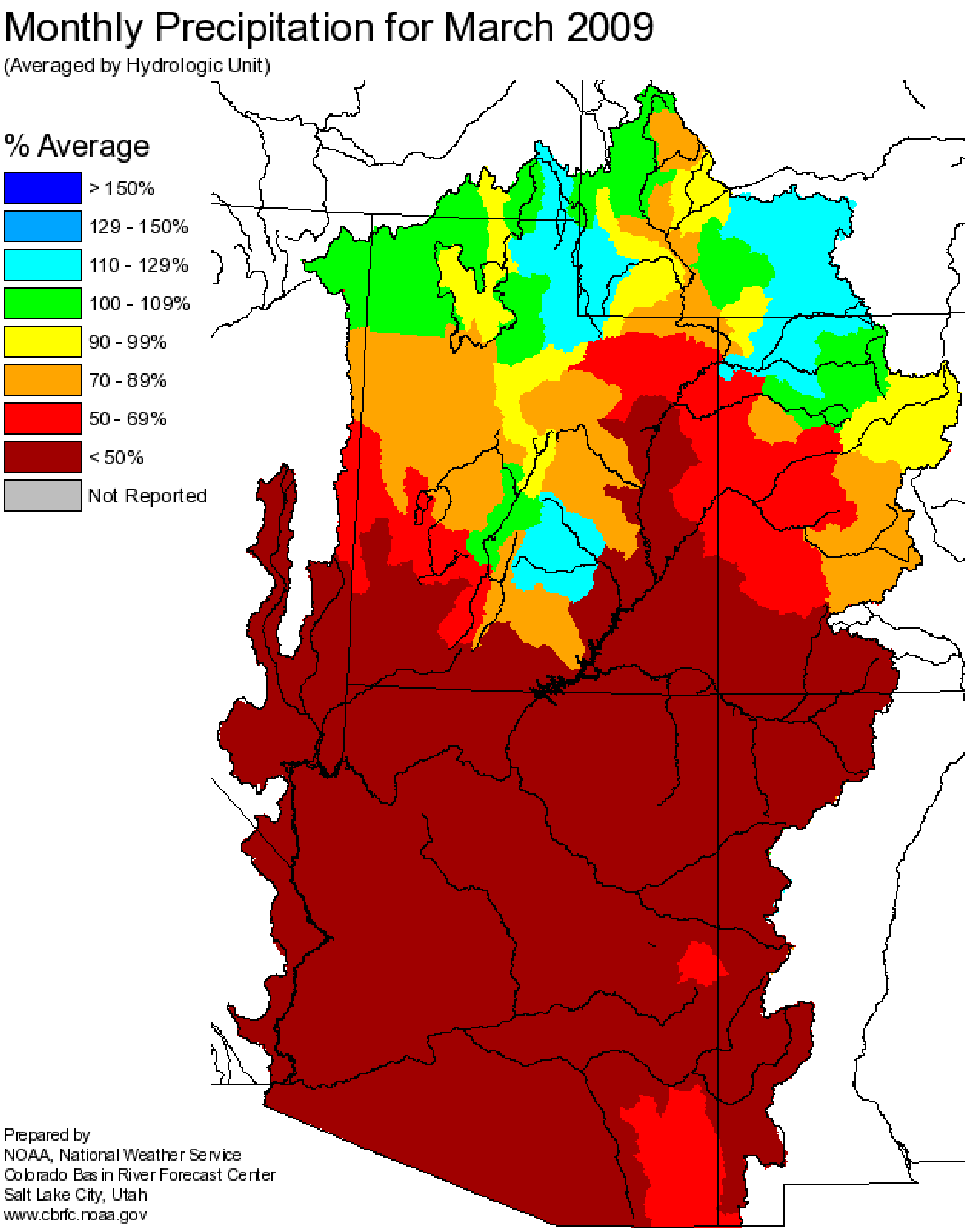

Figure 3.4 March 2009 precipitation

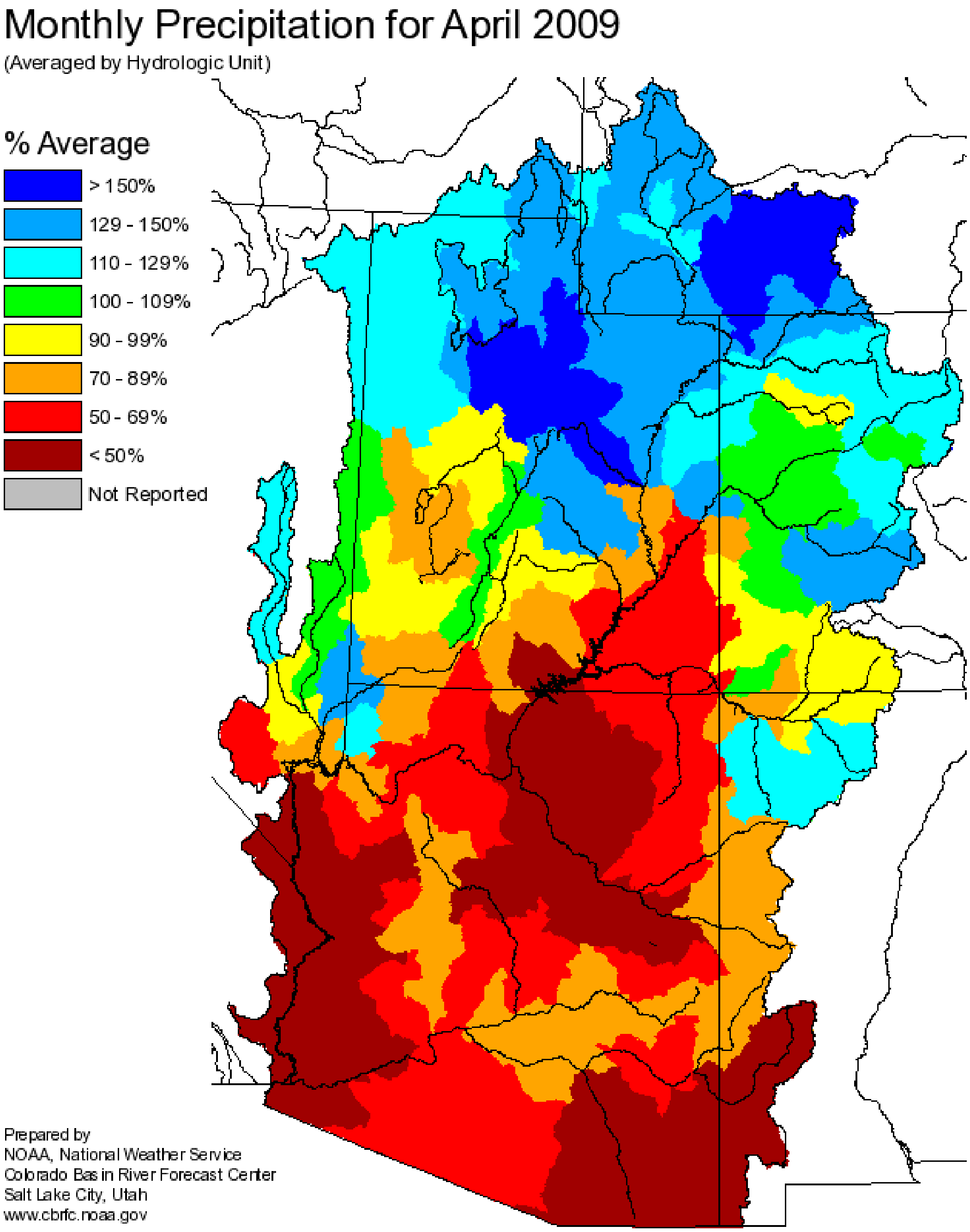

Figure 3.5 April 2009 precipitation

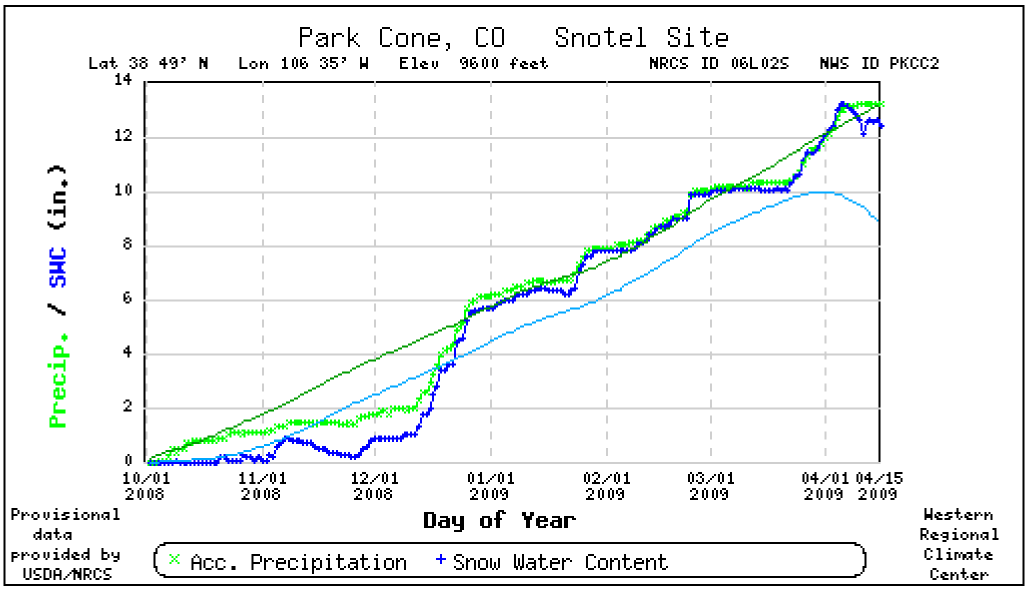

Figure 3.6 NRCS SNOTEL snow and precipitation plot for October 1, 2008 through April 15, 2009 for Park Cone, CO. The smoother, thin lines are the corresponding normals