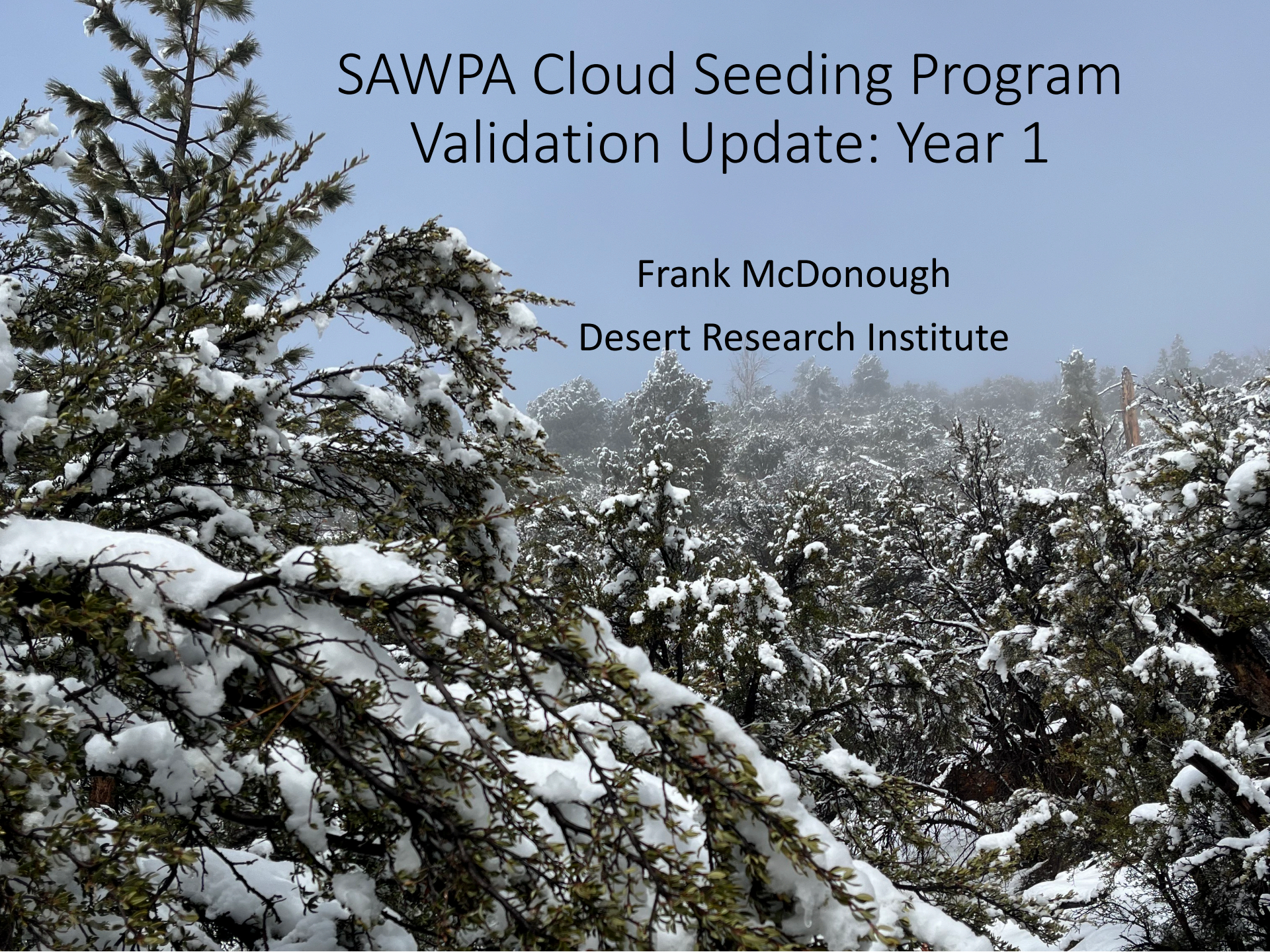


SAWPA Cloud Seeding Program Validation Update: Year 1

Frank McDonough

Desert Research Institute

Background: North America Weather Consultants Feasibility Study 2020

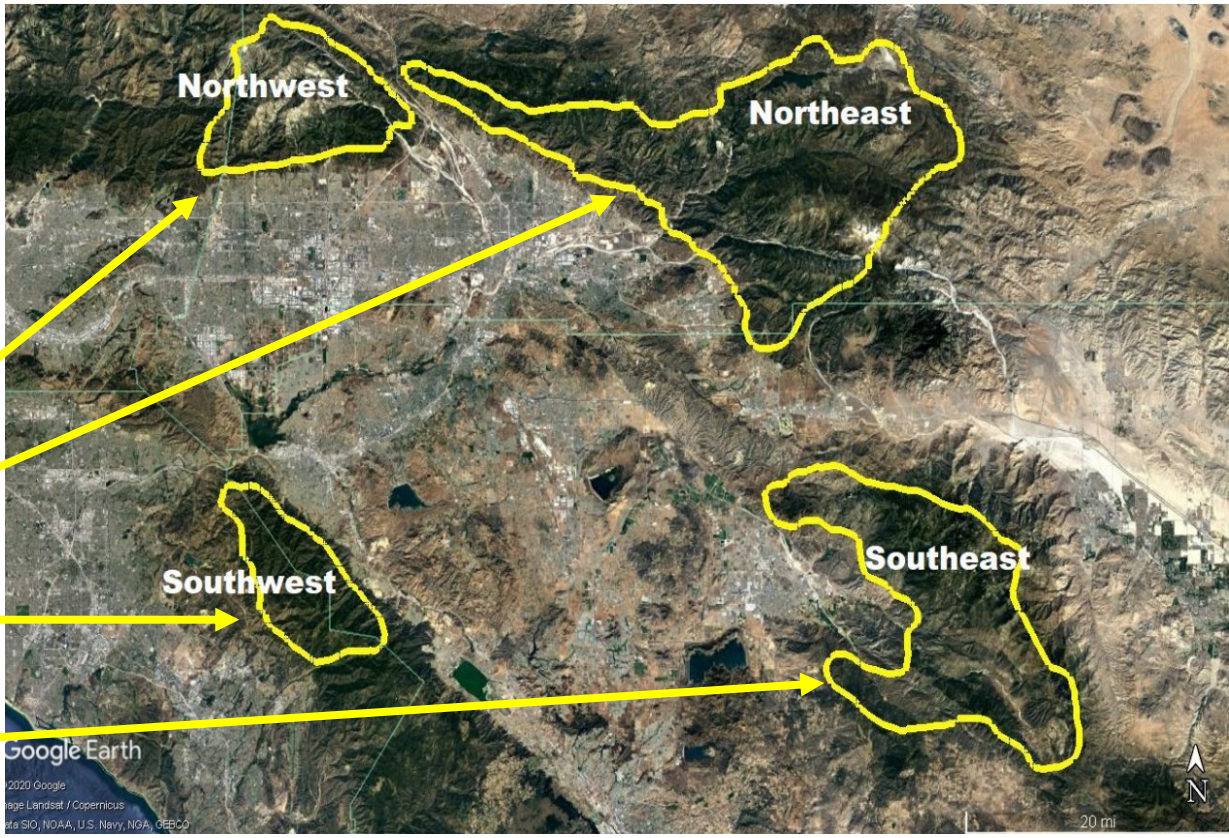
Study suggested that cloud seeding was feasible in the four headwater regions of the Santa Ana River.

Eastern San Gabriel Mountains

San Bernardino Mountains

Eastern side of Santa Ana Mtns

West slopes Mt San Jacinto



Background: Estimated yields from feasibility study

Precipitation Increases beneath the seeding plume

Streamflow increases

Estimated precipitation and streamflow increases

Target Area	Seasonal Precipitation Increase (inches)	Percent Increase	Avg. Natural Streamflow (AF)	Streamflow Increase (AF)	Percent Increase
NW	0.41	3.5%	25,000	2,043	8.2%
NE (ground)	0.49	4.1%	65,000	4,330	6.7%
NE (air & ground) *	0.89	7.3%	65,000	7,772	12.0%
SW	0.59	3.7%	5,000	447	9.0%
SE	0.49	4.5%	10,000	1,373	13.7%
	TOTAL w/ Ground Only		**105,000**	**8,193**	**7.8%**

Validation Tasks

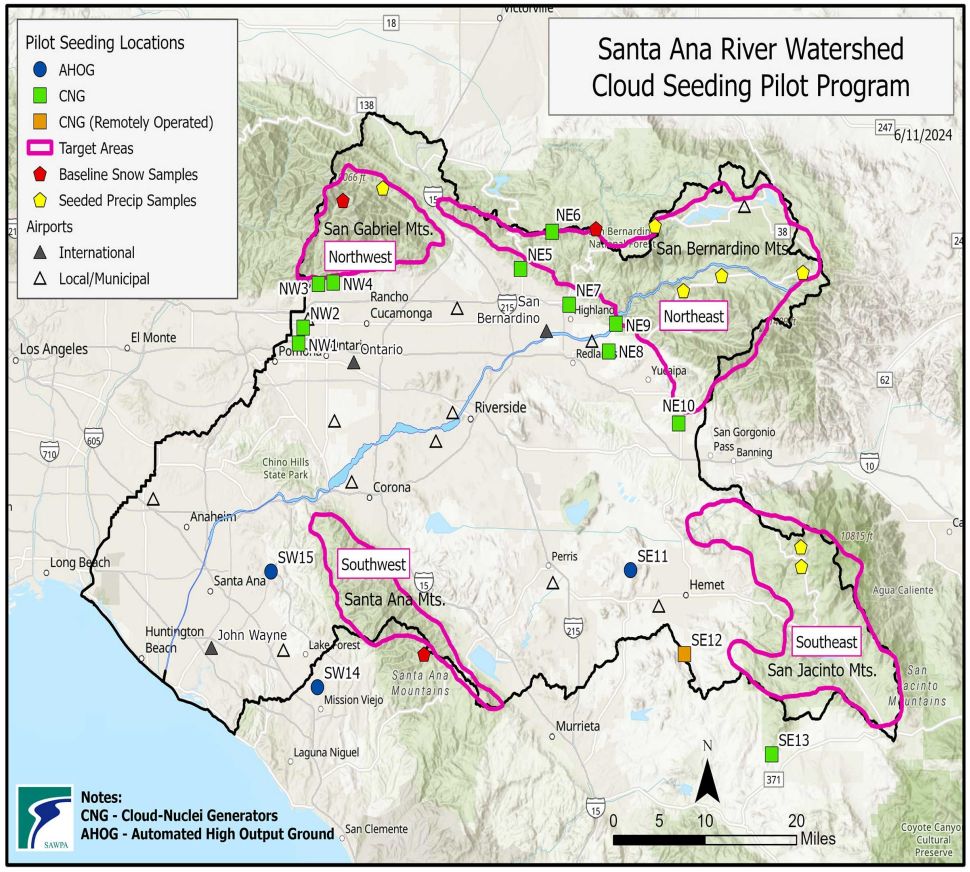
Task 1) ensure that the cloud seeding operations are matched to the seedable storm periods.

