

A WINTER OPERATIONAL CLOUD SEEDING PROGRAM: UPPER GUNNISON RIVER BASIN, COLORADO

WMA ANNUAL MEETING, PARK CITY , UTAH 2011



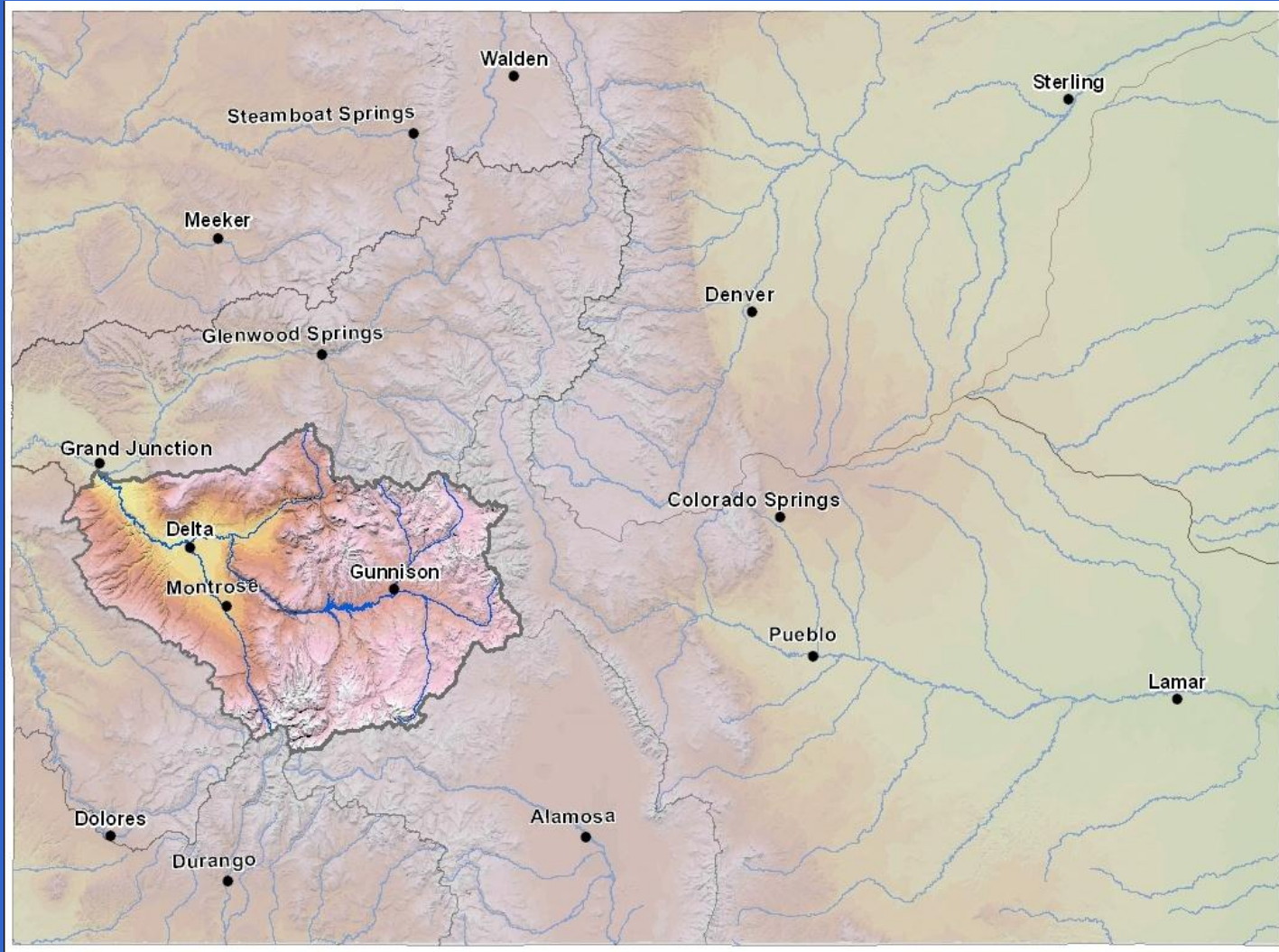
OUTLINE OF TALK

1. PROGRAM BACKGROUND
2. PROGRAM OPERATIONS
3. APRIL 1ST SNOW WATER CONTENT EVALUATIONS
4. ESTIMATED INCREASES IN STREAMFLOW
5. SUMMARY

PROGRAM BACKGROUND

- HISTORY
- PROGRAM SPONSORS
- FEASIBILITY STUDY

GUNNISON RIVER BASIN, COLORADO



HISTORY OF UPPER GUNNISON RIVER WINTER CLOUD SEEDING PROGRAM

- **Feasibility Study Completed December 2002**
- **Permit Process through the Colorado Water Conservation Board completed in early February, 2003. Target Area: Elevations >9000' within Gunnison County**
- **Permit Process Fall of 2003 to Add Upper Gunnison River Tributaries Lying Outside Gunnison County >9000'.**
- **New 5 Year Permit Granted in November 2007 Combining the Two Target Areas.**
- **Seeding February 3, 2003 through April 15, 2003.**
- **Seeding from November 15 – April 15 in each of the following Water Years to the Present.**

PROGRAM SPONSORS

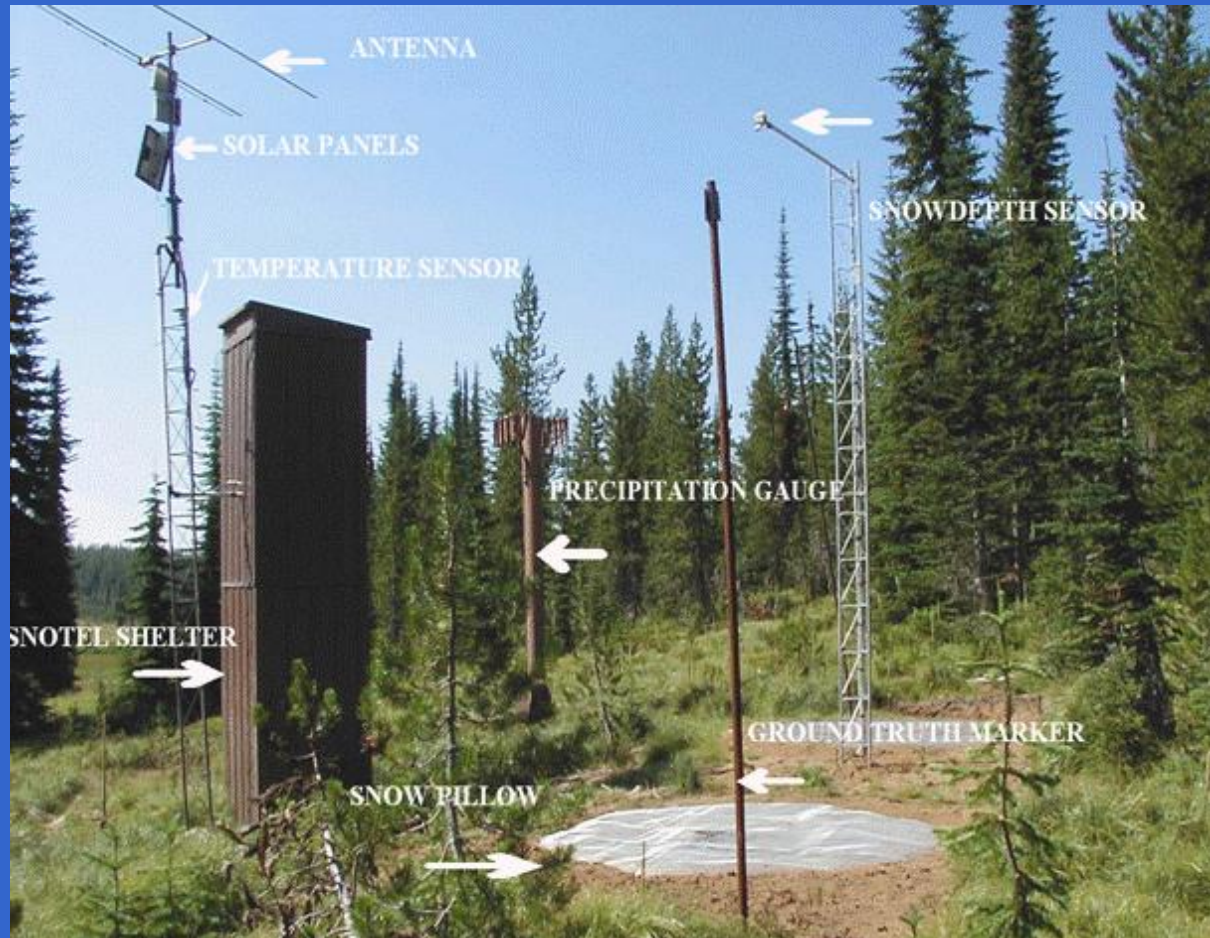
- **City of Gunnison**
- **Dos Rios Water System**
- **East River Regional Sanitation District**
- **Gunnison County**
- **Gunnison County Stock Growers Association**
- **Mt. Crested Butte Water and Sanitation District**
- **Town of Crested Butte**
- **Upper Gunnison River Water Conservation District**

Note: Cost Sharing since 2005-2006 also Provided by the Colorado Water Conservation Board and the Lower Colorado River Basin States.