for the period. This site is located in northeastern Gunnison County.

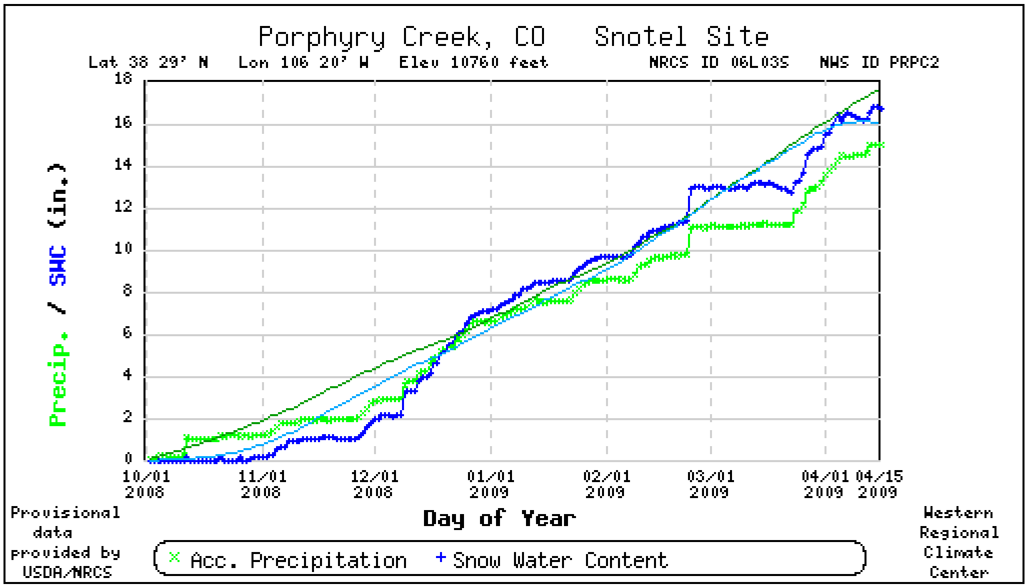

Figure 3.7 NRCS SNOTEL snow and precipitation plot for October 1, 2008 through April 15, 2009 for Porphyry Creek, CO. The smoother, thin lines are the corresponding normals for the period. This site is located in the southeast corner of Gunnison County.