Task 2) ensure that the cloud seeding generator placement is able to deliver seeding material to the target areas

Task 3) determine the estimated amount of additional seeded snowfall/precipitation for each storm, and the winter total in each area.

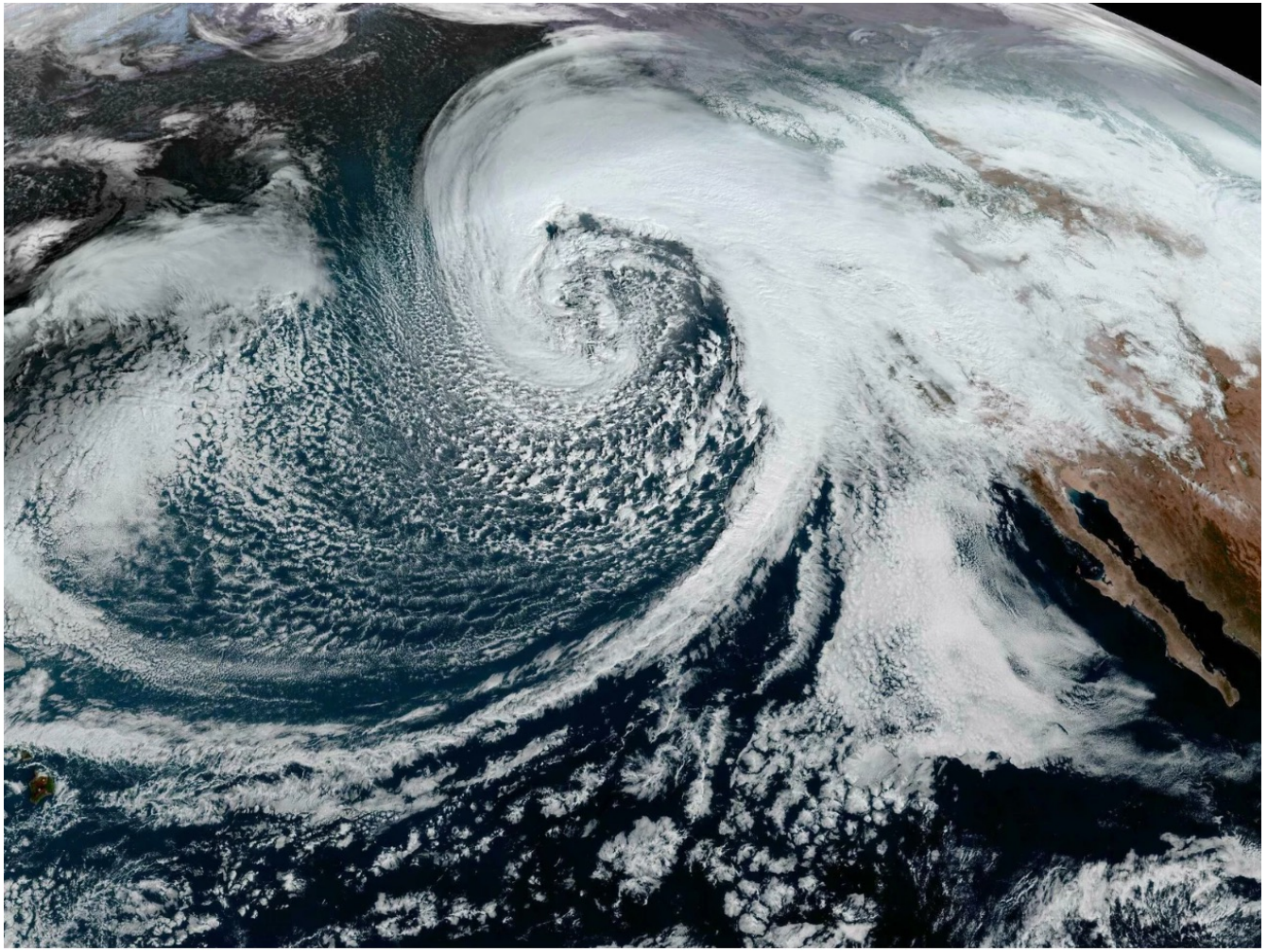
Task 4) compare unseeded seasonal precipitation amounts within the target areas to an adjacent unseeded control area, then compares the seeded year to the long-term relationships.

Task 5) compare the seasonal unseeded stream flow within the target areas to adjacent unseeded control areas, then compares the seeded year to the long-term relationships.



Target Areas and Generator Locations

Task 1: Detailed review winter weather and independent assessment of NAWC operations



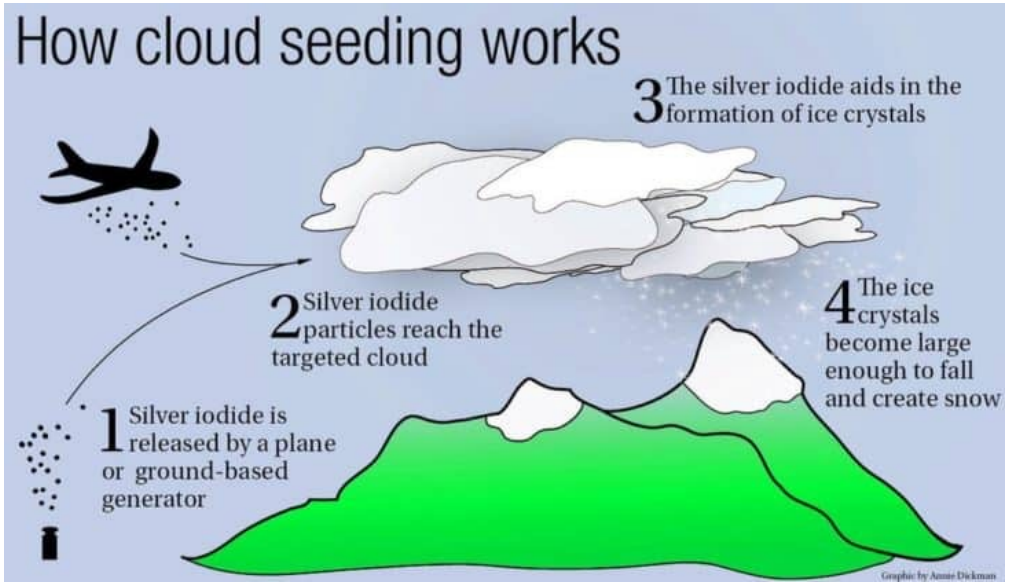
Task 1: Detailed review winter weather and independent assessment of NAWC operations – results

- 13 storms were seeded between November 15, 2023 and April 15, 2024.

- All of these seeded storms contained seedable clouds at or below 11,000’ MSL.

- No seedable storms were missed.

- The total number generator-hours were 2,165, with 1,703 hours of operation during potential seeding conditions.



Task 2) Snow Chemistry

Identifying slightly elevated amounts of silver in fresh seeded precipitation can confirm successful targeting of the from the cloud seeding generator locations.

Precipitation sampling was done during 2 storms to assess the silver in the precipitation.

Sampling the chemical make up of snow

DRI Desert Research Institute

Set up snow collection sites within cloud seeding target area and within a nearby unseeded control area

Collect storm snowfall in ultra clean bags

Keep sample frozen and deliver to DRI Trace Chemistry/Ice Core Lab

Analyze snow samples in DRI Lab using Mass Spectrometry

Task 2) Storm 1– Feb 20 - 21, 2024 (sampling of NW & NE target areas)

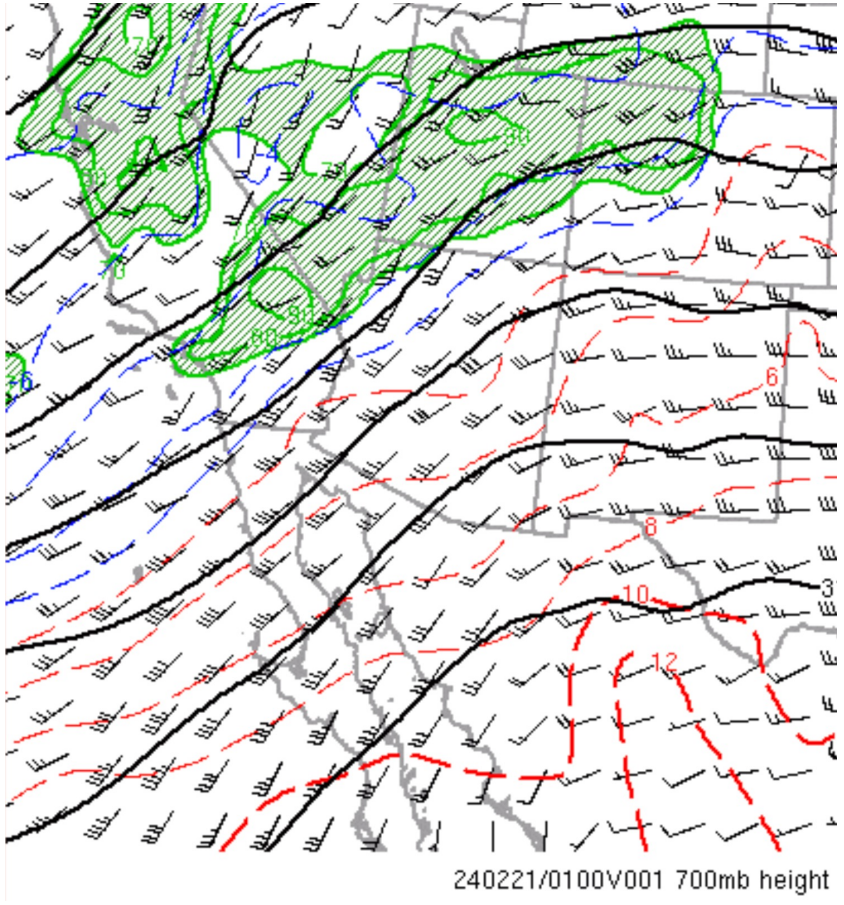
10,000’-MSL cold front/trough crossing area.