FEASIBILITY STUDY (Completed in 2002 Prior to the Start of the Program)

- Based Upon 141 Winter Storm Days (>0.4” observed at least at one of four Target SNOTEL Sites). Identified from the Eleven Year Period of 1990-2001.**
- These storm Days were used to Generate Information on Precipitation, Storm Types, 700 mb Winds and Temperatures, and Atmospheric Stability.**

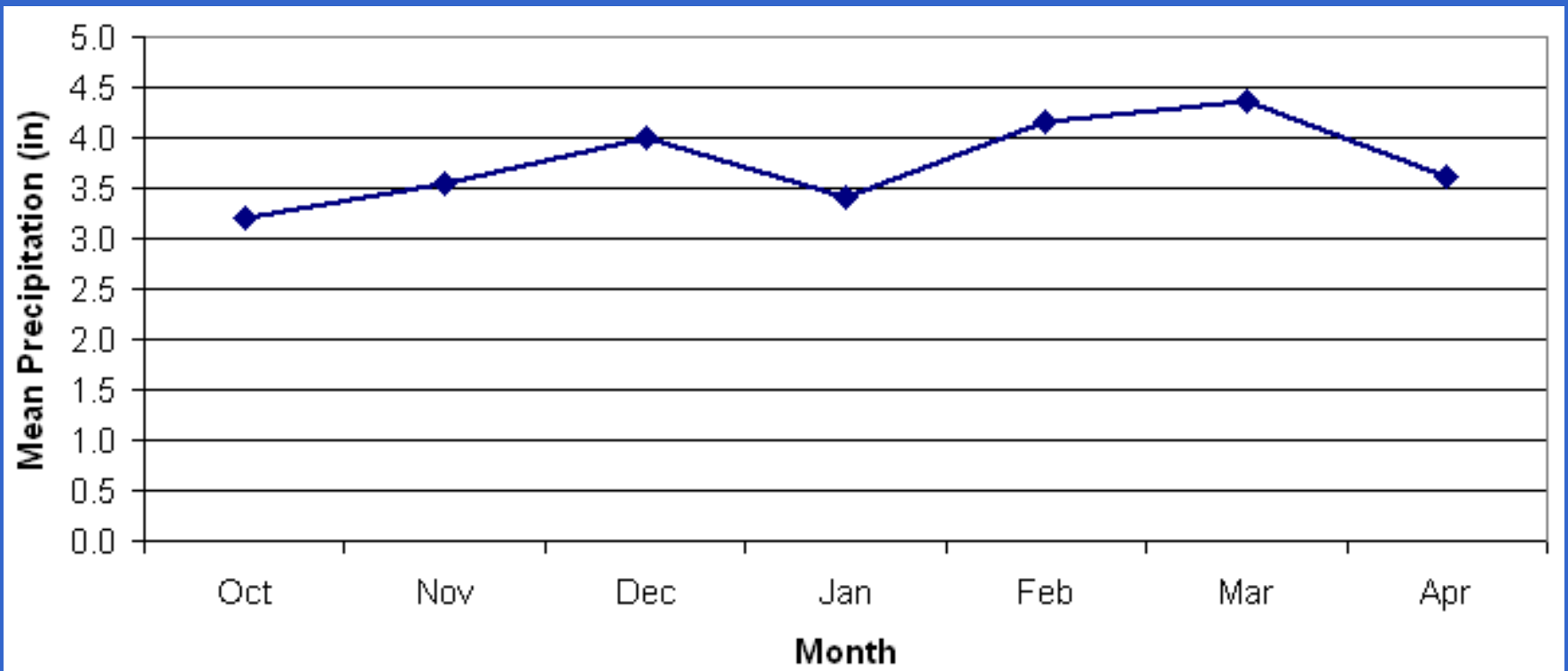
EXAMPLE OF AN NRCS SNOTEL SITE



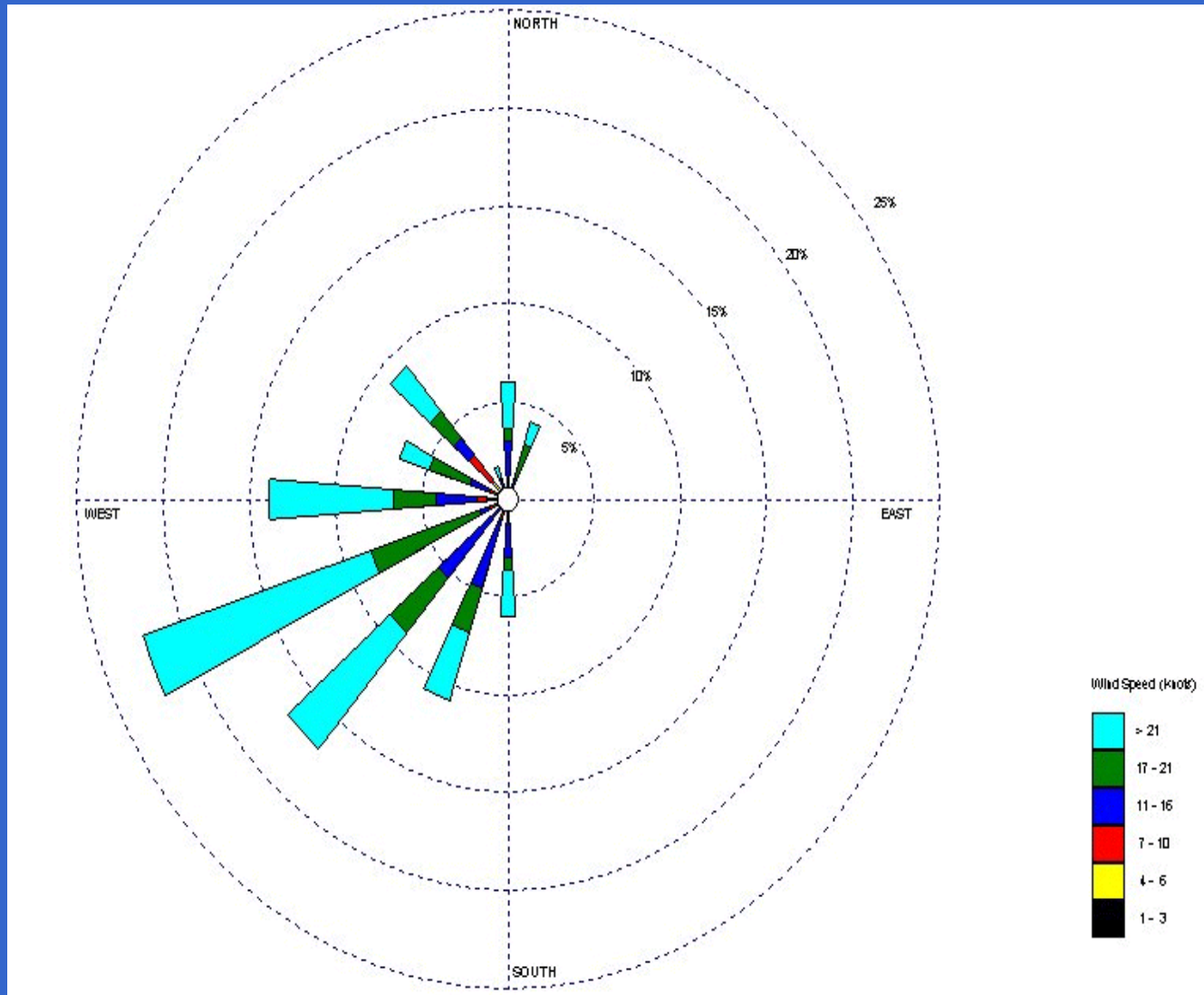
FOUR TARGET AREA SNOTEL SITES AVERAGE MONTHLY PRECIPITATION (inches)

SITE	OCT	NOV	DEC	JAN	FEB	MAR	APR
BUTTE (10160')	1.8	2.7	4.1	2.9	2.7	3.4	2.6
MC CLURE PASS (9500')	3.4	2.7	3.3	3.0	2.8	3.9	2.9
NORTH LOST TRAIL (9200')	3.4	3.2	4.2	3.2	3.4	4.2	4.3
SCHOFIELD PASS (10,700')	4.2	5.6	4.4	4.5	7.7	6.0	4.7