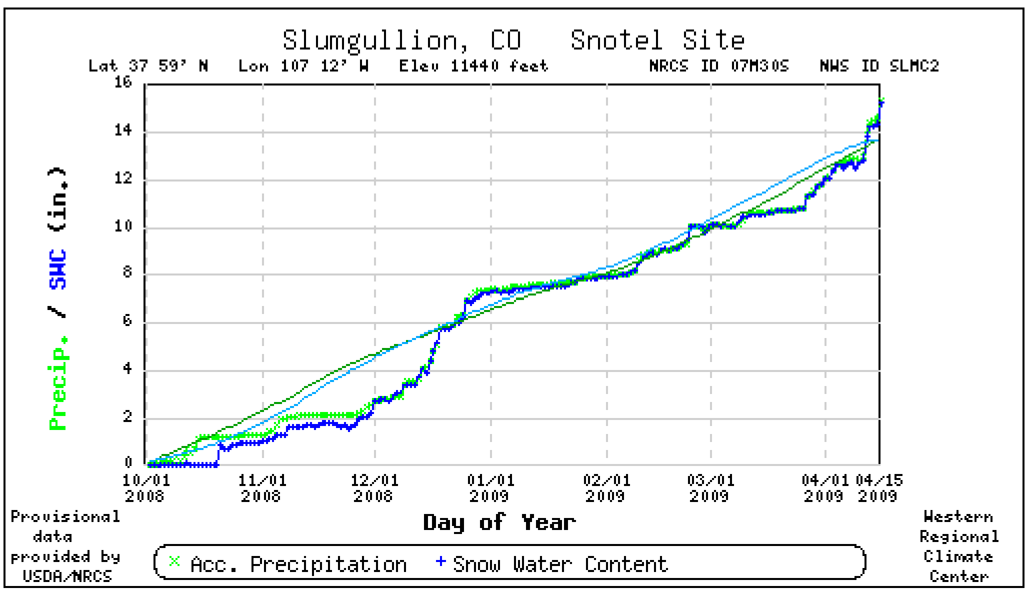

Figure 3.8 NRCS SNOTEL snow and precipitation plot for October 1, 2008 through April 15, 2009 for Slumgullion, CO. The smoother, thin lines are the corresponding normals for the period. This site is located in the southern portion of the target area.