Clouds with bases below mountain top were present.

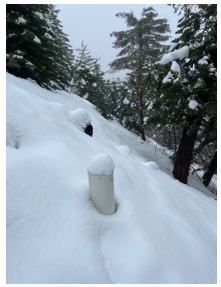
Temperatures at 10,000’ MSL were about -5C (23F).

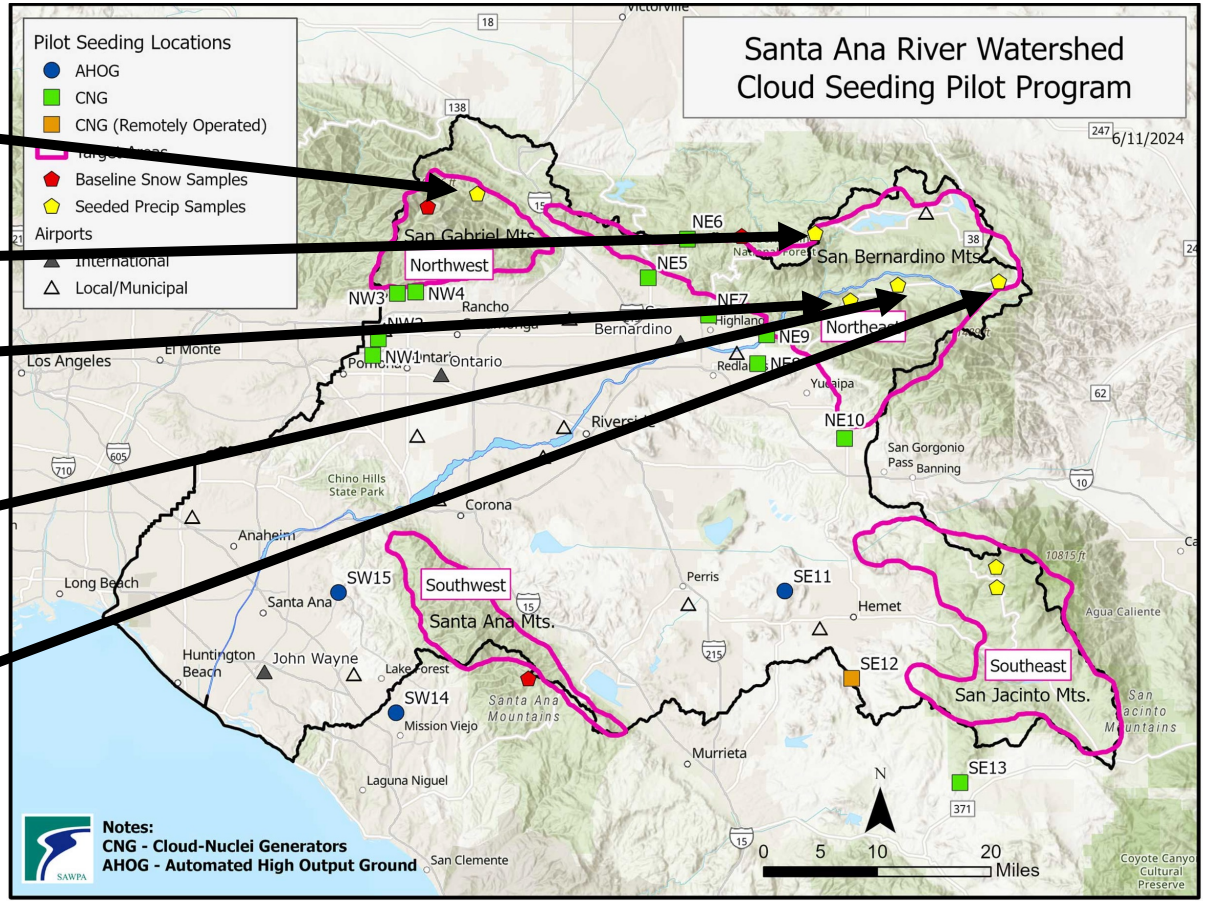
Winds from the southwest.

On-shore flow from Pacific.



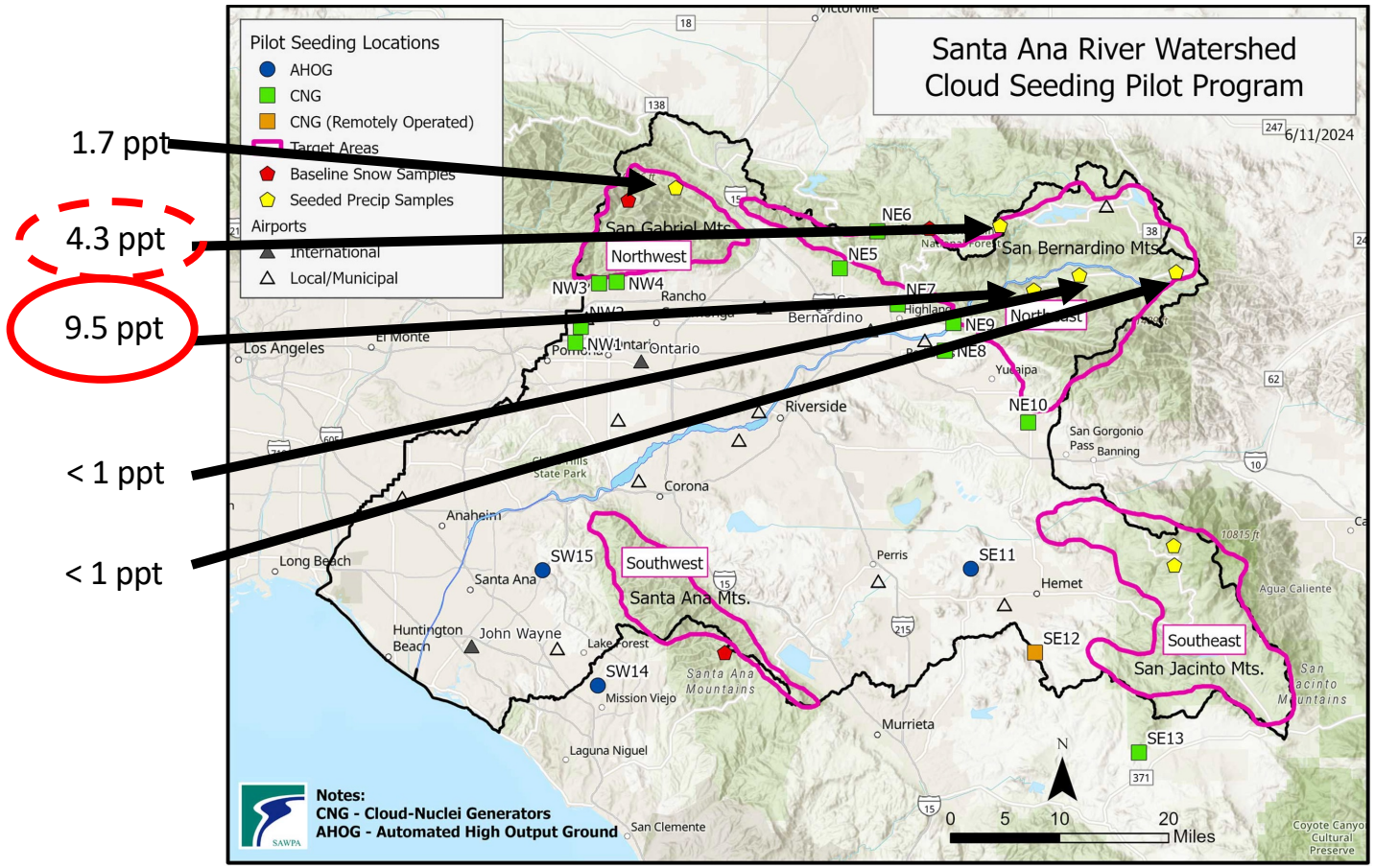
Task 2) Collection sites Feb 20 - 21, 2024 (NW & NE target areas)





Task 2) Snow Chemistry Results
Feb 20 - 21, 2024

Possible successful collection



Task 2) Storm 2 – Mar 6 - 7, 2024 (SE target area)

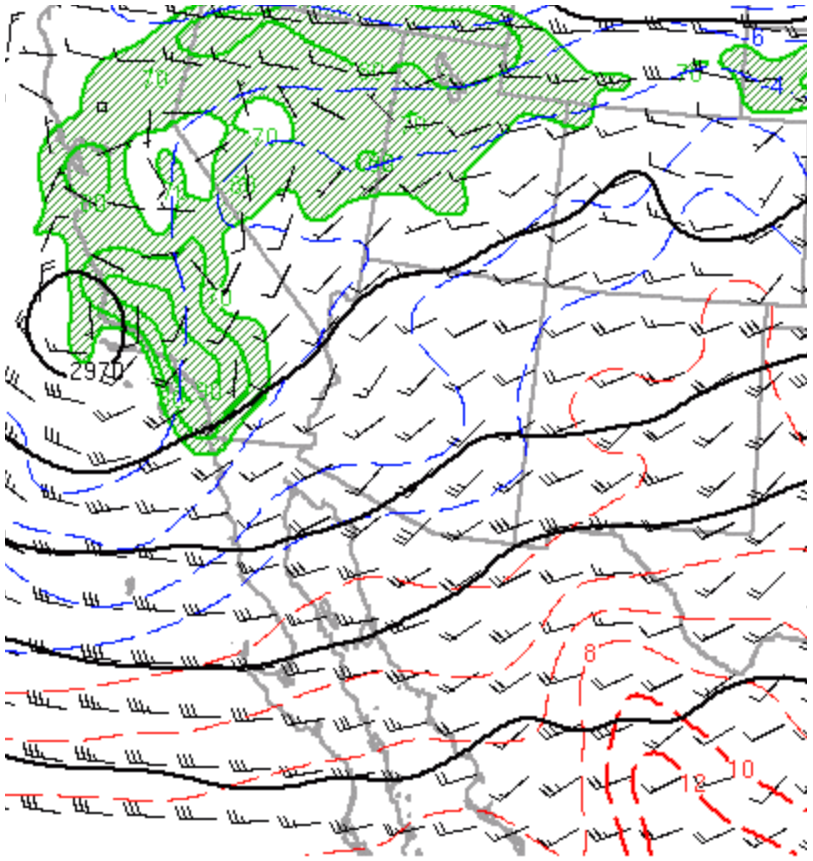
10,000’ (MSL) cold front/closed low crossing area.