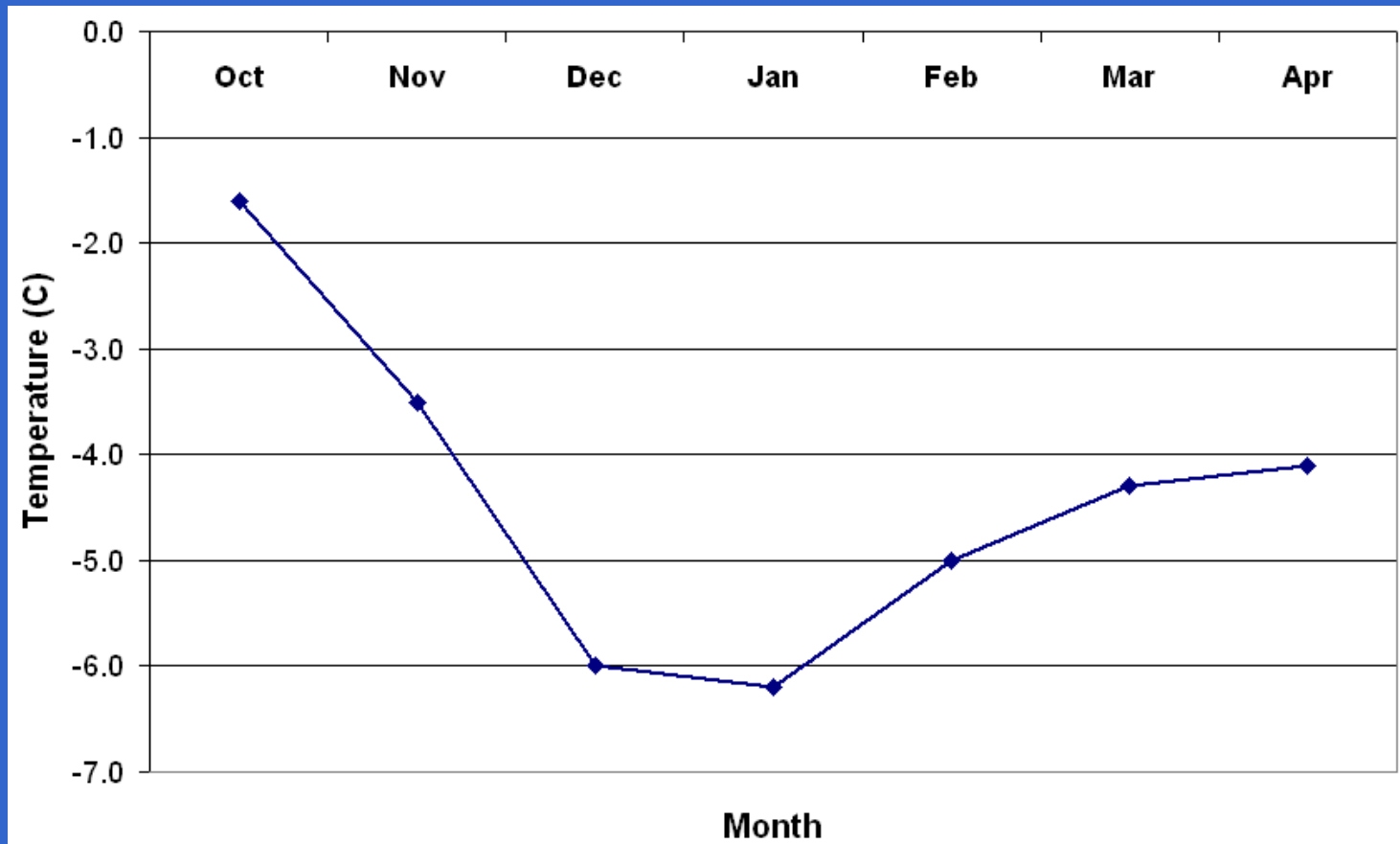
MEAN MONTHLY PRECIPITATION FOR FOUR GUNNISON RIVER BASIN HIGH ELEVATION NRCS SNOTEL SITES



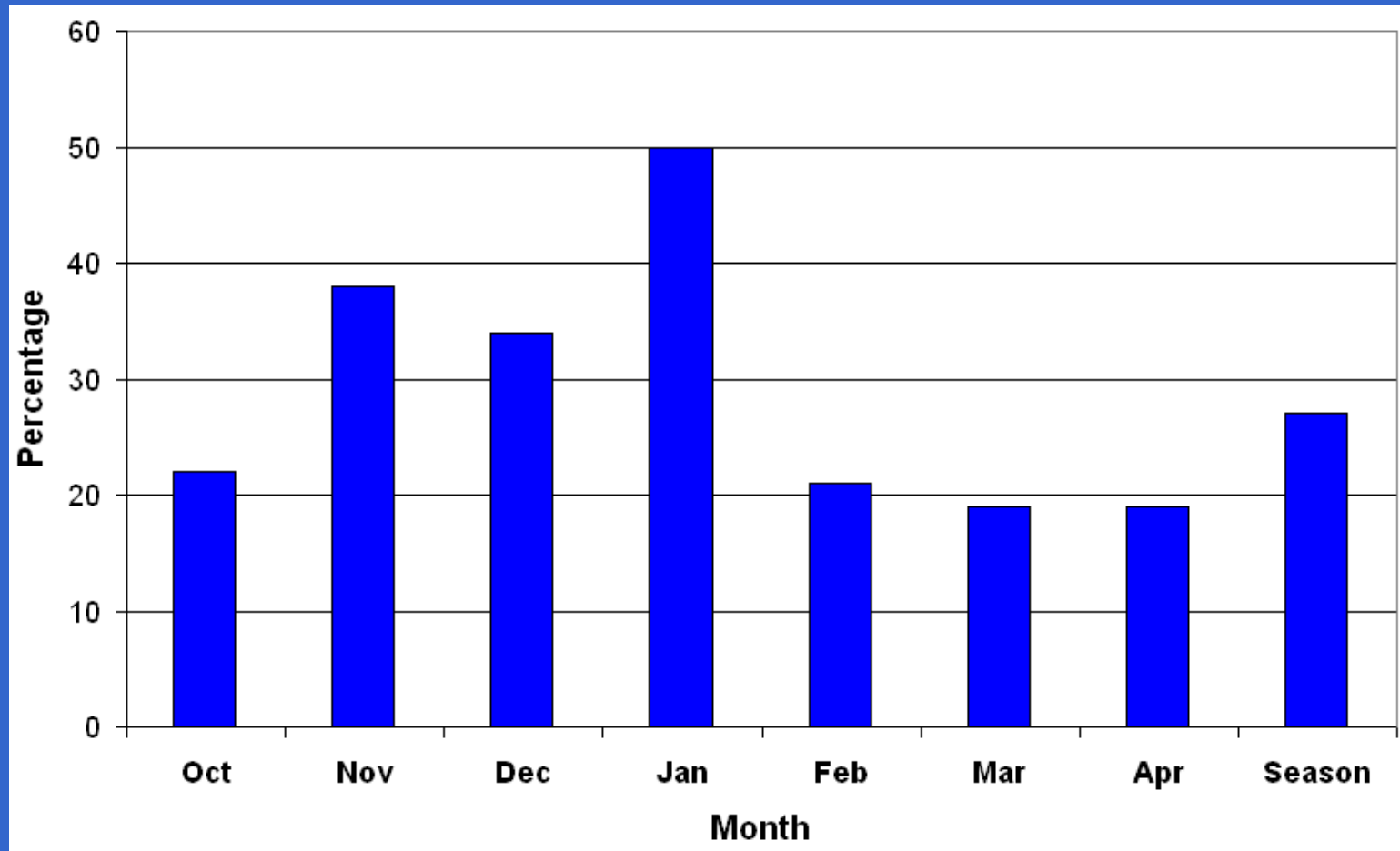
700 mb Wind Rose for October- April (166 Grand Junction soundings)