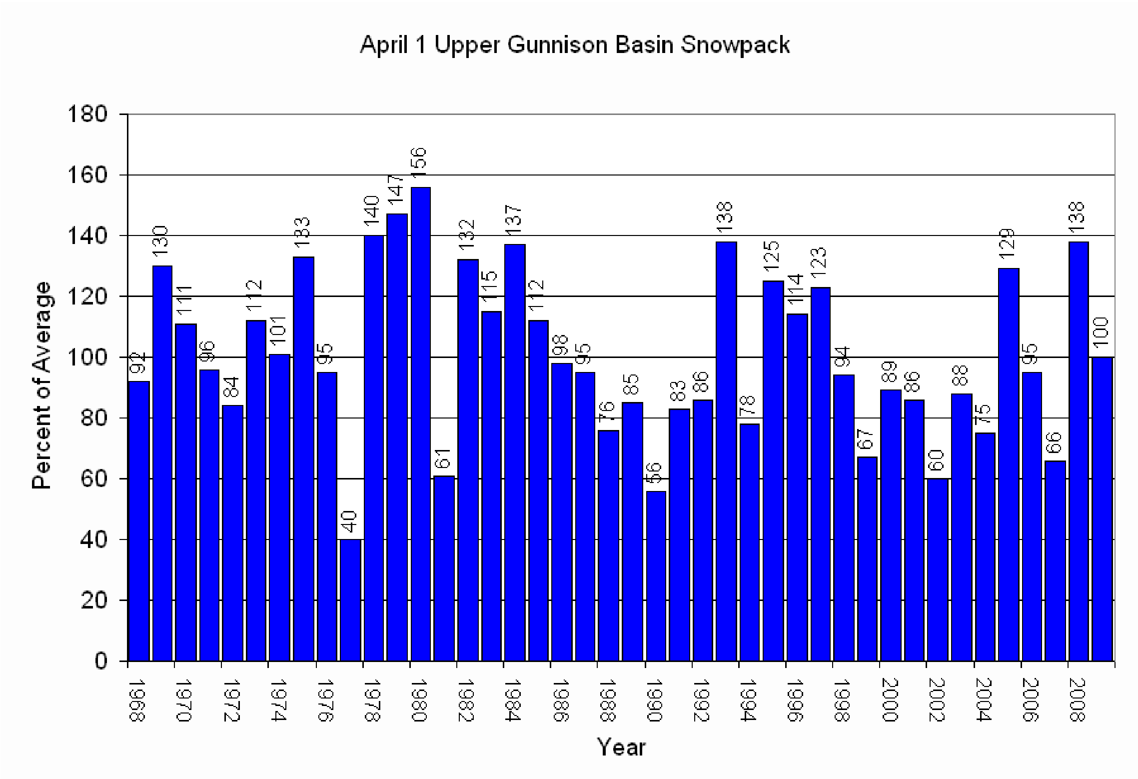

Figure 3.9 Time series of annual April 1st snow water content, 1968-2009

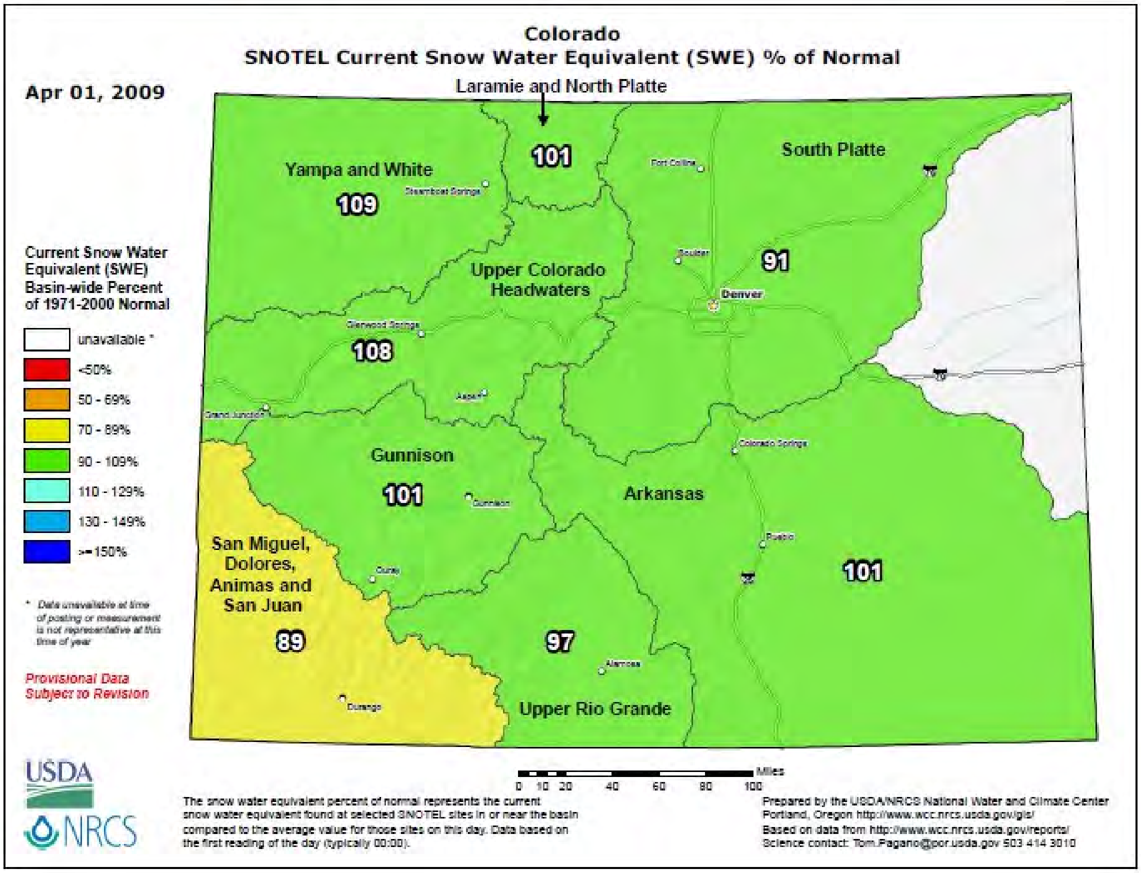

Figure 3.10 Colorado River Basins April 1st snow water content percent of normal

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. Numbers in parentheses correspond to the numbered storm events listed in Table 3-1.

December 2008

Typically the cloud seeding program has begun on November 15th but since the contract was not approved until late November and there were no suitable storms from this date until December 1st, the start date for this winter's program was set as December 1st.

December 2008 was a very active weather month for the upper Gunnison River target area. A large trough developed over the Western U.S. in December, allowing one storm after another to develop and move through the Great Basin and into western Colorado. Conditions were ideal to seed seven storms affecting the target area during the month. After a dry fall, snow water equivalent and water year total precipitation percentages increased to more than 100% of normal at every site in the upper Gunnison River Basin.

A fast moving storm dropped in from the northwest the night of December 2-3 (#1) and 700-mb temperatures dropped to –5C. Seeding was done from sites on the west/northwest side of the target area.

A cold front on the evening of December 8-9 (#2) cooled temperatures at 700-mb to –8 to –10C and seeding was conducted overnight as moderate snow fell through the night. Snowfall of 3-4 inches was common (.30-.40" water content).

A broad trough developed over the Western U.S. during mid-December. A strong pacific cold front the night of December 13-14 (#3) brought a sizable storm to the area. 700-mb temps plunged to –12C and widespread seeding from western and southwestern sites was conducted overnight into mid-morning on the 14th when temperatures fell to –14 to –16C and seeding was stopped due to those cold temperatures, which produce naturally efficient precipitation production. Numerous winter weather warnings were issued for the region and snowfall ranged from 7-12+" in most mountain locations. Schofield Pass received nearly 2" of water from the storm.

Another storm associated with this large western U.S. trough arrived on December 15-16 (#4) as a southwesterly flow pattern set up. The 700-mb temps varied from –10 to –12C but only a few higher elevation CNG sites could be used to seed this storm due to low level stability and calm winds at the surface. A fairly warm closed low off the California coast opened up and moved over the Southwest U.S. on December 18 (#5) and mixed the atmosphere enough to clear the existing temperature inversion. Observed 700-mb temps were –8C, with strong south, southwesterly flow. Many operators reported ground blizzard conditions and several inches of snow fell over the target area.

As the next storm slid into the area from the Northwest, a plume of moisture was pulled up from the southwest and they came together over Colorado for an impressive storm event of December 22-23 (#6). 700-mb temps of –9C and westerly wind provided for favorable conditions for seeding. By midday on the 23rd, Crested Butte reported 18" of new snowfall, and several SNOTEL sites recorded increases of 1-2" of water content. Additionally, around 0900 MST, Colorado Avalanche Information Center (CAIC) reported high avalanche danger around McClure Pass and Grand Mesa, so seeding operations were suspended for the western half of the target area.

Another major low-pressure trough developed off the Northwest coast and brought a Christmas storm to the area on December 25-26 (#7). With cold air and moisture already in place, this warmer air associated with the new storm was lifted over the colder air, creating an overrunning event and heavy snow was observed for several hours. By evening on the 26th, SNOTEL sites had received anywhere from 1.1" to 2.7" of water (1-2 feet of new snow). This storm was seeded from nearly every generator site at some point during the storm.

January 2009

The weather pattern during January was not as active as it was in December, and although high pressure dominated the region, a few storms did affect the area and some seeding opportunities occurred. The high snow pack that was built up in December remained above normal during January, although percentages did drop somewhat.

A quick moving storm arrived from the Northwest on January 3 (#8) accompanied by an impressive cold front. The 700-mb temperatures dropped from –7C to –13C behind the front. Winds at that level were from the west-northwest, and generator sites were activated accordingly. Snowfall accumulation as reported by SNOTEL sites was fairly light (snow water content less than 0.30) due in part to the speed of the storm.

High pressure persisted over the area from January 4-9 causing a strong low-level temperature inversion to form. A fairly weak cold front did move through the area on January 9 (#9) and was seeded from higher elevation site due to the inversion. This inversion was easily detected, as the surface winds were calm in valley locations with a temperature at Gunnison of 19F and 33F at higher elevation sites. Because of this and limited availability from generator operators, seeding was only conducted from one site during this storm. Snowfall for this storm was very light; in the 1-3" range.

High pressure quickly re-developed then held over the region January 10-23; fair weather was the rule. A cold front dropped in from the Northwest on January 26-27 (#10) causing southwesterly flow over the area and cooling 700-mb temps to –12C. The strong winds ahead of the front were enough to clear the temperature inversion that had been in place for the previous two weeks. Seeding was conducted from favorable sites and ran through the night into the morning of the 27th. Snowfall totals reported by generator operators ranged from 2-6” , with 11” of new snow at Crested Butte. SNOTEL sites recorded less than 0.50 new snow water content, equivalent to 5-6” new snowfall. High pressure then returned to the area to conclude January and begin February 2009.