Clouds present below mountain tops.

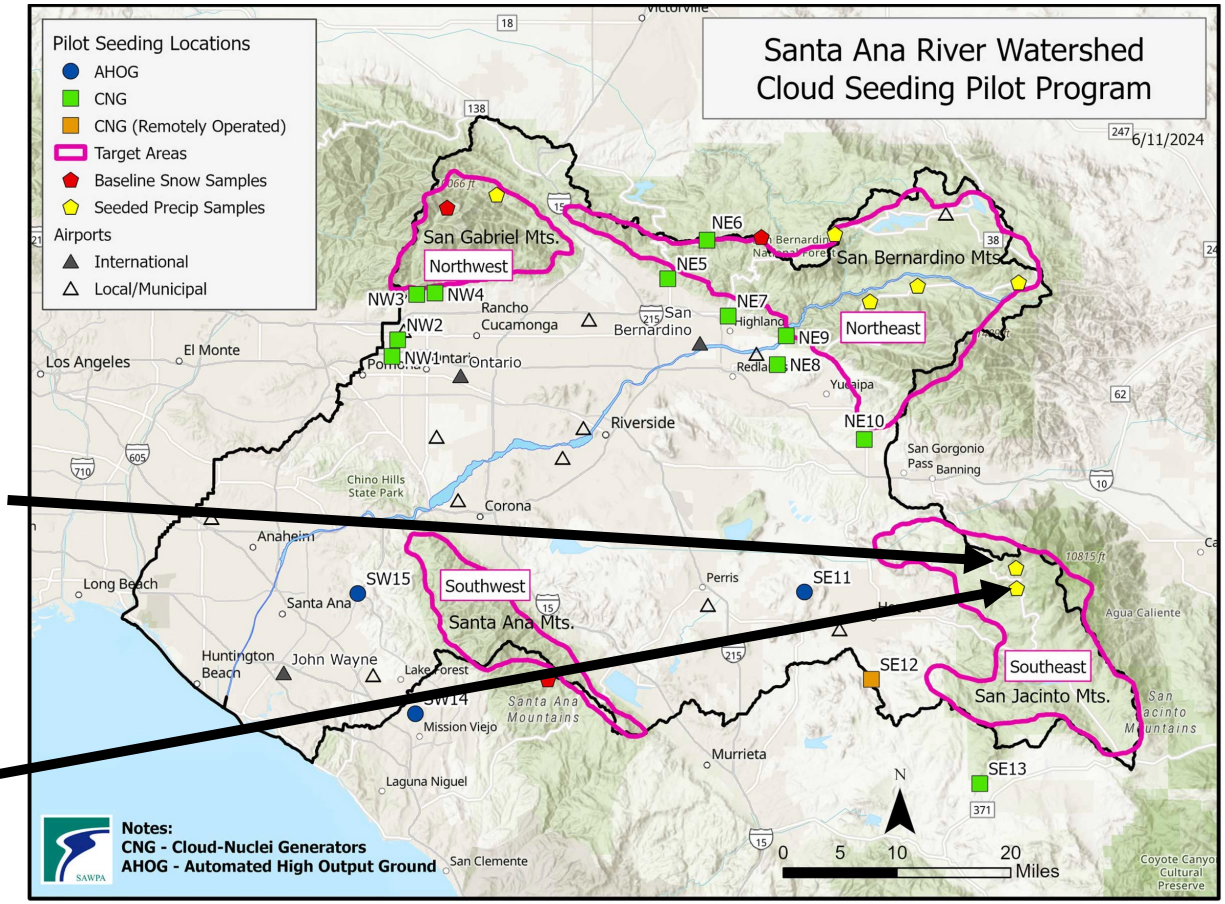
Temperatures at 10,000’ MSL about -5.5C (22F).

Winds from the south-southwest.

On-shore flow from Pacific.

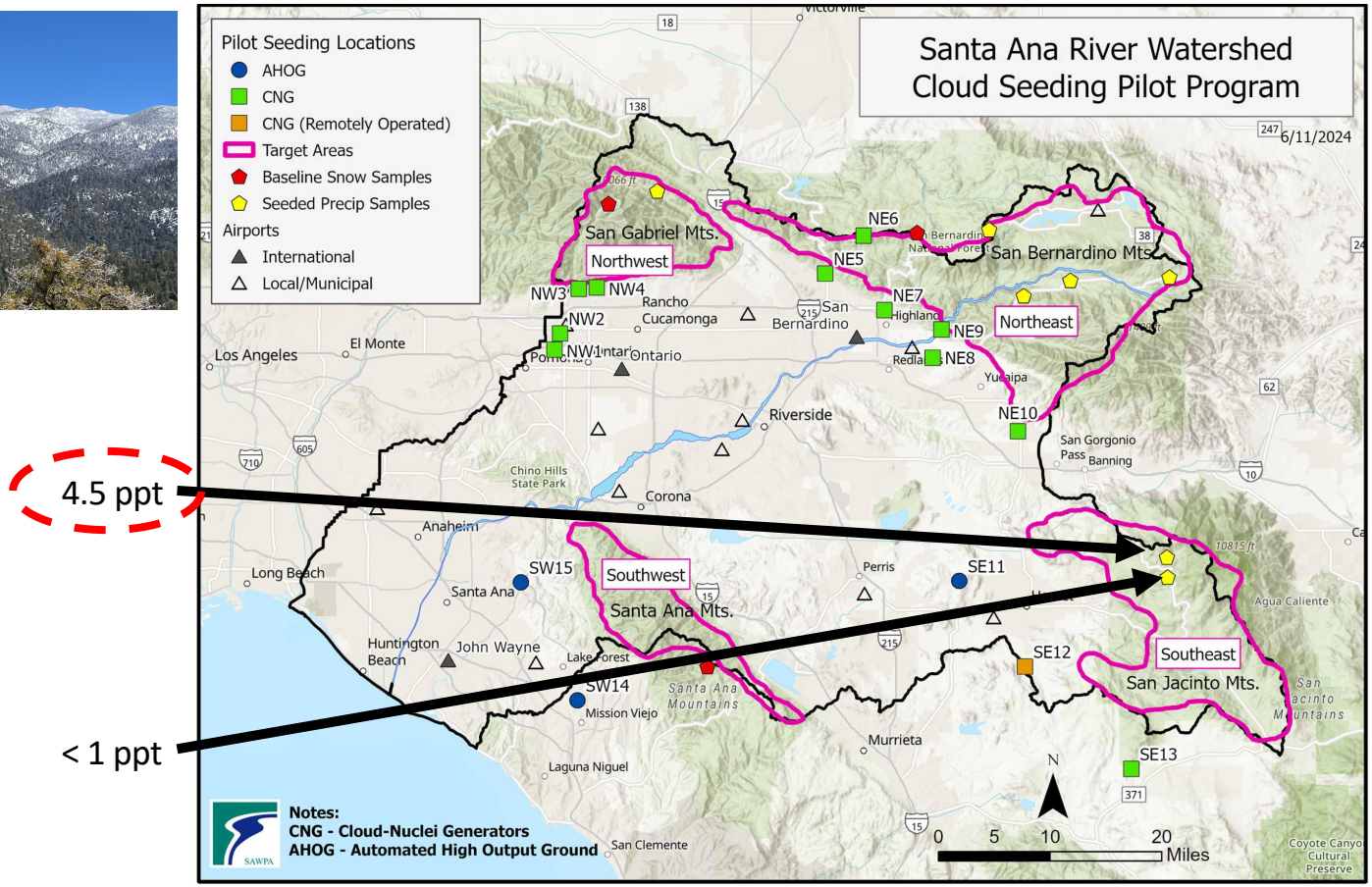


Task 2) Collection Sites – Mar 6 - 7, 2024 (SE target area)



Task 2) Snow Chemistry – Mar 6 - 7, 2024 (SE target area)

Possible successful collection



Task 3) Estimating seeded precipitation

Background:
-50-year project over southern Sierra (Big Creek) showed an average seasonal precipitation increases of 8%. (McGurty 1999) and 4% increases in stream flow.

- Several other historical deep pocket research projects over the central Sierra suggested average increases of 0.01" of snow water equivalent during seedable periods (Huggins 2007, Reynolds (1980).

-$25M project showed a 1statistically significant 14% seasonal increase in precipitation across the Snowy Mountains in Australia.

American Meteorological Society states in their capability statement that seasonal increases of 10% over unseeded precipitation can be realized by a well run cloud seeding program.

- A NSF research program conducted over Idaho showed 200 – 400 acre-feet per hour increases in snow water equivalent during a Pacific storm using a mountain-top cloud radar, research aircraft, and high-resolution precipitation gauges.

Task 3 Estimating seeded precipitation

Assume a 0.01” per hour increase in precipitation along the terrain under generators footprint (30 sq mi) during the time periods when seedable conditions were present.

