Evaluation of the Operational Upper Snake River Cloud Seeding Program in Idaho, 2014-2015 Winter Season

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1.0 Introduction

The following report was prepared by Idaho Power following previous reports presented to High Country Resource Conservation and Development Council (HC RC&DC) by the North American Weather Consultants, Inc (NAWC).

This report will provide a discussion on the 2014-2015 winter meteorological conditions in the Upper Snake River Basin and analysis of the performance of cloud seeding operations for the winter 2014-2015 in the Idaho Portion of the Upper Snake River Basin. The analysis will include results and discussions divided into three areas of interest (northern target area April 1st snow water equivalent, northern target December – March precipitation and eastern target area April 1st snow water equivalent) as defined in previous reports from NAWC. This analysis utilizes the regression model coefficients as determined and presented by NAWC. In addition, the report will include a summary/conclusion of seeding performance.

This report will not reiterate background on the seeding program, development of the Target/Control Evaluation Method for the Upper Snake River Basin, nor a review of the individual generators and the times each was operated as in previous reports. Please refer to the previous NAWC reports for questions concerning any of these areas.

2.0 2014-2015 Winter Season Meteorological Conditions

During September and October 2013, once again seasonal forecasts were indicating an increased likelihood of a drier and warmer winter than usual in Idaho due to the projected development of an El Niño in the tropical Pacific Ocean. The El Niño never fully developed and we remained in warm neutral ENSO conditions with conditions leaning closer to El Niño and conditions in eastern Idaho proved to be warmer and drier than normal. This overview summarizes the slowly developing near El Niño, and how Idaho State's winter weather played out in terms of temperature and precipitation anomalies and snowpack.

Figure 1 shows the sea surface temperature (SST) anomalies from January 2006 through March 2015 in the Niño 3.4 region of the equatorial Pacific Ocean. This past winter was classified as neutral, but featured warmer than normal SST anomalies in the Niño 3.4 region.

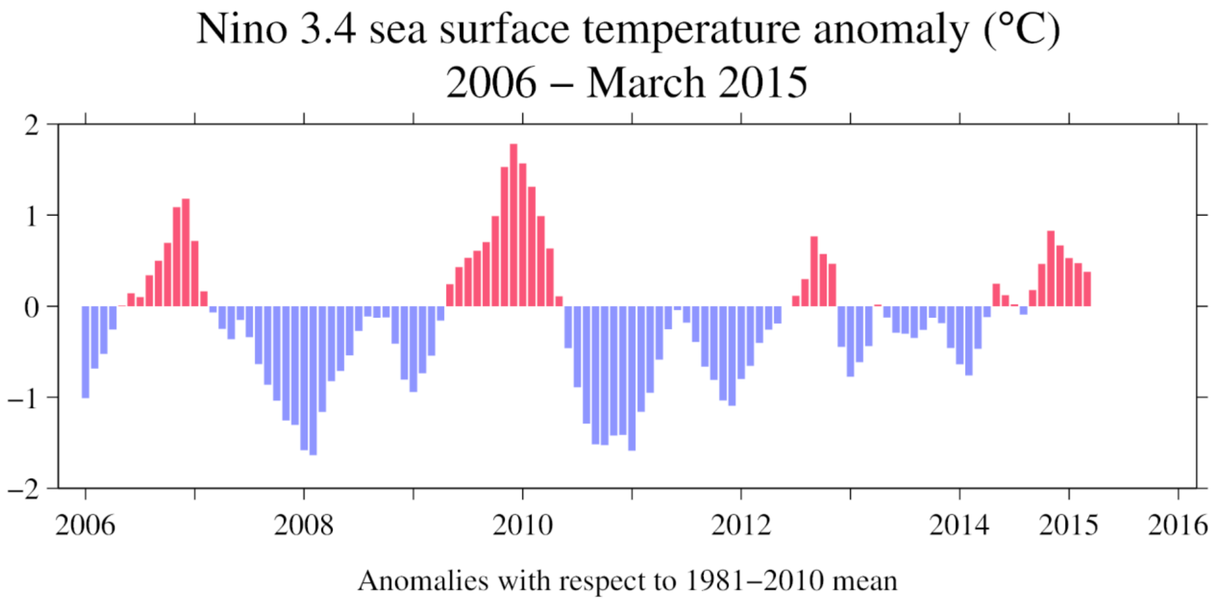

Figure 1: SST anomalies from January 2006 through March 2015 in the Niño 3.4 Region of the tropical Pacific (figure by Todd Mitchell - JISAO).