February 2009

The weather pattern during February was fairly dry in the Gunnison Basin, as a high pressure ridge kept the primary storm track to the north of the target area. A persistent low-pressure trough centered off the California coast fueled a brief stormy period during the second week of the month. Most of the monthly precipitation fell during that week, as three storm events passed through Colorado and provided seeding opportunities. The remainder of the month was relatively quiet, however, as storms affected areas mainly north of the target area.

A cut-off low-pressure system off the coast of California opened up into a trough of low pressure and moved into the target area during the evening of February 9-10 (#11) and seeding persisted overnight into midday on the 10th. With 700-mb temps around –9C and northwesterly flow aloft, 2-4”of snow was reported by most generator operators and SNOTEL sites showed 0.2-0.8” of new snow water content. They heaviest snowfall was in the San Juan Mountains just to the south of the target area.

Another low-pressure system associated with the western trough sent another storm center out of southern Utah and into western Colorado on February 12 (#12). West-southwest flow at 700-mb cooled down to –12C by evening and seeding was conducted overnight and ended by morning on the 13th. SNOTEL sites throughout the target area reported 0.3-0.7” of fresh snow water content.

The pacific low that had lingered off the coast and sent two previous storms through the area finally opened up and moved eastward over the area on February 14 (#13). The 700-mb temps were –10 to –12C and prevailing winds were west-southwesterly. Seeding was conducted from sites favorable for that particular wind direction. Most the activity had died down by late evening and seeding was ended the night of the 14th. Snowfall accumulation throughout the area ranged from 4-10" of fresh snow. Southern portions of the target area received heavy snowfall on the 23rd, but 700-mb temps of 0 to +1C were too warm for effective cloud seeding. A low-level temperature inversion was also in place during that event, further inhibiting seeding operations.

March 2009

The weather pattern during March was quite variable. The month began with warm and dry weather, but a strong pacific storm brought gusty winds and some heavy snow to the target area on March 9-10. High-pressure during mid-March kept the area warm and dry, but a stormy pattern returned during the last week of March and an additional three storms were seeded.

A weakening storm approached the area on March 7 (#14) and primarily affected the southern portions of the target area. 700-mb temps of –8C and west-southwest winds allowed for a brief seeding opportunity from southern seeding sites. By evening on the 7th, skies began to clear and seeding was ended. On average, SNOTEL sites recorded less than 0.25" snow water content or less than 3 inches of snow.

A strong cold front accompanied a low-pressure system that moved in from southern Utah the evening of March 9-10 (#15). During the night of the 9th, very strong winds that "shook the barn" were reported by generator operators. 700-mb temps cooled to –8C with the frontal passage and a band of heavy snow also accompanied the cold front. Seeding continued overnight from southern and western sites and by morning on the 10th, 6-12” snowfall totals were common throughout the target area.

A Pacific storm system worked its way into the area late on March 22-23 (#16) disrupting high pressure that had persisted during the previous week. 700-mb temps cooled from +5 to –5C with the frontal passage. West-southwest flow was dominant and the appropriate seeding generators were activated. The National Weather Service issued winter storm warnings for most of Western and Southwestern Colorado. 1.00” of snow water content was recorded at the McClure Pass SNOTEL site, but 0.25-0.50” amounts were more common throughout most of the target area. A few of the seeding sites around Crested Butte ran overnight into the 24th, as snow showers continued over that area. Seeding there was terminated early in the morning.

A storm dropping out of the Pacific Northwest into Utah and Colorado on the evening of March 25-26 (#17) which brought some light snow to the area ahead of the main storm center that would traverse the area later on the 26th. Seeding began using western generator sites during this initial wave in which

700-mb temps were –8C while winds were westerly. By the morning of the 26th, several more generator sites were activated as snow increased in aerial coverage. 700-mb temps dropped to –10C as winds shifted from west-north-westerly to more of a northeasterly direction as the storm center progressed eastward. By evening seeding had ended for the entire area and 4-8” of new snowfall was reported throughout the area.

This active weather pattern continued as another strong cold front moved into Colorado during the evening of March 29-30 (#18). Before frontal passage, 700-mb temps were +4C and were forecast to drop to –12 to –13C by the next morning. A heavy band of snow accompanied the front through the area, along with very gusty winds. Seeding was conducted from western sites. By morning on the 30th, the storm had tracked to the north further than previously forecasted, and the bulk of the action was found north of the target area on the 30th. The area did receive snowfall but it remained on the light side. However, from the three storms during the last week of March, most SNOTEL sites recorded 1.2” to 4” of snow water content. This much needed water compensated for the warm and dry high-pressure periods that had existeed through much of February and March.

April 2009

The first storm of April arrived on the morning of April 1 (#19). The cold front dropped 700-mb temps to –8C, and winds were primarily westerly. Very strong winds were reported at various locations. A band of heavy snow developed over the target area and seeding continued through the day. By evening, the storm center had pushed off to the east and showers decreased. Seeding did not continue overnight. Snowfall accumulation was difficult to measure due to the high winds at the surface, but generally ranged from 2”- 4”.

A well-organized low-pressure system that developed over the Great Basin, continued to deepen and strengthen as it moved into Colorado on the evening of April 3-4 (#20). Cloud seeding began that evening under west-northwesterly flow. While computer forecast models forecast significant precipitation to develop over the target area, by morning on the 4th, the storm had taken a slightly more northern track than forecast. Satellite imagery the morning of the 4th showed the main cloud deck around and north of Interstate 70. Seeding was ended that morning. A couple of inches of snow fell over the northern target area. This storm did deepen and strengthen over the Front Range and turned out to be a major snowstorm for Eastern Colorado.

A low-pressure system tracking across the four-corners region the evening of April 11-12 (#21) caused a northerly flow pattern over the target area and 700-mb temperatures dropped to –5C. A band of snow moved eastward from Delta and Montrose into the target area and was seeded overnight using all sites situated for northerly winds. The San Juan Mountains saw very heavy precipitation from this event. Snowfall across the Gunnison River Basin was mostly light as 1”-3” inches fell across most of the area.

A low over Northwestern Colorado during the evening of April 15 (#22) caused southerly winds to blow over the target area and a fairly impressive band of precipitation formed that moved northward through the area. 700-mb temperatures hovered between –4 to –5C, and several sites that were favorable for operations in southerly flow were activated. Nearly 1.00” of snow water content was recorded at the Slumgullion SNOTEL site, whereas other SNOTEL sites recorded much lighter amounts. The contractual project period ended on April 15, but this storm was seeded from the evening of the 15th into the 16th so as to seed the entire seedable portion of the storm. By 0800 MST on the 16th, all seeding had ended for the season.