Task 3 Estimating seeded precipitation all seedable times (Northeast)

Storm	Seeding Hours	Flares during seeding	Increased Precipitation (acre-feet)
Dec 21-22, 2023	80.50	-	1288
Dec 29-30, 2023	47.50	-	760
Jan 03, 2024	49.25	-	788
Jan 20-21, 2024	105.25	-	1684
Jan 21-22, 2024	99.75	-	1596
Jan 31- Feb 1, 2024	39.00	-	624
Feb 21-22, 2024	80.00	-	1280
Mar 6-7, 2024	82.50	-	1320
Mar 23-24, 2024	63.00	-	1008
Mar 30-31, 2024	157.25	-	2516
April 5, 2024	80.25	-	1284
April 13-14, 2024	80.00	-	1280
==========	==========	==========	==========
Total	964.25		15428

Task 3 Estimating seeded precipitation all seedable times (Northwest)

Storm	Seeding Hours	Flares during seeding	Increased Precipitation (acre-feet)
Dec 21-22, 2023	24	-	384
Dec 29-30, 2023	31	-	496
Jan 03, 2024	19.25	-	308
Jan 20-21, 2024	0	-	0
Jan 21-22, 2024	0	-	0
Jan 31- Feb 1, 2024	42.75	-	684
Feb 21-22, 2024	144.50	-	2312
Mar 6-7, 2024	44.00	-	704
Mar 23-24, 2024	48.00	-	768
Mar 30-31, 2024	84.50	-	1352
April 5, 2024	39.50	-	632
April 13-14, 2024	26.25	-	420
==========	==========	==========	==========
Total	503.75		8060

Task 3) Estimating seeded precipitation all seedable times (Southeast)

Storm	Seeding Hours	Flares during seeding	Increased Precipitation (acre-feet)
Dec 21-22, 2023	14.75	5 (250 ac-ft)	486
Dec 29-30, 2023	12.00	-	192
Jan 03, 2024	17.75	-	284
Jan 20-21, 2024	15.25	-	244
Jan 21-22, 2024	14.25	4 (200 ac-ft)	228
Jan 31- Feb 1, 2024	26.25	1(50 ac-ft)	420
Feb 21-22, 2024	0	-	0
Mar 6-7, 2024	29.75	-	476
Mar 23-24, 2024	27.50	-	440
Mar 30-31, 2024	55.75	1 (50 ac-ft)	892
April 5, 2024	21.75	-	348
April 13-14, 2024	0	-	0
==========	==========	==========	==========
Total	235.00	11 (550 ac-ft)	4210

Task 3 Estimating seeded precipitation all seedable times (Southwest)

Storm	Seeding Hours	Flares during seeding	Increased Precipitation (acre-feet)
Dec 21-22, 2023	-	1 (50 ac-ft)	50
Dec 29-30, 2023	-	3 (150 ac-ft)	150
Jan 03, 2024	-	-	0
Jan 20-21, 2024	-	1 (50 ac-ft)	50
Jan 21-22, 2024	-	3 (150 ac-ft)	150
Jan 31- Feb 1, 2024	-	1(50 ac-ft)	50
Feb 21-22, 2024	-	-	0
Mar 6-7, 2024	-	3 (150 ac-ft)	150
Mar 23-24, 2024	-	-	0
Mar 30-31, 2024	-	2 (100 ac-ft)	100
April 5, 2024	-	-	0
April 13-14, 2024	-	-	0
==========	==========	==========	==========
Total	-	14 (700 ac-ft)	700

Task 3 Estimating seeded precipitation when precipitation was measured

Assume a 10% increase in precipitation along the terrain under generators footprint (30 sq mi) during the time periods when seedable conditions were present and precipitation was observed.

Task 3 Estimating seeded precipitation all seedable times and precipitation present (Northeast)

Storm	Precip during seeding	Precip increase during seeding (10%)	Number of generators	Precip increase acre feet;
Dec 21-22, 2023	0.31”	0.031”	6	298
Dec 29-30, 2023	0.29”	0.029	6	278
Jan 03, 2024	0.26”	0.026”	6	250
Jan 20-21, 2024	0.67”	0.067”	6	643
Jan 21-22, 2024	1.43”	0.143”	5	1373
Jan 31- Feb 1, 2024	1.12”	0.112”	4	717
Feb 21-22, 2024	0.36	0.036”	4	230
Mar 6-7, 2024	0.40	0.040”	5	320
Mar 23-24, 2024	0.27	0.027”	6	259
Mar 30-31, 2024	1.22”	0.12”	5	960
April 5, 2024	0.23	0.023	6	221
April 13-14, 2024	0.80	0.080	6	768
=========	========	==========		==========
Total	7.36”	0.736		6,017

Task 3 Estimating seeded precipitation all seedable times and precipitation present (Northwest)

Storm	Precip during seeding	Precip increase during seeding (10%)	Number of generators	Precip increase acre feet;
Dec 21-22, 2023	0.79”	0.079”	2	253
Dec 29-30, 2023	0.17”	0.017”	4	109
Jan 03, 2024	0.39”	0.039”	3	187
Jan 20-21, 2024	1.02”	0.102”	0	0
Jan 21-22, 2024	1.76”	0.176”	0	0
Jan 31- Feb 1, 2024	2.06”	0.206”	3	989
Feb 21-22, 2024	0.00”	0.000”	3	0
Mar 6-7, 2024	0.00”	0.000”	3	0
Mar 23-24, 2024	0.33”	0.033”	4	211
Mar 30-31, 2024	1.96”	0.196”	3	941
April 5, 2024	0.00”	0.000”	4	0
April 13-14, 2024	0.70	0.070”	4	448
=========	=========	==========		==========
Total	9.18”	0.918		3,138

Task 3) Estimating seeded precipitation all seedable times and precipitation present (Southeast

Storm	Precip during seeding	Precip increase during seeding (10%)	Number of generators (flares)	Precip increase acre feet;
Dec 21-22, 2023	0.25”	0.025”	2 (5)	80
Dec 29-30, 2023	0.46”	0.046”	2	147
Jan 03, 2024	0.43”	0.043”	2 (2)	187
Jan 20-21, 2024	0.84”	0.084”	1	134
Jan 21-22, 2024	0.98”	0.098”	1	157
Jan 31- Feb 1, 2024	1.05”	0.105”	2	336
Feb 21-22, 2024	0.00”	0.000”	0	0
Mar 6-7, 2024	0.44”	0.044”	2 (1)	140
Mar 23-24, 2024	0.00”	0.000”	0	0
Mar 30-31, 2024	1.41”	0.141”	2	541
April 5, 2024	0.10”	0.010”	2	32
April 13-14, 2024	0.48”	0.048”	0	0
=========	========	==========		==========
Total	6.44”	0.644		1754

Task 3) Estimating seeded precipitation Summary

Target Area	Seedable Clouds Present	Seedable Clouds and Precipitation Present
Northeast	15,428	6,017
Northwest	8,060	3,138
Southeast	4,210	1,754
Southwest	700	338

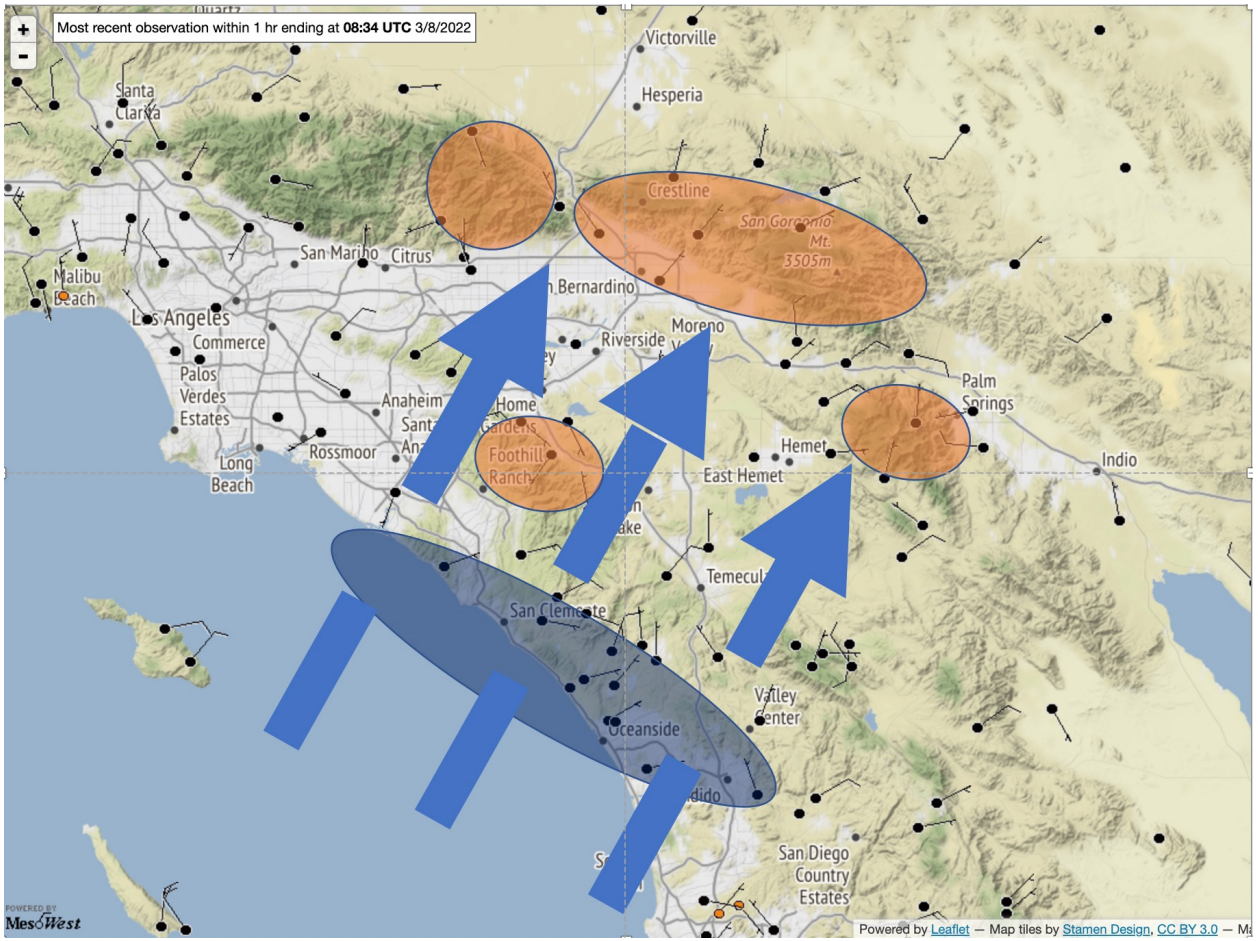
Task 4 Target Control Assessement (only one year)

Target area climatology and project design. require south through southwesterly winds when seeding conditions are present.

An upstream control site was identified (Santa Rosa Plateau).

Gauges within the target area were identified.

The non-seeded seasonal relationship between the target and control were computed and plotted with the clouds seeding season added to the plots.