Mean Storm-Period 700 mb Temperature by Month



Percentage of Storm Events with Low-Level Inversions



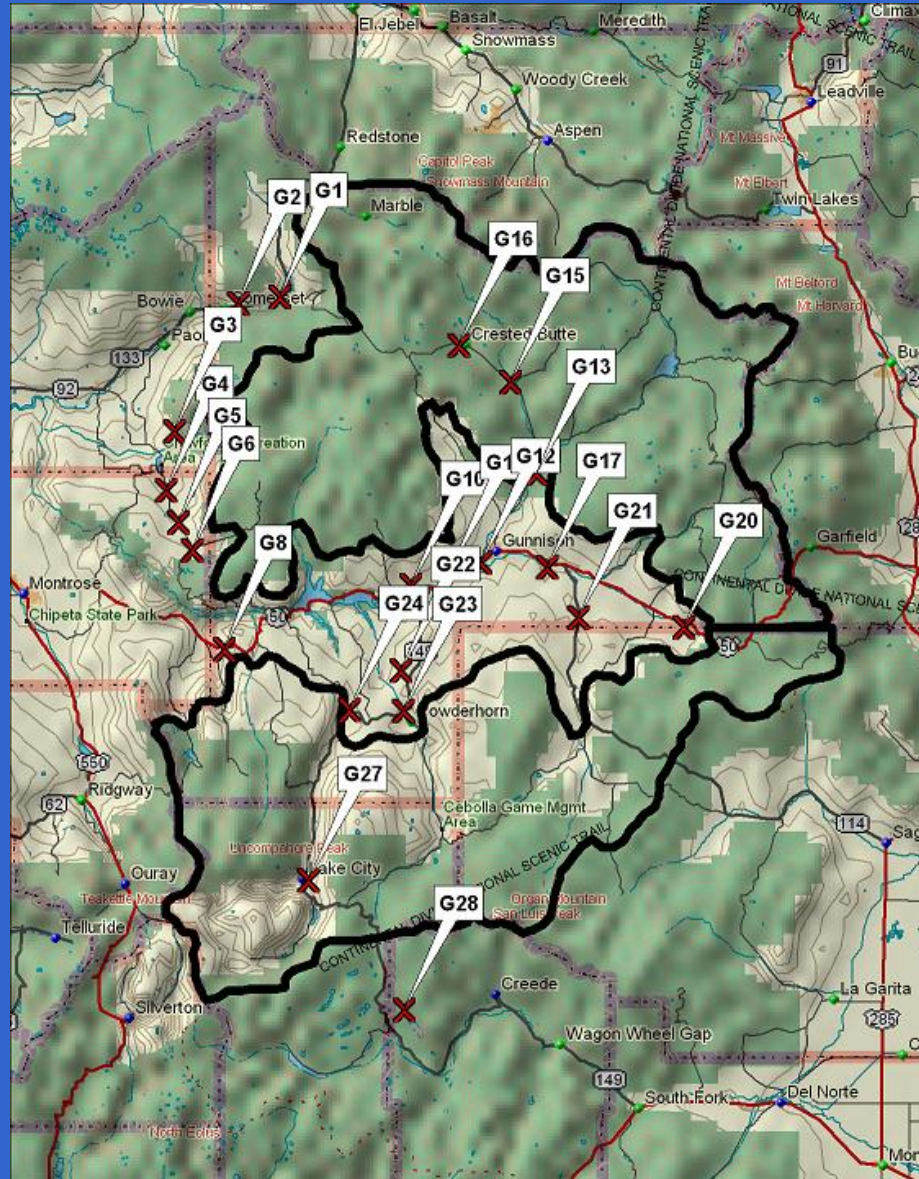
PROGRAM OPERATIONS

- **Operational Period: November 15-April 15th**
- **Ground Based, Manually Operated Silver Iodide Generators**
- **Standardized Seeding Criteria**
- **Seeding Decisions made Based on Weather Information Available on the Internet**
- **Adherence to Suspension Criteria**