4.0 EVALUATIONS OF SEEDING EFFECTIVENESS

The task of determining the effects of cloud seeding has 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 variability 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 feasible only when existing clouds are near to (or already are) producing precipitation, it is not usually obvious if, and how much, the 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 number of seeded events, compared with the natural variability in the precipitation pattern. Larger seeding effects can be detected more easily and with a smaller number of seeded cases than are required to detect smaller increases.

Historically, the 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 the order of a 5-15 percent seasonal increase. In part, this relatively small percentage increase accounts for the significant number of cases 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 is 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 the one utilized by NAWC in this assessment, is the "target" and "control" comparison. This technique is one described by Dr. Arnett Dennis in his 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 snowpack). Records of the variable to be tested are acquired for an historical period of many years duration (20 years or more if possible). 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 snowpack) 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 how effective the seeding was. This past winter season was the sixth seeded season (the first seeded season was only two and one half months long) for this program, so only general indications of the overall success of the seeding can be expected at this point.

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 last few seasons. Earlier 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 there were nine target sites 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 these 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 such sites of questionable value for use as statistical control sites.

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 a reproduction of a map prepared by the Colorado Water Conservation Board that provides the locations of the target areas for all of the cloud seeding projects conducted during the 2008-2009 winter season in Colorado. Similar programs have been conducted during the last few seasons. Data from the Denver Water study, as well as that contained in Fig. 4.1, were used to determine the areas in Colorado that might serve as uncontaminated control areas for the Gunnison seeding program.

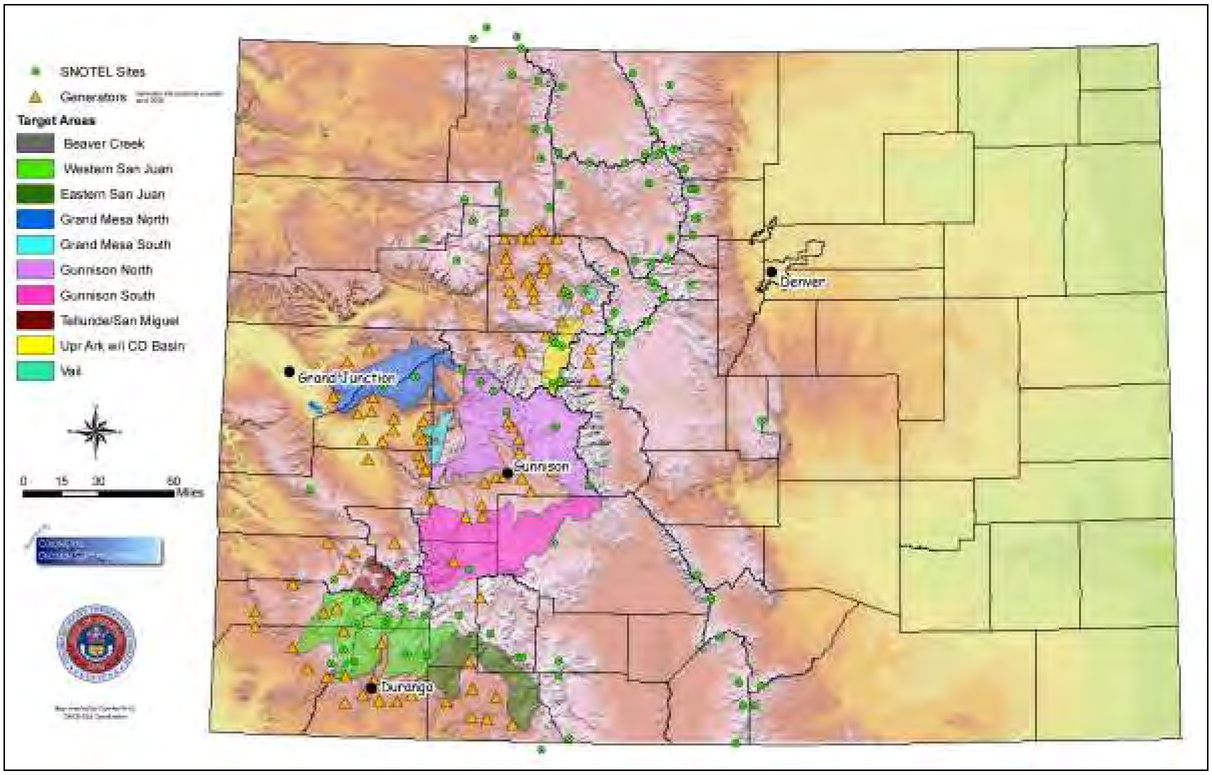

Figure 4.1 Map of 2008-2009 cloud seeding programs in Colorado (CWCB)

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 make 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 <u>near</u> 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 the mixture of manual snowcourse and SNOTEL measurements. We believe that using these NRCS estimates can at least help account for the inherent systematic bias 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 be 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 the 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 possible 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 border, 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, they 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. There is also more general guidance provided by the downwind study, that 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, there is the potential 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.

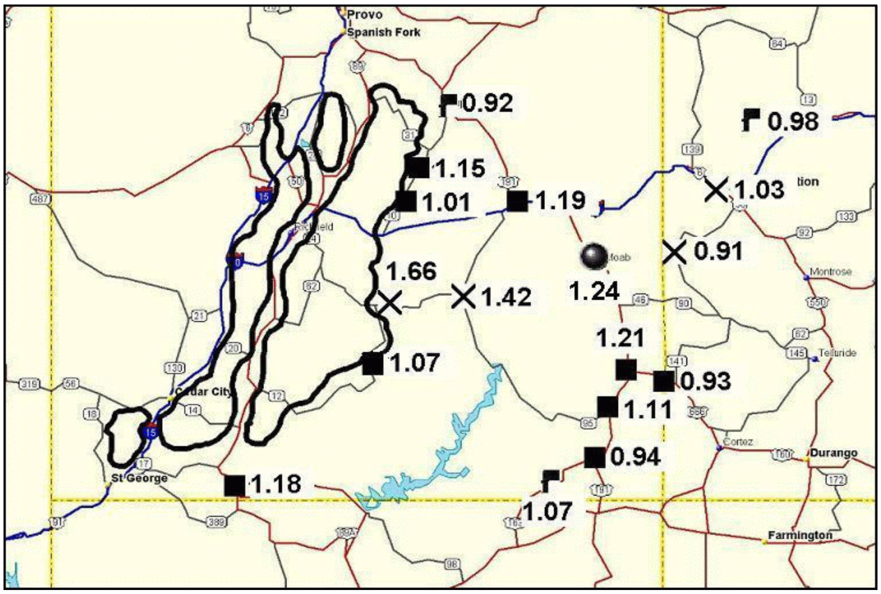

Figure 4.2 Ratios of actual/predicted downwind precipitation from Utah study

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, are 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 dropped 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 of those 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