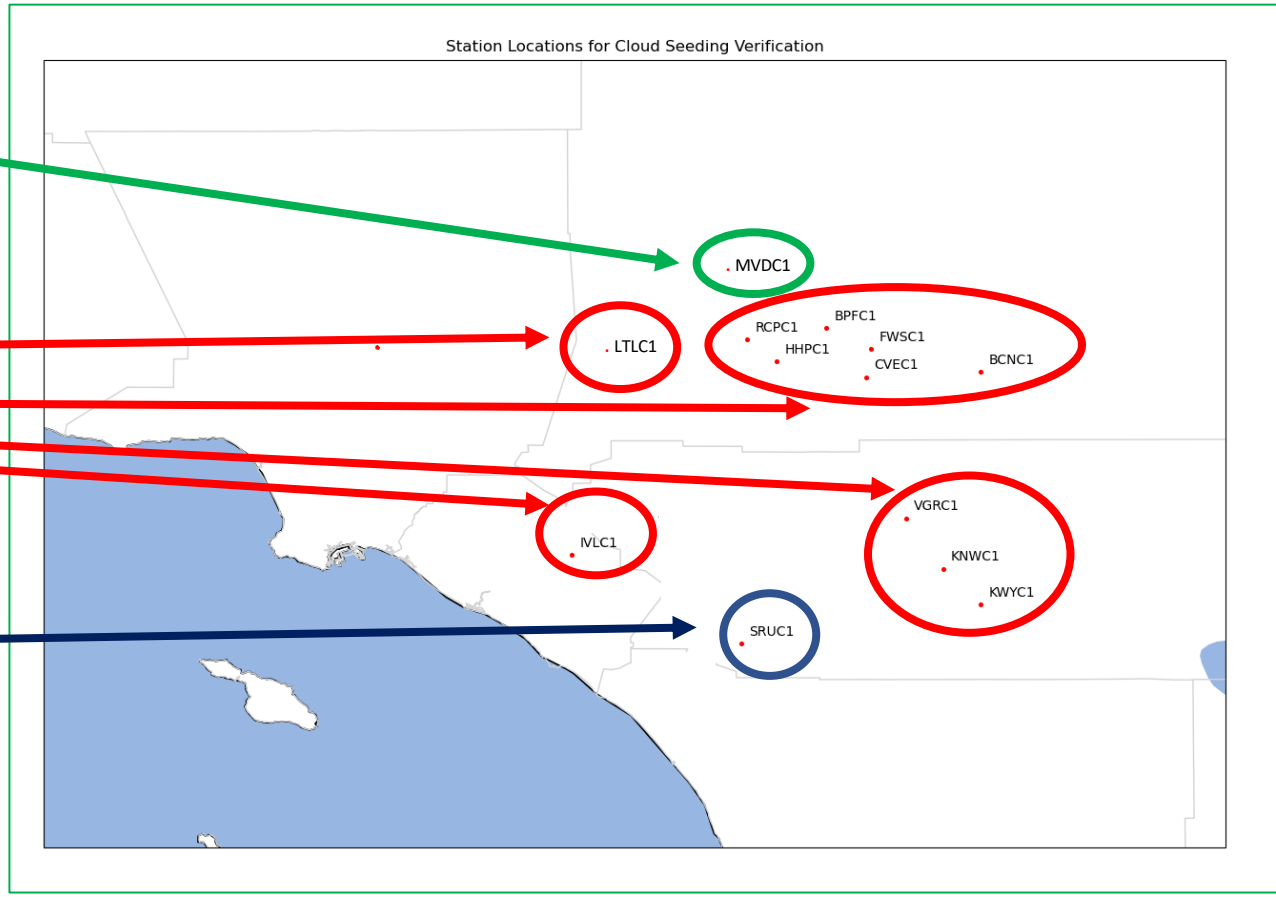


Task 4) Target-Control – Sites

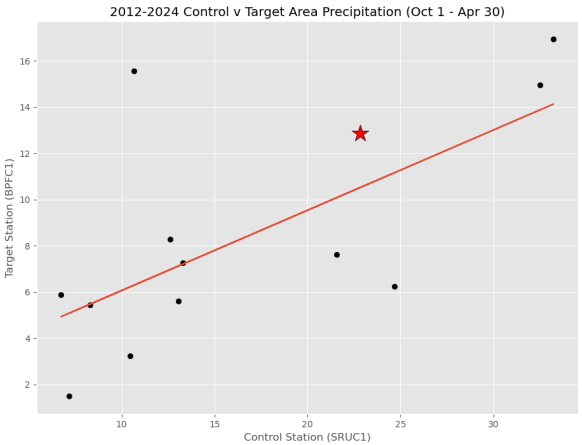
Extra-area gauge

Target Areas

Control gauge

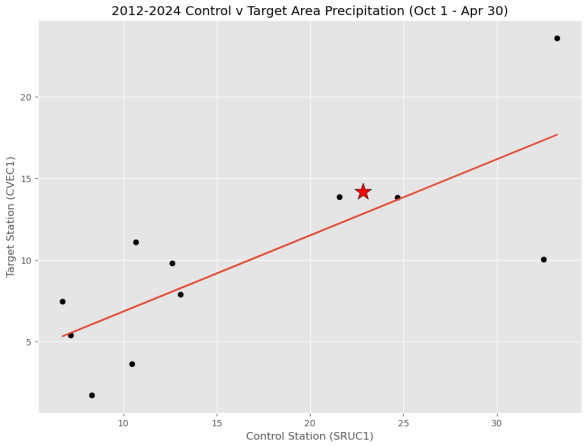


Task 4) San Bernardino Target Upstream Control – Results



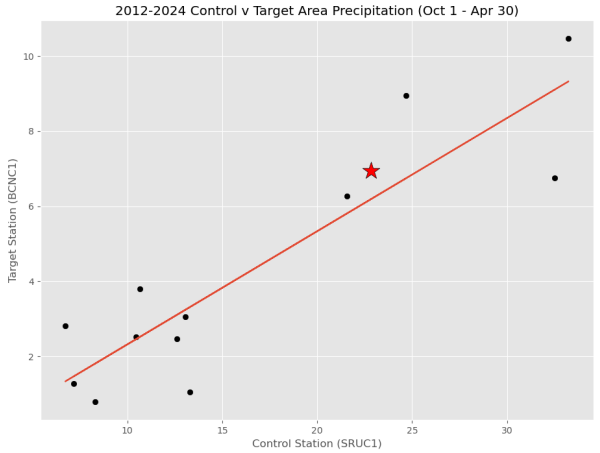
Big Pine Flat (6,851')
V
Santa Rosa Plateau (1,987')

Expected precipitation 10.2"
observed 12.8"
(+25.5%)



Converse (5,618')
V
Santa Rosa Plateau (1,987')

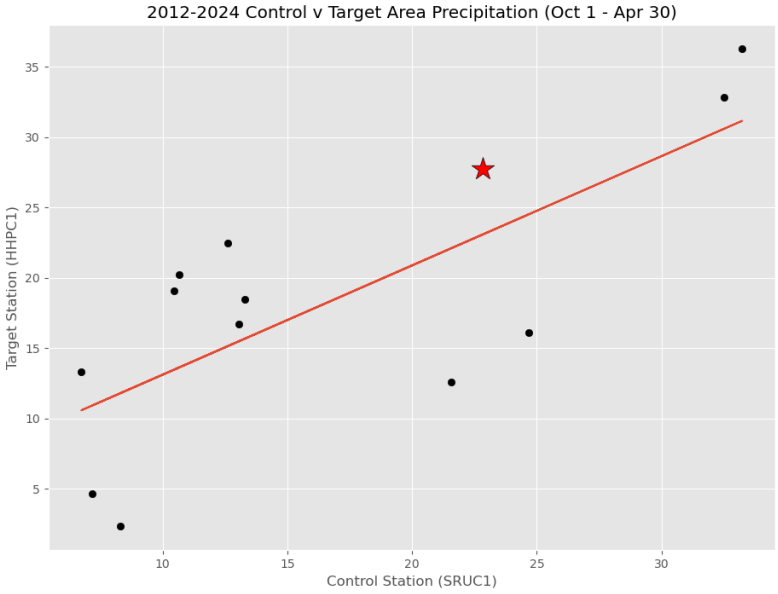
Expected precipitation 13.0" observed 14.4"
(+10.7%)



Burns Canyon (6,284')
V
Santa Rosa Plateau (1,987')

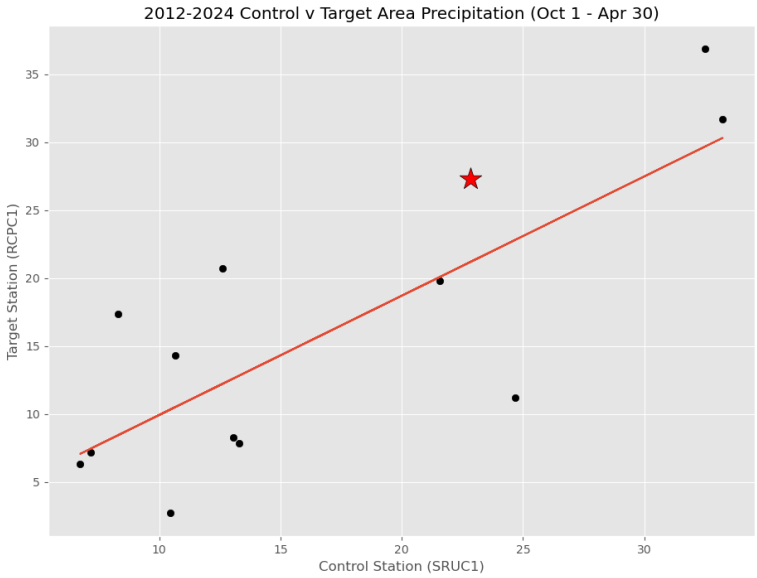
Expected precipitation 6.1" observed 6.9"
(+12.1%)

Task 4) San Bernardino Target Upstream Control – Results



Heaps Peak (6,455’)
V
Santa Rosa Plateau (1,987’)

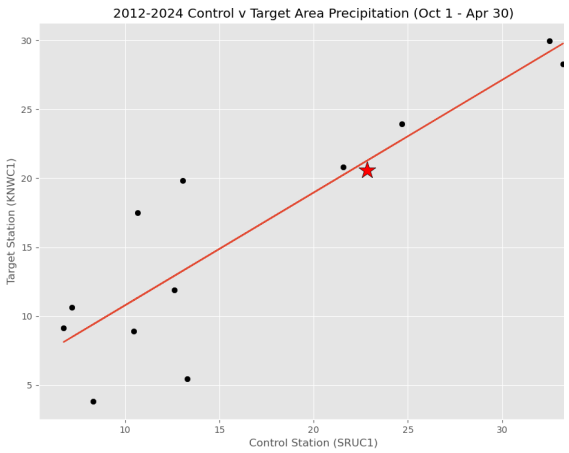
Expected precipitation 23.5” observed 27.2”
(+15.7%)