Neutral ENSO conditions do not provide as systematic of a signal in the temperature and precipitation anomalies for the PNW when compared to either an El Niño or a La Niña event. Figure 2 shows that seasonal precipitation (Oct – Apr) was below normal for most parts of the Eastern Snake River.

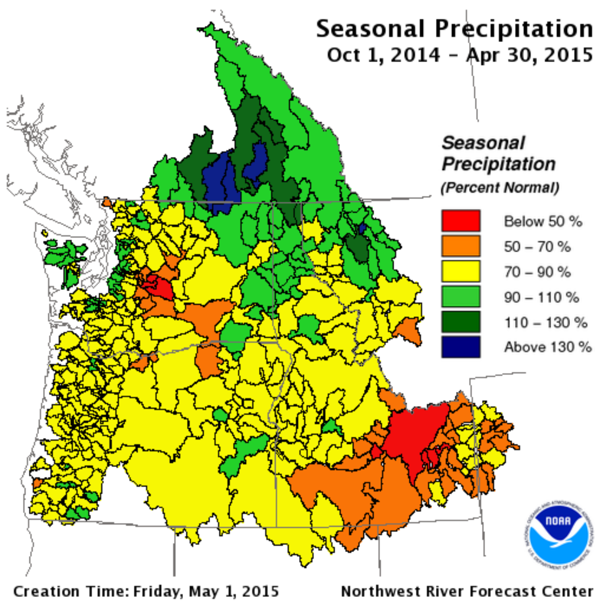

Figure 2: Seasonal Precipitation (Oct1, 2013 – April 30, 2015) for the Pacific Northwest (figure by the Northwest River Forecast Center).

Tables 1 and 2. Table 1 shows the Upper Snake Basins receiving below normal precipitation (average 64%) for the months October to April with November being the only bright month of the period at slightly above normal precipitation. May broke that trend and the Upper Snake Basins saw above 169% of the normal precipitation for that month. The combined effects of the abnormal November through May are shown in Table 2 with the Upper Snake Basins averaging 80% of their normal precipitation. Table 3 shows that the basins saw a mix of above normal and below normal temperatures mixed throughout the period, with an average of +4.67 degrees above normal.

Table 1: Water Year 2015 Monthly Divisions Averages Mean Areal Precipitation
Snake River

	Oct		Nov		Dec		Jan		Feb		Mar		Apr		May	
DIVISION NAME	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM
Henrys Fork River Basin	0.73	36	3.31	109	3.62	103	2.26	63	1.44	56	0.77	26	1.77	73	4.86	151
Upper Snake Tributaries	0.44	23	3.05	108	2.8	94	1.76	54	1.54	64	0.82	29	1.64	68	4.96	169
Upper Snake River Basin abv American Falls Dam	0.39	25	2.38	109	2.31	98	1.39	55	1.11	60	0.58	26	1.18	63	4.51	186
Middle Snake Tributaries	0.67	50	2.09	93	2.91	118	0.95	40	1.41	72	0.73	33	0.85	49	3.05	146
Malheur-Owyhee-Boise River Basins	0.69	65	1.99	110	2.89	141	0.89	46	1.54	101	0.69	38	1.08	76	2.72	166
Payette River Basin	1.54	81	4.48	120	5.36	126	1.98	48	2.51	77	1.43	43	1.24	49	2.36	96
Snake River Basin abv Hells Canyon Dam	0.59	47	2.15	105	2.66	118	1.08	48	1.31	77	0.69	35	0.97	61	3.21	165
Clearwater River Basin	2.46	86	7.07	140	5.09	97	3.68	71	2.95	80	3.59	88	1.37	39	2.25	58
Salmon River Basin	1.38	73	3.73	121	3.67	107	1.83	55	2.26	88	1.61	56	1.41	56	2.55	86
Grande Ronde River Basin	1.36	72	3.57	96	4.54	121	1.69	48	2.32	85	2.01	67	0.95	36	3.73	136
Palouse River Basin	1.03	75	2.68	99	3.1	107	1.79	74	1.78	95	2.86	144	0.71	42	2.04	105
Snake River Basin abv Ice Harbor Dam	0.92	60	2.85	111	3.08	112	1.45	53	1.64	80	1.22	52	1.04	53	2.96	129