MANUALLY OPERATED, GROUND BASED SILVER IODIDE GENERATOR



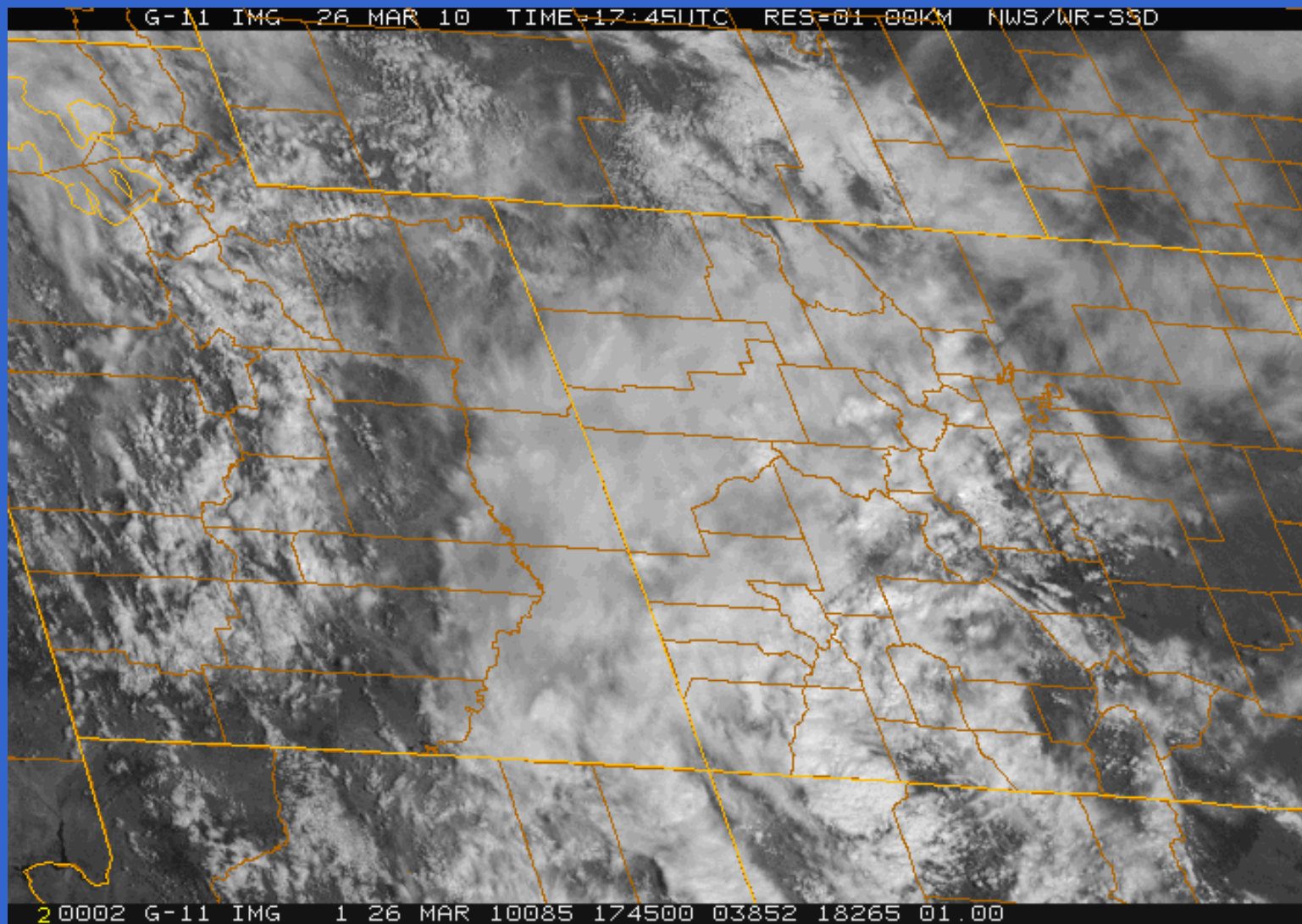
UPPER GUNNISON RIVER BASIN TARGET AREA AND GROUND GENERATOR LOCATIONS



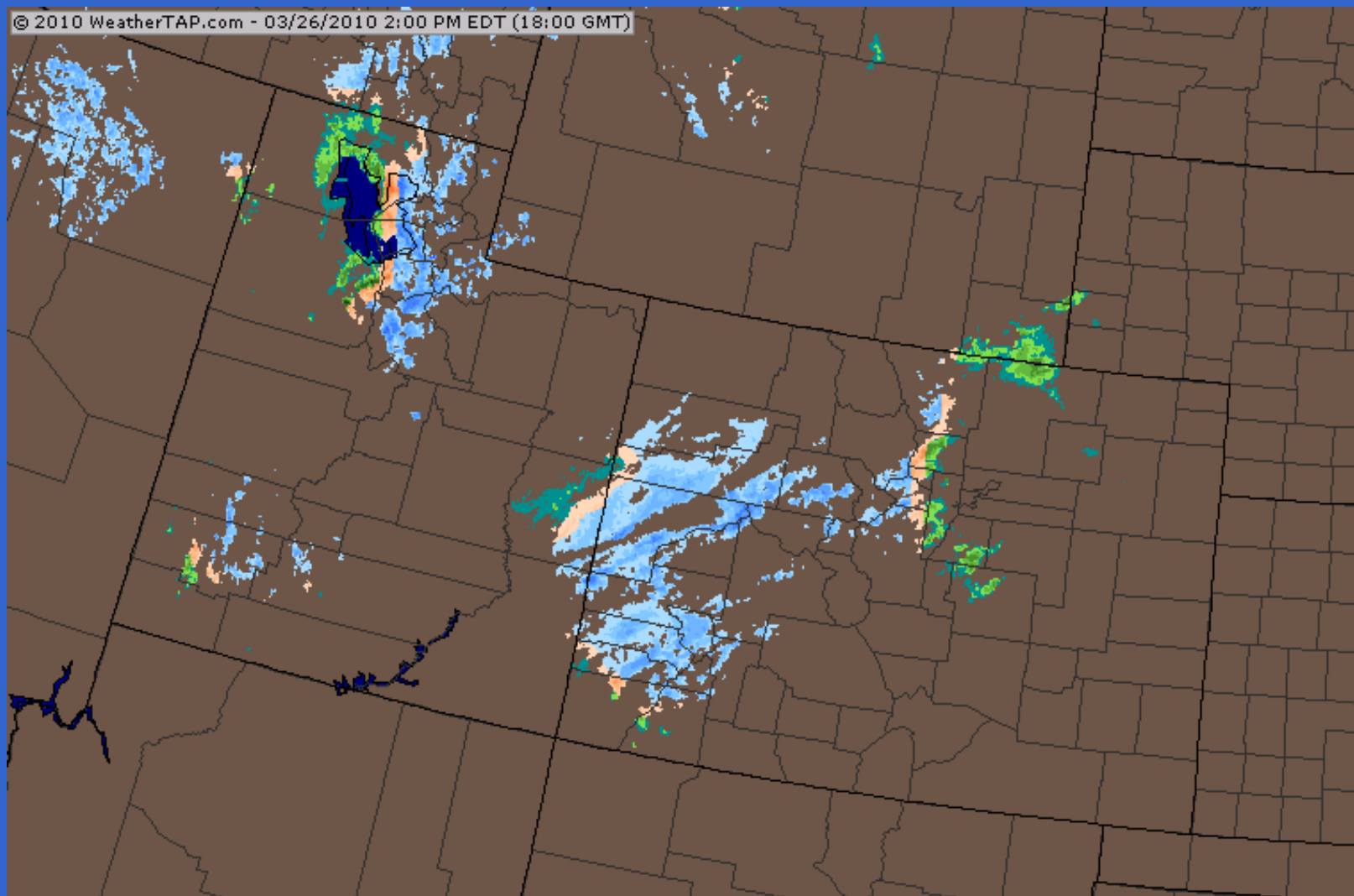
NAWC WINTER OROGRAPHIC GENERALIZED CLOUD SEEDING CRITERIA

- 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).

Satellite Image of Eastern Utah and Western Colorado at 1145 MDT on March 26, 2010

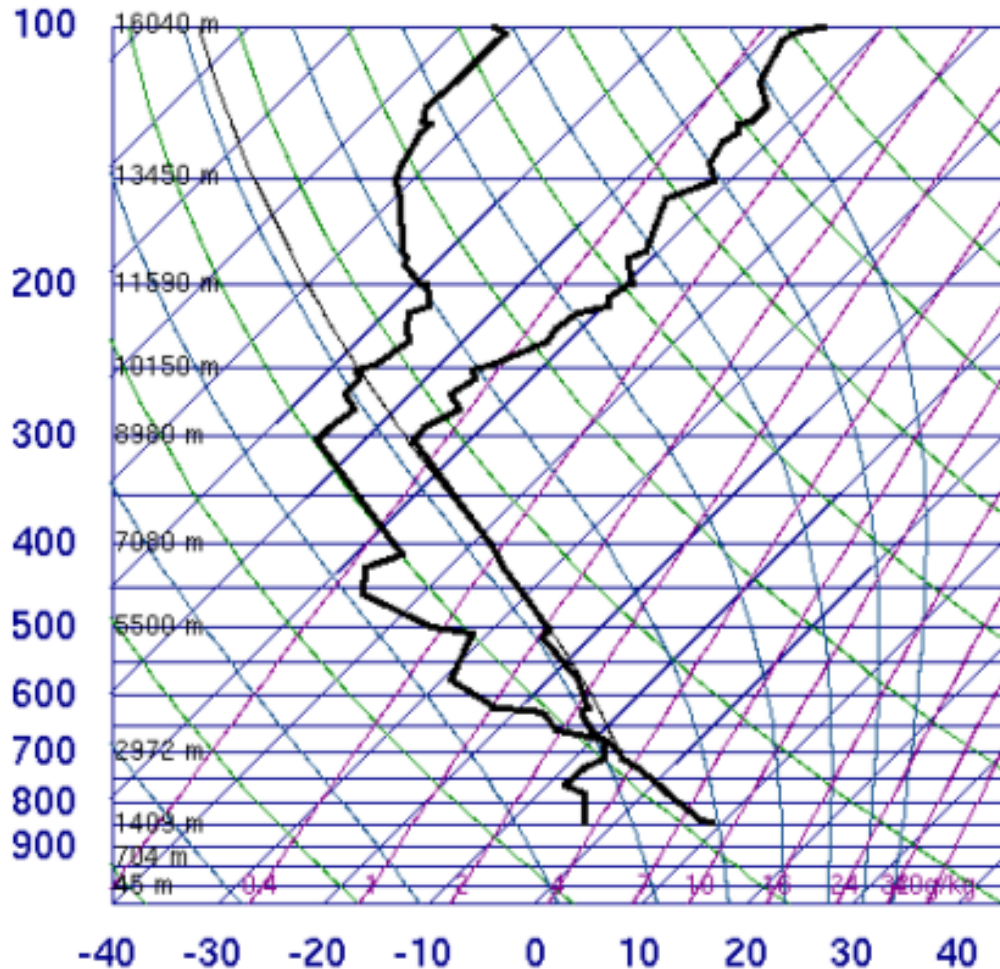


Regional Radar Image at 1200 MDT on March 26, 2010, Near the Time of the Satellite Image