Rock Camp (4,900’)
V
Santa Rosa Plateau (1,987’)

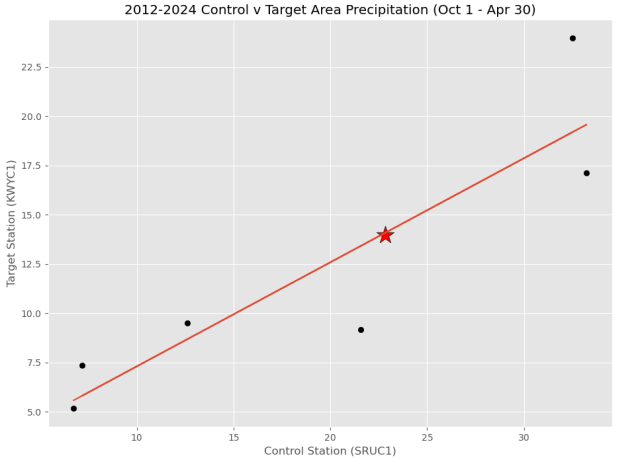
Expected precipitation 20.9” observed 26.2”
(+25.3%)

Task 4) San Jacinto Target Upstream Control – Results



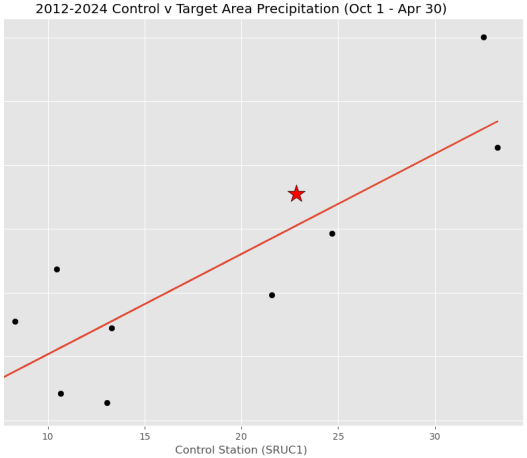
Keenwild (4,752')
V
Santa Rosa Plateau (1,987')

Expected precipitation 20.3" observed 20.1"
(-1.0%)



Kenworthy (4,590')
V
Santa Rosa Plateau (1,987')

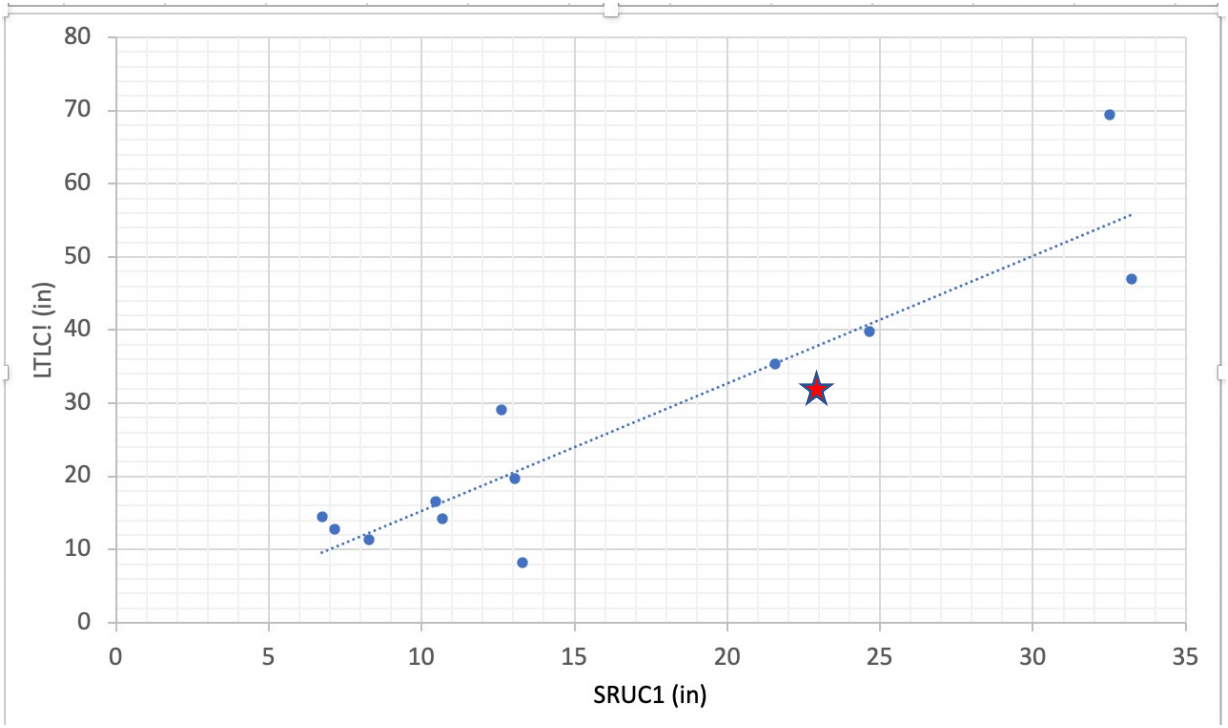
Expected precipitation 13.7"
observed 13.6"
(-0.7%)



Vista Grande (4,906')
V
Santa Rosa Plateau (1,987')

Expected precipitation 20.1"
observed 22.9"
(+13.9%)

Task 4) Santa Ana Target Upstream Control – Results

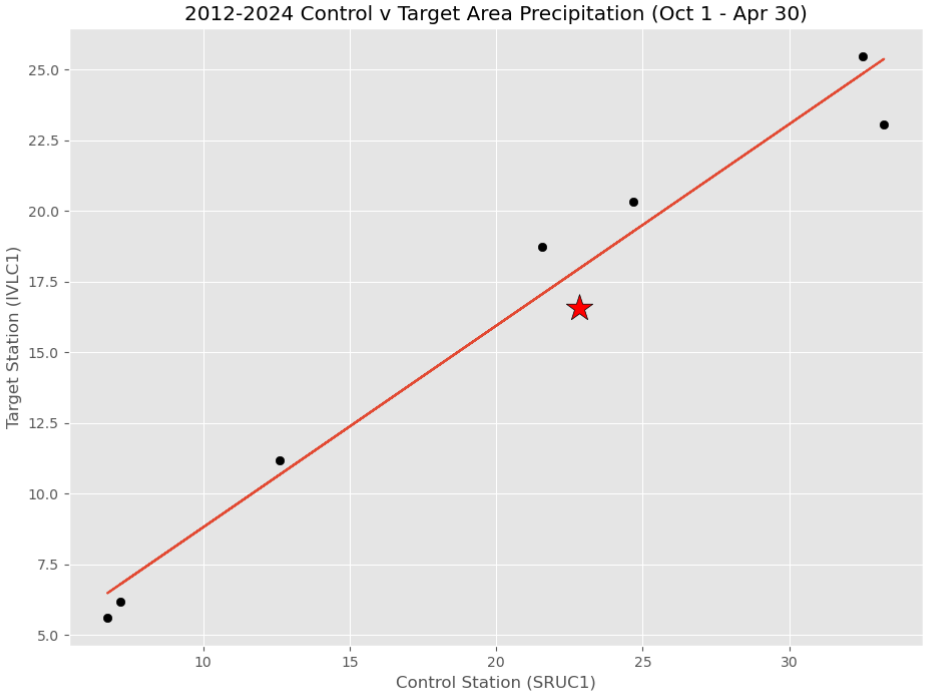


$R^2 = 0.91$

Lytle Creek(2,792')
V
Santa Rosa Plateau (1,105')

Expected precipitation 37.7" observed 31.8"
(-18.5%)

Task 4) Santa Ana Target Upstream Control – Results

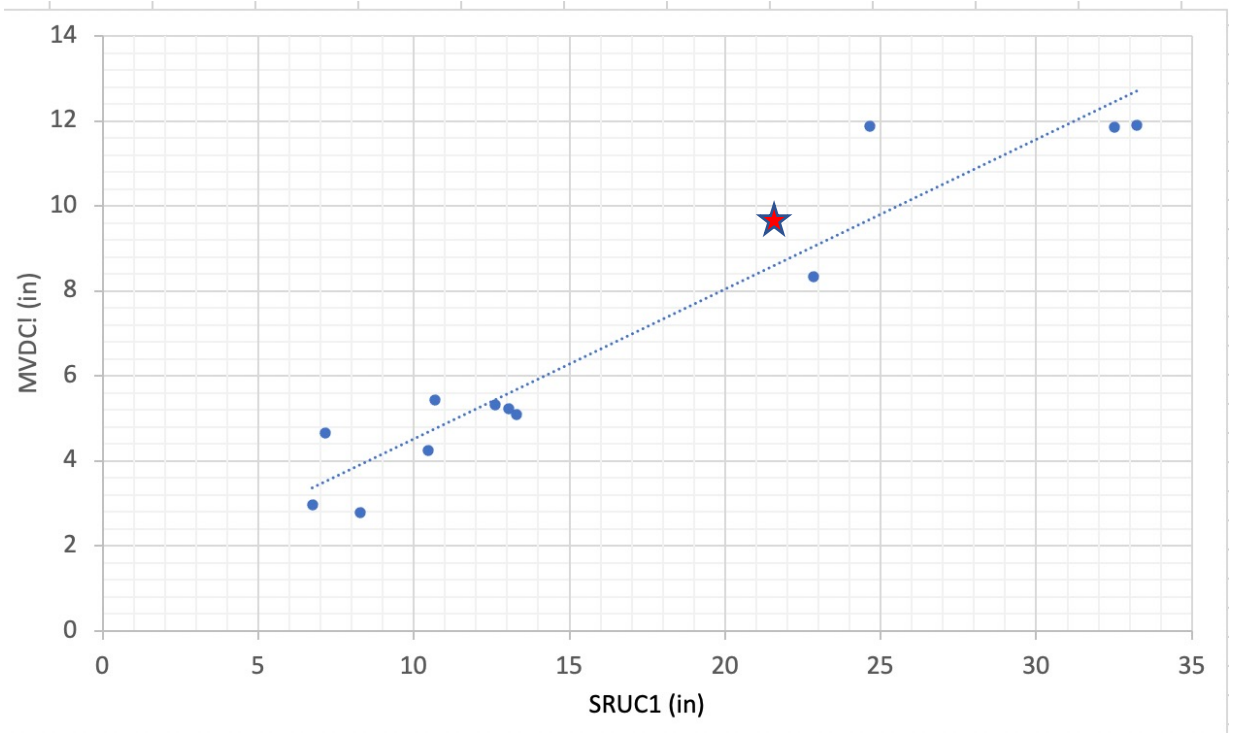


$R^2 = 0.91$

Silverado (4,752’)
V
Santa Rosa Plateau (1,105’)