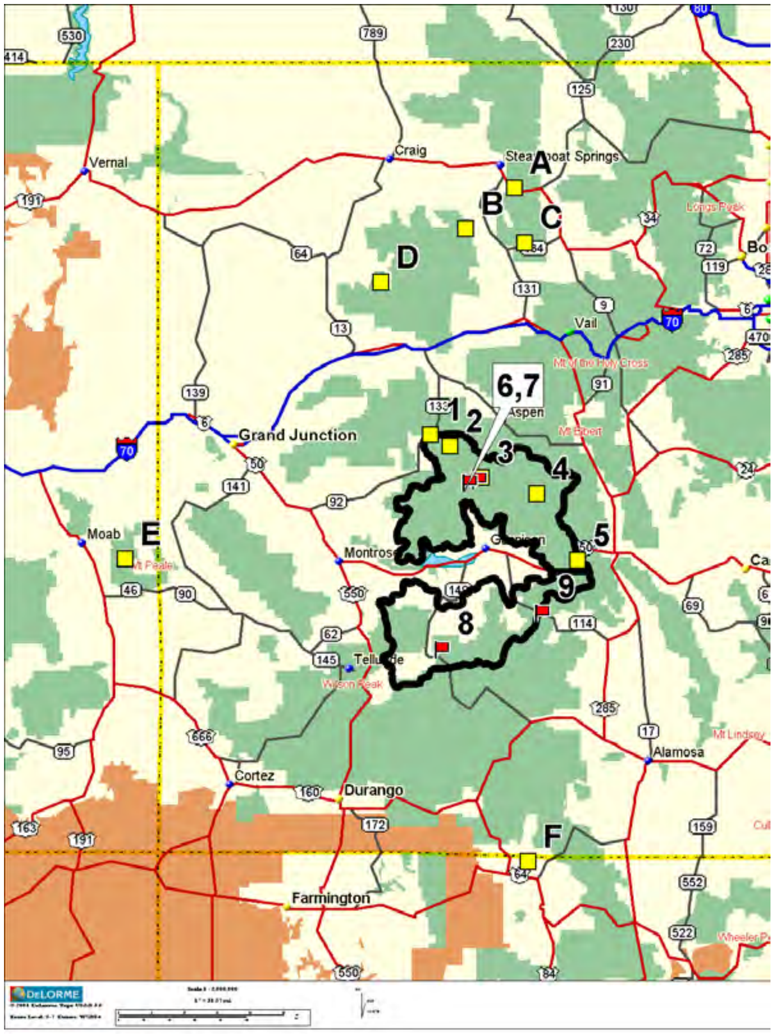

Figure 4.3 Snowpack target sites (1-9) and control sites (A-F)

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	40º22'	106º44'
B	Crosho	07J04	9,100	40º10'	107º03'
C	Lynx Pass	06J06	8,880	40º05'	106º40'
D	Burro Mtn	07K02	9,400	39º53'	107º36'
E	LaSal Mtn, UT	09L03	9,850	38º29'	109º16'
F	Chamita, NM	06N03	8,400	36º57'	106º39'

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	39º08'	107º17'
2	North Lost Trail	07K01	9,200	39º04'	107º09'
3	Butte	06L11	10,160	38º54'	106º57'
4	Park Cone	06L02	9,600	38º49'	106º35'
5	Porphyry Creek	06L03	10,760	38º29'	106º20'
6	Keystone	07L04	9,960	38º52'	107º02'
7	Crested Butte	07L01	8,920	38º53'	107º00'
8	Lake City	07M08	10,160	37º59'	107º15'
9	Cochetopa Pass	06L06	10,000	38º10'	106º36'

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:

$$Yc = 0.75 * Xo + 1.67 \tag{1}$$

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 regression, the data from each control site is related independently with 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 Rabbit 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 Mexico), and Yc is the 9-station target area average. The r-value for equation (2) is 0.89, suggesting that 79% of the target/control variation is explained by the equation.

4.1.2 Evaluation Results

The April 1, 2009 average snow water content for the control group was 15.2 inches. 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 13.09 inches. The actual observed April 1st average water content in the target was 13.11 inches. This yielded a ratio of 1.00, which is essentially the same as that predicted by the control stations using equation (1) (the simple linear regression technique).

When the observed individual control area site snow water content amounts for April 1, 2009 were entered into equation (2) (the multiple linear regression technique), the predicted average April 1st snow water content in the target area was 12.6 inches. The actual observed April 1st average water content for this target group was 13.1 inches. This yields an observed/predicted ratio of 1.04, which is 4 % more than the value predicted by the control stations and equation (2). The estimated seasonal seeding effect (in percentage) is obtained using equation (3):

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

4.2 Summary and Discussion of Seeding Evaluations

Tables 4-3 and 4-4 provide the historical regression period and seeded period data. The April 1st snowpack evaluations of the 2008-2009 winter season suggest increases of 0% (simple regression) and 4% (multiple regression), based on ratios of 1.00 and 1.04 for snowpack (for the single and multiple regression evaluations, respectively). 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. Table 4-5 documents the variability of the April 1st snow water content amounts for the control and target sites for this past season.