Upper-air Sounding Taken at Grand Junction on the Afternoon of March 26, 2010

72476 GJT Grand Junction



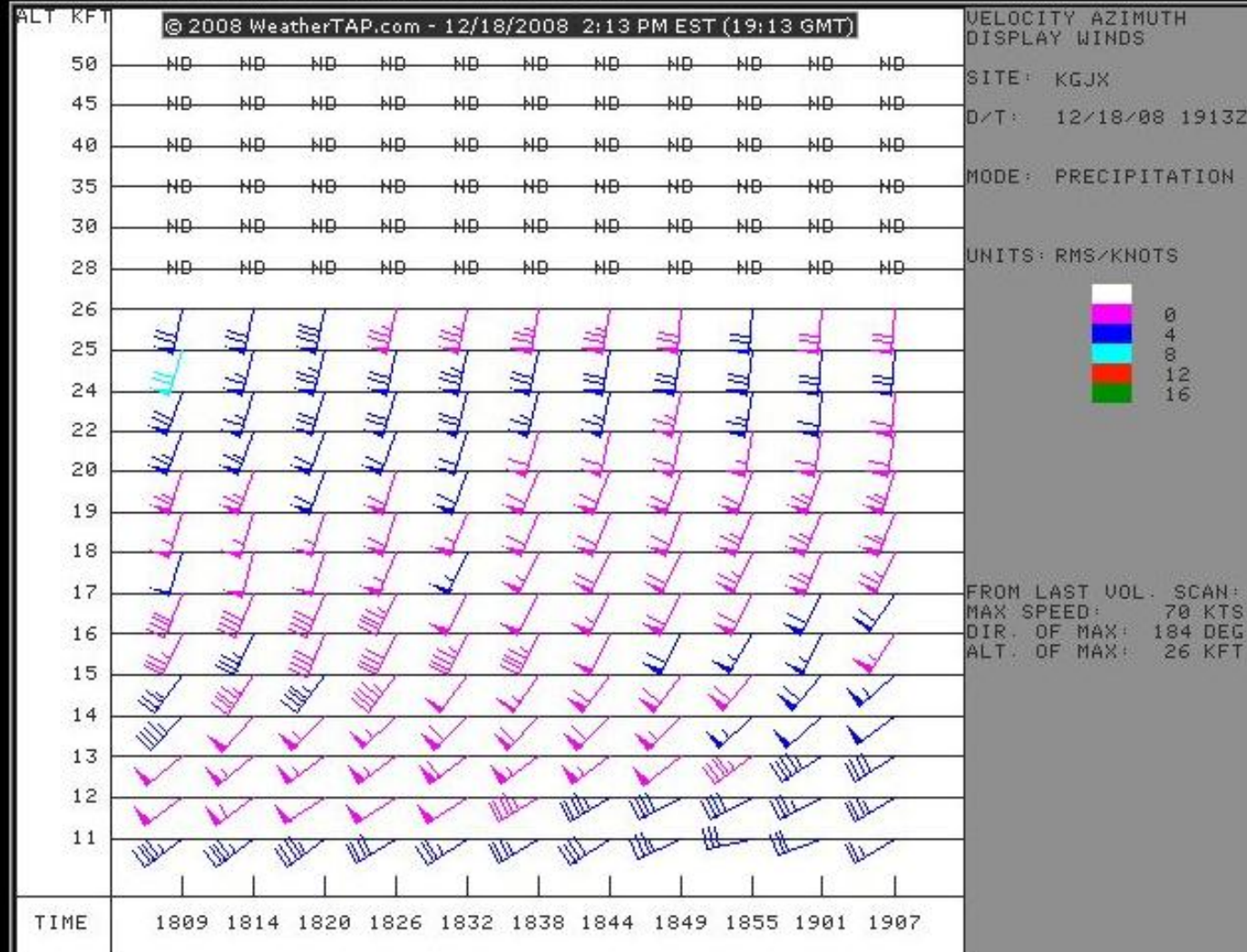
SLAT 39.11
 SLON -108.5
 SELV 1475.
 SHOW -9999
 LIFT -0.20
 LFTV -0.30
 SWET -9999
 KINX -9999
 CTOT -9999
 VTOT -9999
 TOTL -9999
 CAPE 100.5
 CAPV 119.7
 CINS -1.15
 CINV 0.00
 EQLV 417.4
 EQTV 416.1
 LFCT 700.0
 LFCV 700.0
 BRCH 8.88
 BRCV 10.58
 LCLT 266.9
 LCLP 700.0
 MLTH 295.5
 MLMR 3.45
 THCK 5455.
 PWAT 7.40