Expected precipitation 17.7” observed 16.9”
(-4.7%)

Task 4) Target Control – Extra Area Effects



$R^2 = 0.95$

Mojave Dam (3,134')
V
Santa Rosa Plateau (1,105')

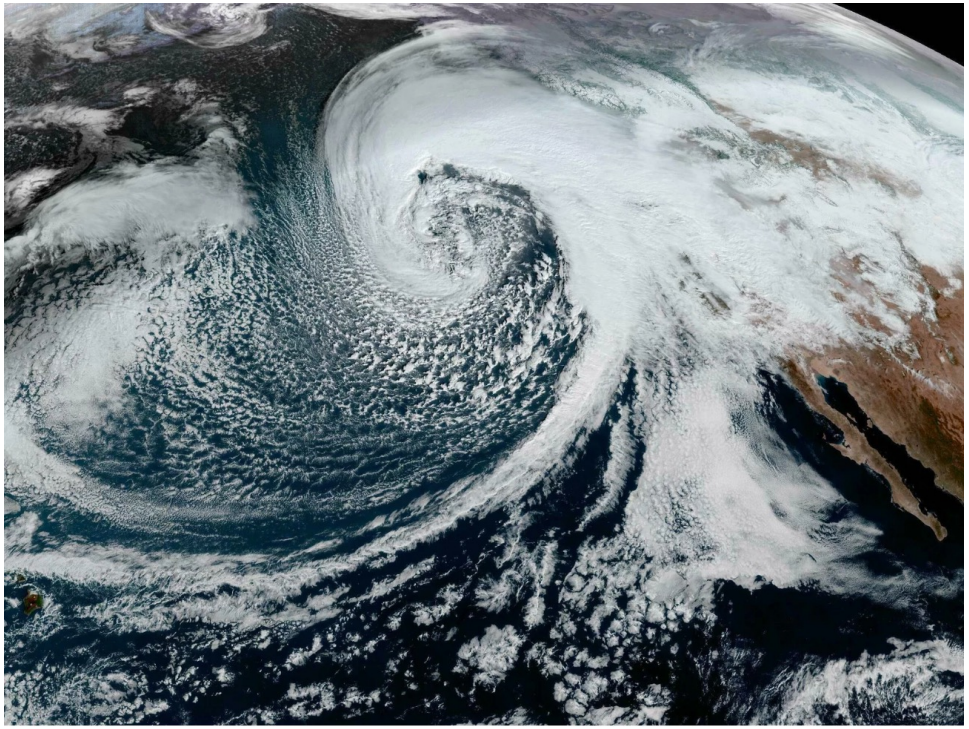
Expected precipitation 8.5" observed 9.6"
(+12.9%)

Task 4) Estimating seeded precipitation Summary

Potential positive seasonal seeding precipitation increases for the Northeast target area and the northern gauge of the Southeast target area.

Neutral to negative seasonal precipitation increases over the Northwest (1 gauge) and the Southeast (limited seeding)

The extra-area gauge suggested a precipitation increase.

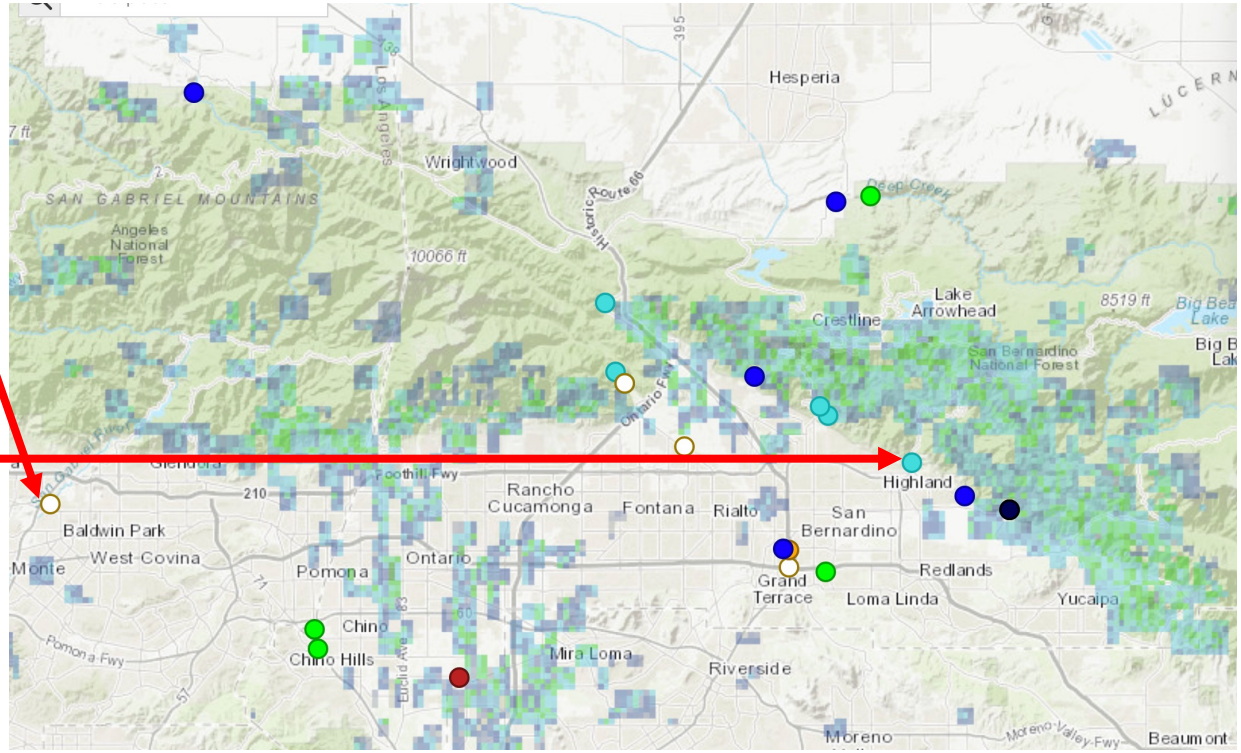


Task 5) Target-Control Runoff Evaluation

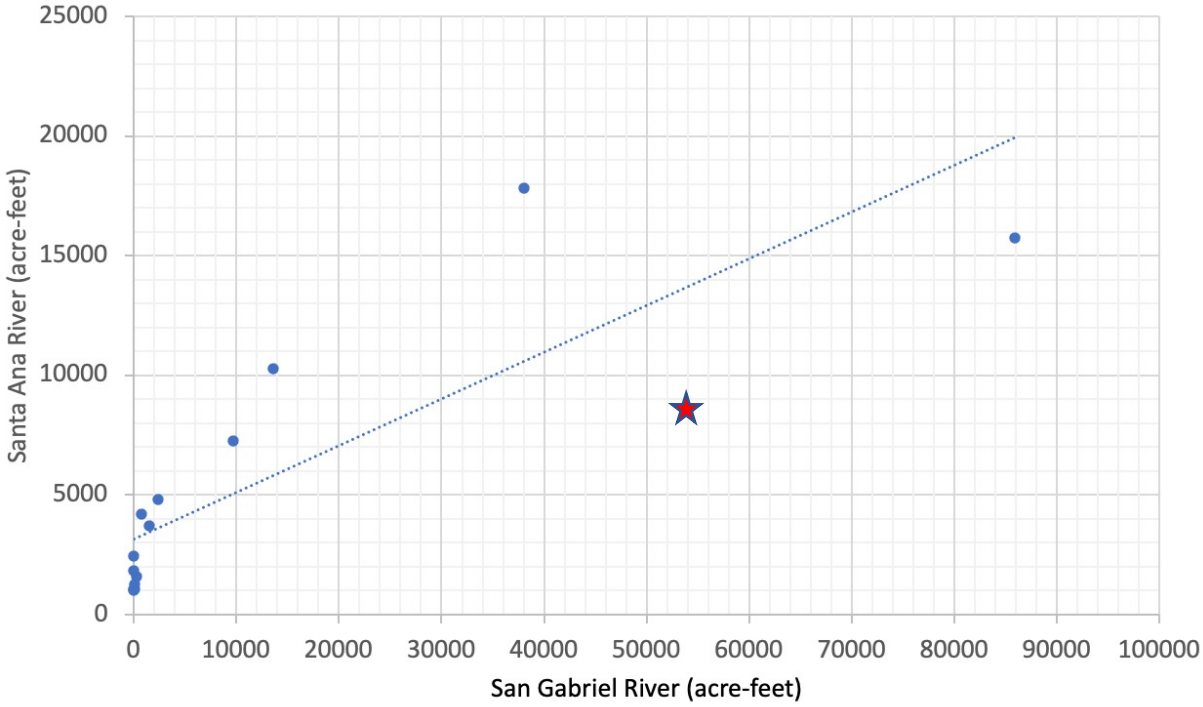
San Gabriel River (Control)

vs.

Santa Ana watershed (Target)
-City C Near Highlands



Task 4) Target Control – Runoff



$R^2 = 0.96$

San Gabriel River Gauge
V
City C Near Highlands Gauge

The expect runoff would have been 13,800 acre ft, This was 5,000 acre-feet below the expected value.
Note: San Gabriel runoff was excessive during very wet years possibly due to full upstream reservoir releases.

Summary

- 13 storms were seeded, with 1,703 generator-hours and 22 flares.
- All time periods with favorable conditions were seeded (outside the early Feb atmos. River).
- The snow chemistry showed mostly low values of seeding material in the assessed snowpack.
- If all seeding time periods were successfully seeded, as much as 29,000 acre-feet of additional precipitation was possible.
- If all seeding time periods where precipitation was measured were successful seeded, as much as 11,000 acre-feet of additional precipitations was possible.
- The precipitation target and upstream control analysis of the seasonal snowpack suggested, the target area gauges had more precipitation than climatologically expected for the most locations.
- The was no evidence of a decrease in precipitation downwind of the project area.
- The streamflow analysis was likely not valid due to the extreme runoff this winter in the control (San Gabriel River).

Thank You/Questions