Table 4-3
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	14.00	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

Water Year	Control Average	Target Average	Predicted Target Snow Water Content	Observed/ Predicted Ratio	Observed Minus Predicted Precip.
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**
2008	**17.1**	**20.8**	**14.6**	**1.43**	**6.2**
2009	**15.2**	**13.11**	**13.09**	**1.00**	**0.02**
Mean	**13.6**	**13.7**	**11.9**	**1.15**	**1.8**

* 2003 snowpack analysis not used since seeding was only conducted during February and March

Table 4-4
Summary of historical regression period and seeded period evaluations using April 1 snowpack data and a multiple linear regression 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

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.
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**
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**
Mean	**27.0**	**11.6**	**14.5**	**11.8**	**10.1**	**6.7**	**13.7**	**11.3**	**1.21**	**2.4**

* 2003 snowpack analysis not included since seeding was only conducted during February and March

Table 4-5

Actual, Average and Percent of Normal Snow Water Content on April 1, 2009

Site	Actual Apr. 1st Snow Water Content	Average Apr. 1st Snow Water Content	% of Average for the 2008-2009 season
Control Sites			
Rabbit Ears Pass	30.4	27.1	112%
Crosho	14.5	12.1	120%
Lynx Pass	13.6	12.7	107%
Burro Mt.	15.9	19.2	83%
La Sal Mt., UT	9.9	13.5	73%
Chamita, NM	6.6	9.3	71%
Summation	**90.9**	**93.9**	**97%**

Target Sites			
McClure Pass	21.2	18.3	116%
North Lost Trail	21.7	18.2	119%
Butte	16.8	15.6	108%
Park Cone	12.0	10.4	115%
Porphyry Cr.	15.4	15.8	97%
Keystone	20.0	20.4	98%
Crested Butte	14.3	14.4	99%
Lake City	4.8	7.4	65%
Cochetopa Pass	3.8	6.0	63%
Summation	**130.0**	**126.5**	**103%**

4.3 Best Estimate of Seeding Effects

When the evaluation results of the past six full seeded seasons are combined, the average indicated increases are 15% and 21% (for single and multiple regressions, respectively) for April 1 snowpack (Tables 4-3 and 4-4). Even these six-season combined results may be skewed by natural variability in snowpack accumulation, and thus these numbers may be imprecise. However, it is estimated from these evaluations as well as those of similar programs in the mountainous west that a real seeding increase in the often stated range of 5-15%, and possibly higher, has resulted from this seeding program.

As discussed previously, in the evaluation of only a few winter seasons of seeding, it is difficult to attach much significance to the results unless the correlation coefficient between target and control areas is extremely high (e.g., > 0.95) and the indicated effects of seeding are quite large (perhaps > 20%). Normally, at least several seasons of seeding are necessary to obtain a reasonable estimate of seeding effects. Also, the potential impacts on the Upper Gunnison River target area evaluation from seeding programs (both current and historical) over the Grand Mesa and West Elk Mountains are unknown.

5.0 SUMMARY AND RECOMMENDATIONS

A new 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, which was valid for a five-year period, was obtained from the Colorado Water Conservation Board to add the expanded area. Several local sponsors joined together to obtain the funds required to organize and conduct this project. Sponsors include: 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 was continued, to impact the two permitted target areas during the 2004-2005 through the 2008-2009 winter seasons. 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. The 2008-2009 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 conducted for the past five winter seasons. Grants were authorized by the CWCB for last winter. 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.

Twenty-five ground-based, manually operated silver iodide generators were installed for the project this season. Twenty-two storm periods were seeded during the operational period of December 1, 2008 through April 15, 2009. The first seeding opportunity began late on December 2nd, with the final seeded event beginning on April

15th. A total of 2867.75 generator hours were utilized resulting in the release of 34,413 grams of silver iodide.

Precipitation and snowpack were near normal in most of the basin this season. As of April 1, 2009, SNOTEL sites in the Gunnison Basin had snow water equivalent (SWE) values averaging 101% of normal (average).

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. 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 area. Linear regression equations were developed, relating target area to control area April 1st snowpack during the historical not seeded periods. Individual site historical April 1st data were used in the development of the multiple linear regression equation. Reasonably good correlations were established between control and target areas, r values of 0.86 and 0.89 for the simple and multiple regression techniques, respectively. The regression equations were then used to estimate the amount of snow water content that would be expected for the 2008-2009 winter season and past seeded seasons, based upon the observations at the control sites. These estimates were then compared to the observed average snow water content at the target sites.

The indications produced by snowpack evaluation methods discussed in section 4.0 suggest increases of 0% and 4% for the simple and multiple linear regression, respectively for the 2008-2009 winter season. The six-season averages for these evaluations (2002-2003 was not included due to a short seeding period) suggest increases of 15% (simple) and 21% (multiple) linear regression techniques. We suspect that the very high numbers from the 2007-2008 season are inflating these six-year averages. The actual effects of the cloud seeding program are more likely in the 5 – 15 % range.

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

We performed a snowpack/streamflow analysis 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, NAWC obtained the monthly mean streamflow data (in cubic feet per second) and converted these data 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" year 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 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 streamflow increases of approximately 11.6% – 13.2% **for a 10% snow water increase in an average year**. Streamflow increases of about 17.3% – 19.8% are indicated **for a 15% increase in snow water content in an average 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 previous 6 seeded full winter seasons suggest an average increase in April 1st snow water contents of 15% which may be on the high side due to the abnormal 2007-2008 winter. The 10 – 15% estimates used in the above are probably in the proper range of effects.

The above increases in streamflow are of interest, but no doubt underestimate the total amount of additional streamflow into Blue Mesa that may be attributed 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 basis. 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 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. We have found this to be a rather common 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 there can be any runoff. 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, then this increase is almost entirely converted into increases in streamflow.

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 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 5- 1 and 5-2 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 5-1 Estimated Increases of 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 5-2 Estimated Increases of 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 year 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 2008 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 B contains the regression equation information.

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. Consequently, we typically recommend that 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 30 of the past 31 winter seasons, as well as in other areas of the western U.S. Contractual provisions can be 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 below 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, valuable 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 basis 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 the 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 reasonably 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 be 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

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	12.60	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	16.17	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	12.62	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	16.62	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**
Mean	13.60	13.72	11.92	**1.15**	**1.80**

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

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**
Mean	27.0	11.6	14.5	11.8	10.1	6.7	13.7	11.3	**1.21**	**2.4**

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		

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	
1976	13.53	234456	336622	0.70	-102166	
1977	5.58	77042	106404	0.72	-29361	
1978	17.77	384267	459126	0.84	-74858	
1979	20.34	485474	533722	0.91	-48248	
1980	21.49	471530	566839	0.83	-95310	
1981	7.44	127640	160421	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	410896	1.24	97674	
1986	15.09	524606	381636	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	437262	1.28	123607	
1998	12.57	275883	308648	0.89	-32765	
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:	16.27		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	520153.46	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	886876.17	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	20.36	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	133523.65	
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	1.1692062	**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

North American
Weather Consultants, Inc.

8180 S. Highland Dr., Suite B-2
Sandy, Utah 84093

801-942-9005