00Z 27 Mar 2010

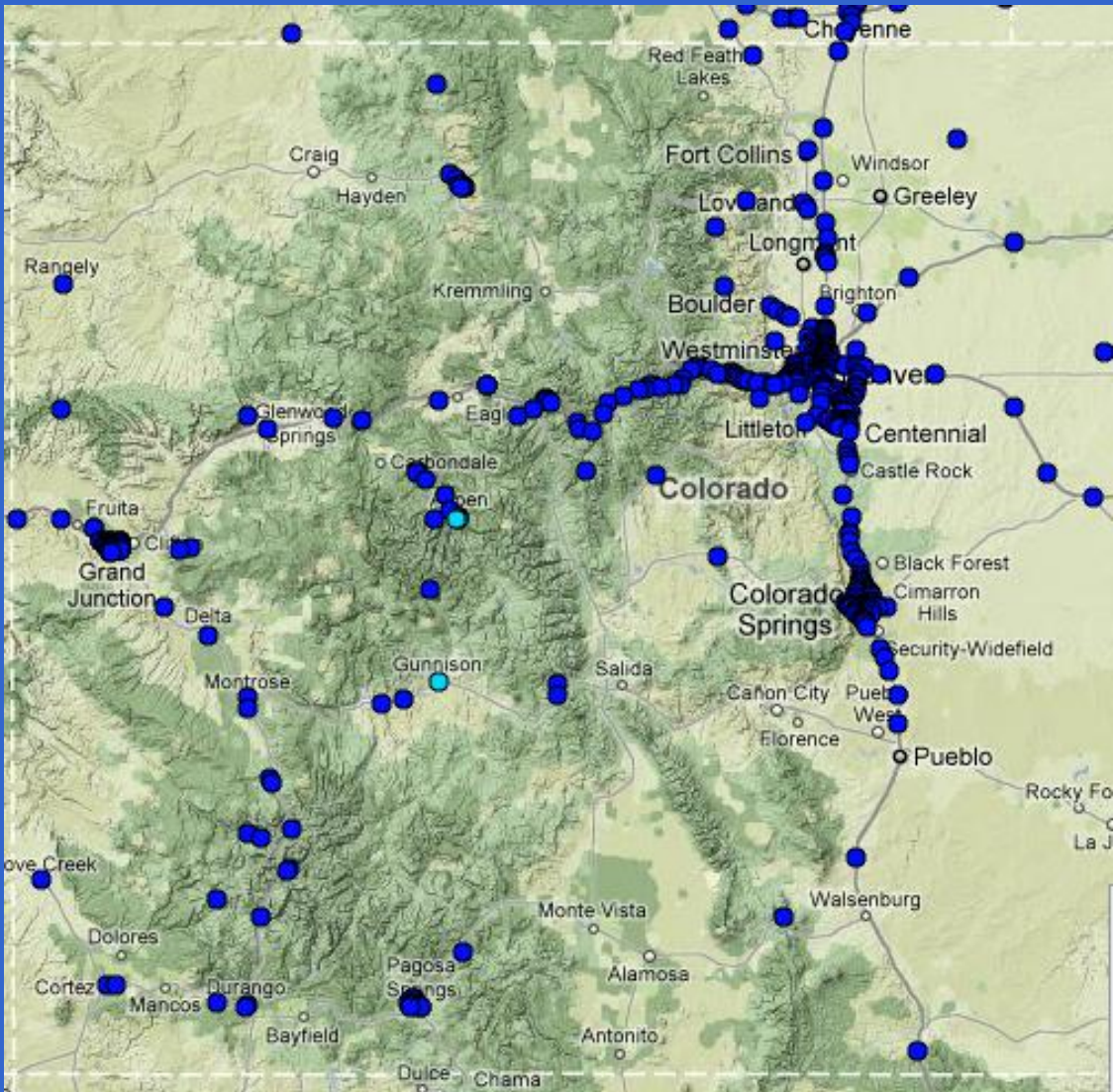
University of Wyoming

Grand Junction NEXRAD Radar VAD Winds December 18, 2008

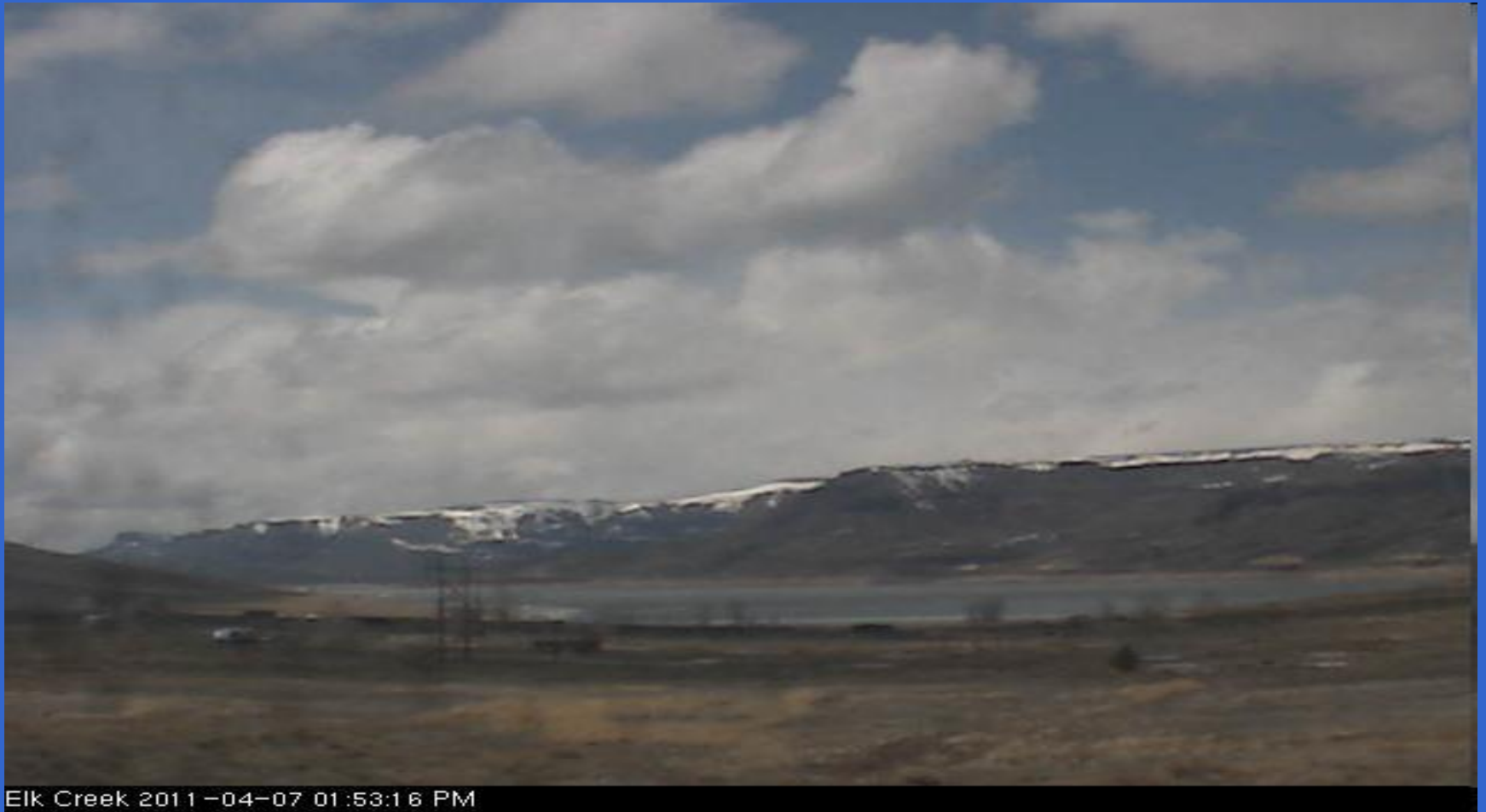
Grand Junction, CO - VAD Wind Profile



WESTERN COLORADO WEB CAM LOCATIONS

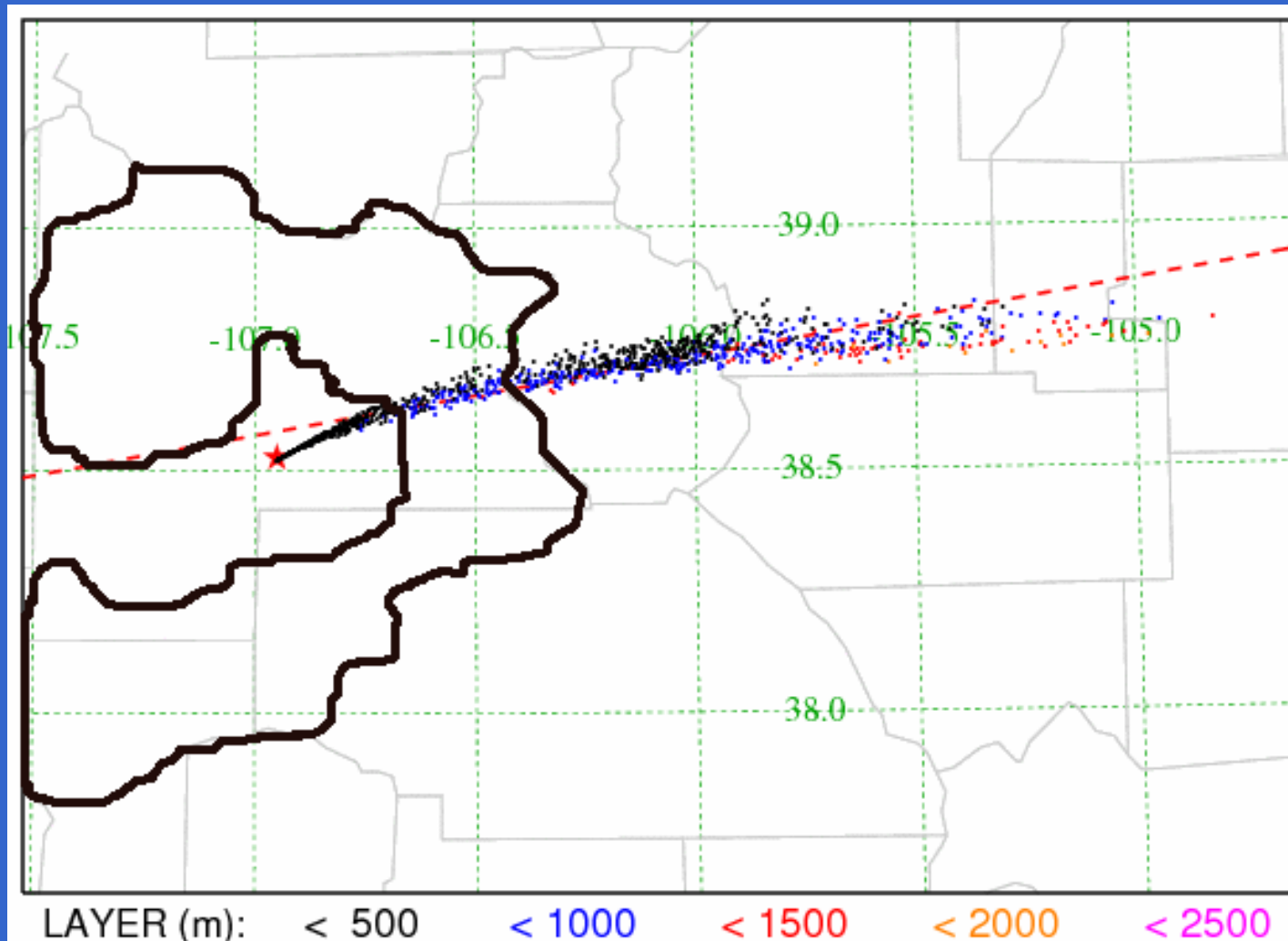


WEB CAM, BLUE MESA RESERVOIR, APRIL 7, 2011



Elk Creek 2011-04-07 01:53:16 PM

HYSPLIT Trajectory Simulation of a 4 Hr. Ground Release, Feb. 20, 2011



Note: color coding indicates height of plume above ground level

OPERATIONS BY SEASON

Seeded Season	Number of Storms	Generator Hours
2003-2004	20	3299
2004-2005	19	3416
2005-2006	18	4231
2006-2007	13	3297
2007-2008	14*	1473*
2008-2009	22	2868
2009-2010	19	2919

* Seeding Operations Terminated on Feb. 27th for rest of season

PROGRAM SUSPENSIONS

Dates of Suspension	Reason for Suspension	Parts of Target Area Impacted by Suspension
Jan. 2-4, 2004	Avalanche Warning	Entire Target Area
Jan. 9-11, 2005	Avalanche Warning	Southern Target Area
Dec. 19-20, 2006	Avalanche Warning	Southern Target Area
Dec. 7-8, 2007	Avalanche Warning	Northern Target Area
Jan. 6-7, 2008	Avalanche Warning	Entire Target Area
Jan. 27-28, 2008	Avalanche Warning	Entire Target Area
Feb. 3-4, 2008	Avalanche Warning, Excess <u>Snowpack</u>	Entire Target Area
Feb. 7-8, 2008	Excess <u>Snowpack</u>	Northern Target Area
Feb. 24-25, 2008	Excess <u>Snowpack</u>	Northern Target Area
Feb. 27- Apr. 15, 2008	Excess Snow pack	Entire Target Area
Dec. 23, 2008	Avalanche Warning	Western Target Area

SNOW WATER CONTENT EVALUATIONS

- **Target and Control Historical Regression Technique Applied to April 1st Snow Water Content Data from NRCS SNOTEL Sites for an Historical Period of 20 Not Seeded Winter Seasons**
- **Selection of Control Sites made Difficult due to Existing Seeding Programs in the Grand Mesa and San Juan Areas. Selected Control and Target Sites have Remained the Same Since the 2003-2004 Winter Season. Six Control Sites and Nine Target Sites**