Table 2: October 1, 2014 to June 1, 2015 Water Year Precipitation Percent Normal
Snake River

DIVISION NAME	OBSERVED (in)	NORMAL (in)	DEPARTURE (in)	PERCENT of NORMAL
Henrys Fork River Basin	18.8	23.40	-4.60	80
Upper Snake Tributaries	17	21.60	-4.60	79
Upper Snake River Basin abv American Falls Dam	13.8	16.90	-3.10	82
Middle Snake Tributaries	12.7	16.50	-3.80	77
Malheur-Owyhee-Boise River Basins	12.5	13.20	-0.70	94
Payette River Basin	20.9	25.50	-4.60	82
Snake River Basin abv Hells Canyon Dam	12.7	15.00	-2.40	84
Clearwater River Basin	28.5	33.60	-5.10	85
Salmon River Basin	18.4	22.70	-4.30	81
Grande Ronde River Basin	20.2	24.00	-3.80	84
Palouse River Basin	16	16.90	-0.90	95
Snake River Basin abv Ice Harbor Dam	15.1	18.20	-3.00	83

Table 3: Water Year 2015 Monthly Departure from Normal Mean Areal Temperature (Deg F) Snake River

DIVISION NAME	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Henrys Fork River Basin	4.2	-0.2	6.4	7.1	9.4	7.9	2.1
Upper Snake Tributaries	3.5	-0.5	5.3	6.6	7.7	7.2	1.8
Upper Snake River Basin abv American Falls Dam	3.5	-1.1	5.4	5.8	8.3	6.7	1
Middle Snake Tributaries	4.4	-0.7	4.9	5.8	8.4	6.9	1
Malheur-Owyhee-Boise River Basins	3.3	-1.5	4.1	4.6	6.8	5.1	-0.5
Payette River Basin	3.9	-0.6	5.6	5.5	8.5	5.9	0.8
Snake River Basin abv Hells Canyon Dam	3.7	-1.3	4.9	5.2	7.7	5.8	0.2
Clearwater River Basin	5.7	-0.3	4.9	6.9	7	6.4	1.6
Salmon River Basin	5.3	-0.4	4.5	6.9	8.1	7.1	1.6
Grande Ronde River Basin	5.5	-0.9	4.5	7.9	7.4	6.1	0.4
Palouse River Basin	4.2	-3.2	2.4	3.3	5.2	3.8	-0.9
Snake River Basin abv Ice Harbor Dam	4.3	-1.1	4.7	5.6	7.6	6	0.5

3.0 Results and recommendations for new analysis

As in the previous reports provided by the NAWCs and IPC, two types of analysis were completed for each target area. The first analysis was a simple linear regression where the average value from the control sites was regressed against the average value from the target sites to produce a regression coefficient plus an intercept value. Second analysis conducted was a multiple linear regression where multiple control site values were regressed against the average value of the target sites to produce multiple regression coefficients plus an intercept value. The results for each analysis are shown for the 2014-2015 winter season as well as the average result for the water years 1997 through 2015.

The analysis work completed by NAWC provided a good representation of the benefits that cloud seeding provided in the eastern Snake River prior to cloud seeding operations beginning in the Boise and Wood River basins in the 2013-2014 season. Based upon computer modeling being conducted by the National Center for Atmospheric Research (NCAR) for Idaho Power, it appears that using the previously established target/control analysis conducted by NAWC is no longer valid as the control sites are likely now being augmented by the operations in the Boise and Wood basins. The changes in the control sites, likely make analysis indicate negative seeding effects at the target sites. The effect is caused by a change in the regression relationships established by NAWC due to increased snowfall at the control sites from cloud seeding.

Through additional analysis, it is recommended that the target/control analysis be reestablished using sites not affected by other cloud seeding operations.

Sections 3.1 through 3.4 provide the results of the NAWC designed target control, without modification. Sections 3.5 through 3.6 provides suggested changes in the target control analysis and results for the 2014-2015 season, if those changes are accepted.

3.1 Equations used

The following equations were extracted from the NAWC Evaluation of the Operational Upper Snake River Cloud Seeding Program in Idaho, 2011-2012 Winter Season report.

North Target, April 1st Snow Water Equivalent

Linear: $Y = 3.422523 + 1.049539(X_1)$

Multiple Linear: $Y = 3.62875068 + 0.535530397(X_1) + 0.103707666(X_2) + 0.191589827(X_3) + 0.189297403(X_4) + 0.034293647(X_5)$

North Target, December – March Precipitation

Linear: $Y = 3.922858+ 1.049187(X_1)$

Multiple Linear: $Y = 4.503407639 + 0.564441873(X_1) + 0.208982316 (X_2) + 0.206228981(X_3) + 0.1215289(X_4)$

East Target, April 1st Snow Water Equivalent

Linear: $Y = 2.420452 + 1.045792(X_1)$

Multiple Linear: $Y = 2.822263341 + 0.295055937(X_1) + 0.281113544(X_2) + 0.245711416(X_3) + 0.15418512(X_4)$

3.2 North Target, April 1st Snow Water Equivalent

The simple linear regression technique predicted 8.17 inches of SWE with an observed SWE value of 8.03 inches. A ratio of predicted SWE to observed SWE of 0.98 with an observed SWE minus predicted SWE of -0.14 inches. This indicates a **-1.67% decrease** in SWE. The multiple linear regression technique predicted 8.68 inches of SWE with an observed SWE value of 8.03 inches. A ratio of predicted SWE to observed SWE of 0.93 with an observed SWE minus predicted SWE of -0.65 inches. This indicates a **-7.45% decrease** in SWE.

Looking at the averaged simple linear regression predicted value of 14.92 inches of SWE with an averaged observed SWE value of 15.09 inches. A ratio of average predicted SWE to average observed SWE of 1.01 with an observed SWE minus predicted SWE of 0.17 inches. This indicates an average **1.16% increase** in SWE over the 19 years (1997-2015). The multiple linear regression technique average predicted 14.76 inches of SWE with an average observed SWE value of 15.49. A ratio of predicted SWE to observed SWE of 1.02 with an observed SWE minus predicted SWE of 0.33 inches. This indicates an average **2.25% increase** in SWE over the 19 years (1997-2015).

Table 4 shows the results for the North Target area April 1st SWE

3.3 North Target, December – March Precipitation

The simple linear regression technique predicted 11.63 inches of precipitation with an observed precipitation value of 7.35 inches. A ratio of predicted precipitation to observed precipitation of 0.68 with an observed precipitation minus predicted precipitation of -3.70 inches. This indicates a **31.81% decrease** in precipitation. The multiple linear regression technique predicted 11.70 inches of precipitation with an observed precipitation value of 7.93 inches. A ratio of predicted precipitation to observed precipitation of 0.68 with an observed precipitation minus predicted precipitation of -3.76 inches. This indicates a **-32.18% decrease** in precipitation.

Looking at the averaged simple linear regression predicted value of 14.60 inches of precipitation with an averaged observed precipitation value of 14.52 inches. A ratio of average predicted precipitation to average observed precipitation of 0.99 with an observed precipitation minus predicted precipitation of -0.09 inches. This indicates an average **-0.60% decrease** in precipitation over the 19 years (1997-2015). The multiple linear regression technique average predicted 14.39 inches of precipitation with an average observed precipitation value of 14.52. A ratio of predicted precipitation to observed precipitation of 1.01 with an observed precipitation minus predicted precipitation of 0.12 inches. This indicates an average **0.87% increase** in precipitation over the 19 years (1997-2015).

Note: Looking at past analysis and the associated regression skill, it was suggested last year to no longer complete this analysis, as it does not seem to reasonably represent the conditions that occurred in the region. In future reports, this will not be computed.

Table 5 shows the results for the North Target area December – March Precipitation

3.4 East Target, April 1st Snow Water Equivalent

The simple linear regression technique predicted 7.99 inches of SWE with an observed SWE value of 8.33 inches. A ratio of predicted SWE to observed SWE of 1.04 with an observed SWE minus predicted SWE of 0.34 inches. This indicates a **4.28% increase** in SWE. The multiple linear regression technique predicted 8.06 inches of SWE with an observed SWE value of 8.33 inches. A ratio of predicted SWE to observed SWE of 1.03 with an observed SWE minus predicted SWE of 0.27 inches. This indicates a **3.37% increase** in SWE.