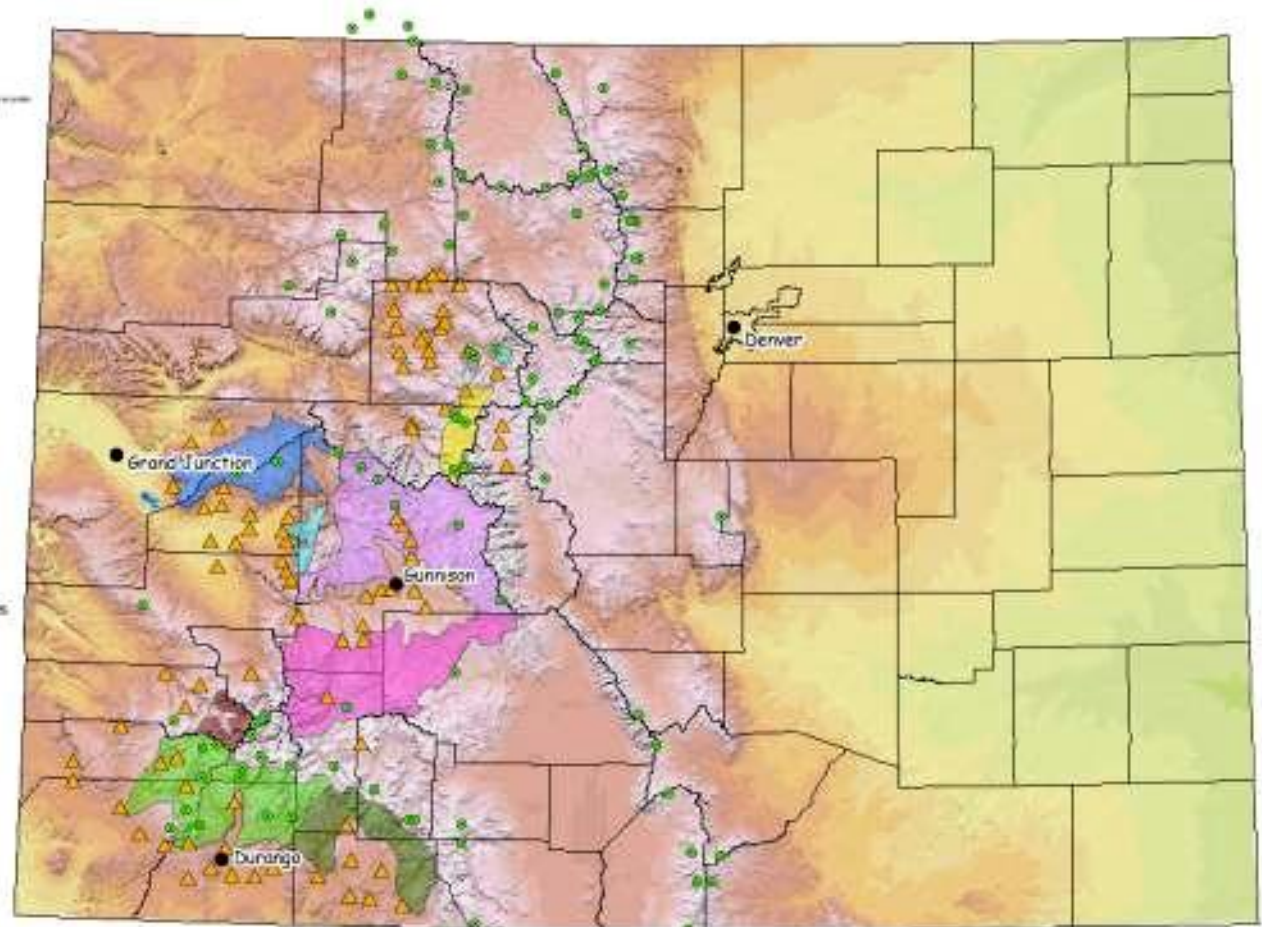
LOCATIONS OF COLORADO WINTER CLOUD SEEDING PROJECTS, 2010-2011

Weather Modification Sites and Target Areas

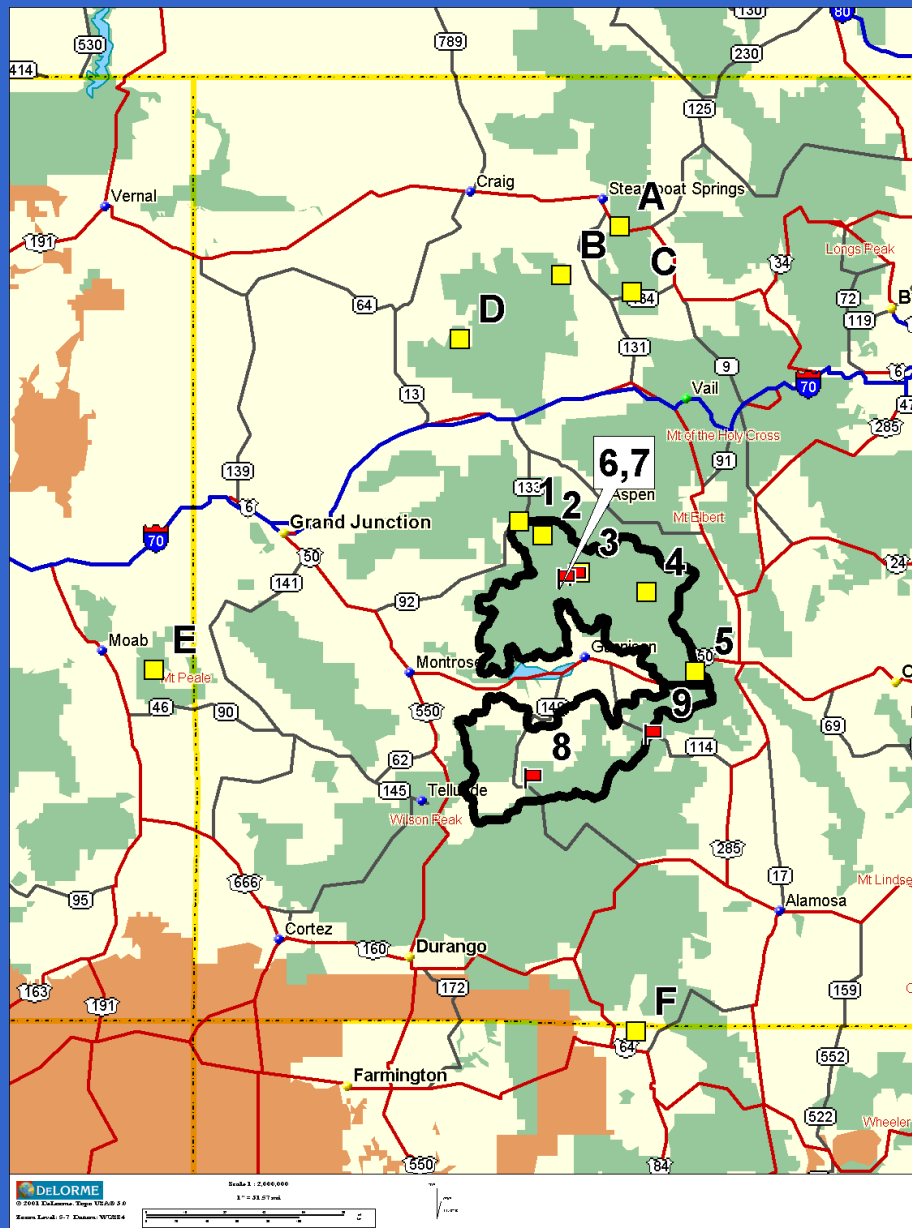
- SNOTEL Sites
- ▲ Generators
- Target Areas**
 - Beaver Creek
 - Western San Juan
 - Eastern San Juan
 - Grand Mesa North
 - Grand Mesa South
 - Gunnison North
 - Gunnison South
 - Telluride/San Miguel
 - Upr Arki w/ CO Basin
 - Vail



Map provided by Colorado State University
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NRCS SNOTEL TARGET AND CONTROL SITES



Summary of Seeded Seasons Evaluations using April 1 Snowpack Data, Based on Simple Linear Regression Equation ($r^2 = 0.74$)

Water Year	Control Average	Target Average	Predicted Target Snow Water Content	Observed/Predicted Ratio	Observed Minus Predicted <u>Precip.</u>
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	14.4	13.1	1.10	1.35
2010	12.9	12.1	11.4	1.07	0.79
Mean	13.5	13.7	11.8	1.16	1.8

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

** Southern Colorado watersheds favored in this heavy snowfall winter due to prevailing storm track. Therefore, results from this season probably high. Seeding operations suspended in late February.

Summary of Seeded Seasons Evaluations using April 1 Snowpack Data, Based on Multiple Linear Regression Equation ($r^2 = 0.79$)

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 <u>Precip.</u>
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	14.4	12.6	1.14	1.8
2010	14.7	9.6	13.9	8.6	17.0	13.3	12.1	12.0	1.01	0.1
Mean	25.2	11.3	14.4	11.3	11.1	7.7	13.7	11.4	1.20	2.3

□

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

** Southern Colorado watersheds favored in this heavy snowfall winter due to prevailing storm track. Therefore, results from this season probably high. Seeding operations suspended in late February.

ESTIMATED INCREASES OF INFLOW INTO BLUE MESA RESERVOIR

- Average of Nine Target Area SNOTEL Observations Correlated with Calculated April-July Blue Mesa Reservoir Inflows (Multiple Linear Regression Equation) for a 30 Season Period**
- Assumed 10% and 15% Increase in the Average April 1st Snow Water Contents at these Sites were Inserted Into the Multiple Linear Regression Equation to Predict the Increase in April-July Inflow due to a 10% or 15% Increase in April 1st Snow Water Content in an Average, in a 125% of Average, and a 75% of Average Water Year**

Estimated Increases of April – July Streamflow Into Blue Mesa Reservoir, Based on Multiple Regression Equation ($r^2 = 0.82$)

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

SUMMARY

- **An Operational Winter Cloud Seeding Program has been Conducted for the Gunnison River Basin above Blue Mesa Reservoir; 2002-2003 to Present. Seeding Mode: Ground Based Silver Iodide Generators.**
- **Program Operated Under Permits Issued by the Colorado Water Conservation Board. Program Funding Derived from Local Water User Groups.**
- **Supplemental Funding of the Program Provided by the Colorado Water Conservation Board beginning in the 2005-2006 winter season and also by The Lower Colorado River Basin States during the 2007-2009 Seasons.**
- **Historical Target/Control Evaluations Suggest Increases in Apr. 1st Target Area Snow Water Content of ~10-15%. These Results Should be Considered Preliminary. Results from this Type of Non-Randomized Analysis May Require 10-15 or even 20 Seeded Seasons to Stabilize.**

Summary (continued)

- **Correlations Between Target Area April 1st Snow Water Content and April - July Inflow to Blue Mesa Reservoir Used to Make Estimates of Increases in Streamflow Attributed to Cloud Seeding.**
- **During an Average Water Year, Increases of 10% or 15% in Snow Water Content Resulted in Estimated April – July Inflow of 79,600 and 96,200 Acre-Feet, Respectively.**
- **Equating the Program Costs with these Estimated Increases Results in Costs per Acre-Foot of \$0.94 to \$1.13, Respectively.**
- **A Paper on this Program will appear in the 2011 WMA *Journal of Weather Modification*.**