Looking at the averaged simple linear regression predicted value of 13.42 inches of SWE with an averaged observed SWE value of 14.64 inches. A ratio of average predicted SWE to average observed SWE of 1.09 with an observed SWE minus predicted SWE of 1.22 inches. This indicates an average **9.07% increase** in SWE over the 18 years (1997-2014). The multiple linear regression technique average predicted 13.45 inches of SWE with an average observed SWE value of 14.64. A ratio of predicted SWE to observed SWE of 1.19 with an observed SWE minus predicted SWE of 1.19 inches. This indicates an average **8.8% increase** in SWE over the 18 years (1997-2014).

Table 6 shows the results for the North Target area April 1st SWE

Table 4: Results for North Target April 1st Snow Water Equivalent

Target	Predicted Apr 1st SWE	Observed Apr 1st SWE	Ratio Predicted/Observed SWE	Observed minus Predicted SWE (inches)	Percent Differences
Linear Regression WY 2015	8.17	8.03	0.98	-0.14	-1.67%
Linear Regression WY 1997 - 2015	14.92	15.09	1.01	0.17	1.16%
Multiple Linear Regression WY 2015	8.68	8.03	0.93	-0.67	-7.45%
Multiple Linear Regression WY 1997 - 2015	14.76	15.09	1.02	0.33	2.25%

Table 5: Results for North Target, December - March Precipitation

Target	Predicted Apr 1st SWE	Observed Apr 1st SWE	Ratio Predicted/Observed SWE	Observed minus Predicted SWE (inches)	Percent Differences
Linear Regression WY 2015	11.63	7.93	0.68	-3.70	-31.81%
Linear Regression WY 1997 - 2015	14.60	14.52	0.99	-0.09	-0.60%
Multiple Linear Regression WY 2015	11.70	7.93	0.68	-3.76	-32.18%
Multiple Linear Regression WY 1997 - 2015	14.39	14.52	1.01	0.12	0.87%

Table 6: Results for East Target, April 1st Snow Water Equivalent

Target	Predicted Apr 1st SWE	Observed Apr 1st SWE	Ratio Predicted/Observed SWE	Observed minus Predicted SWE (inches)	Percent Differences
Linear Regression WY 2015	7.99	8.33	1.04	0.34	4.28%
Linear Regression WY 1997 - 2015	13.42	14.64	1.09	1.22	9.07%
Multiple Linear Regression WY 2015	8.06	8.33	1.03	0.27	3.37%
Multiple Linear Regression WY 1997 - 2015	13.45	14.64	1.09	1.19	8.83%

3.5 Suggested target control sites

Figure 3 shows the original target control sites and suggested new sites to replace the original sites. As easily seen in the figure, some of the original North control sites sit within close proximity to the Wood River basin, and the remainder of the North and all of the East control sites are directly downwind of the Payette, Boise and Wood Basins and their respective cloud seeding operations. Developing these new sites into a well-developed target control analysis will require additional work to robustly test the analysis, but results from this preliminary analysis is presented in section 3.6 for comparison.

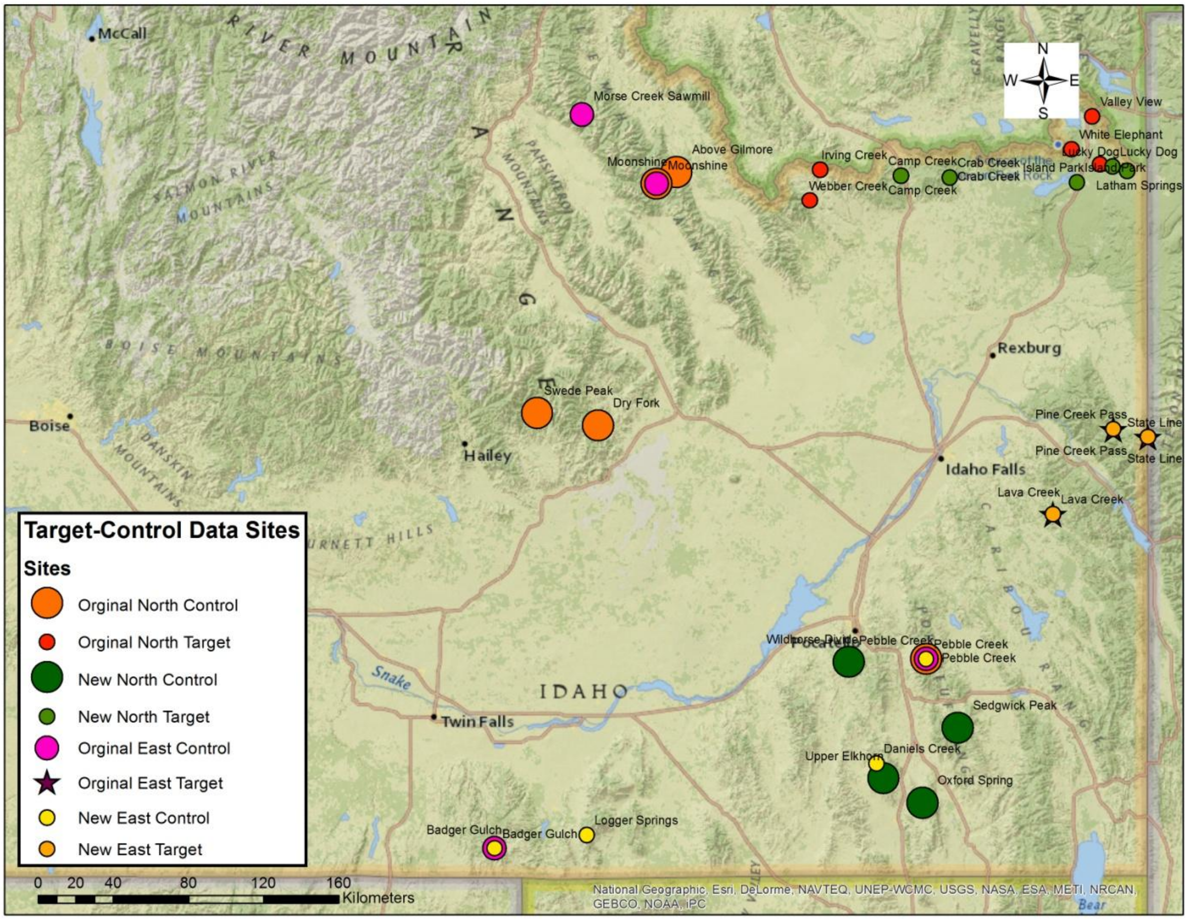

Figure 3: Original and suggested new target control site locations

3.6 New target control analysis results

Tables 7 and 8 show the results indicated by the new Target Control analysis. More work needs to be completed on the suggested analysis before completely replacing the established analysis.

Table 7: Results for North Target April 1st Snow Water Equivalent Using New Target Control Sites

Target	Predicted Apr 1st SWE	Observed Apr 1st SWE	Ratio Predicted/Observed	Observed minus Predicted SWE (inches)	Percent Differences
Linear Regression WY 2015	9.14	9.22	1.01	0.08	0.91%
Linear Regression WY 1997 - 2015	15.73	16.09	1.02	0.35	2.25%
Multiple Linear Regression WY 2015	9.01	9.22	1.02	0.21	2.37%
Multiple Linear Regression WY 1997 - 2015	15.86	16.09	1.01	0.23	1.46%

Table 8: Results for East Target, April 1st Snow Water Equivalent Using New Target Control Sites

Target	Predicted Apr 1st SWE	Observed Apr 1st SWE	Ratio Predicted/Observed SWE	Observed minus Predicted SWE (inches)	Percent Differences
Linear Regression WY 2015	8.00	8.17	1.02	0.17	2.08%
Linear Regression WY 1997 - 2015	13.19	14.29	1.08	1.10	8.37%
Multiple Linear Regression WY 2015	8.07	8.17	1.01	0.10	1.21%
Multiple Linear Regression WY 1997 - 2015	13.24	14.29	1.08	1.05	7.93%

4.0 Discussion

This analysis is based upon previous work of the North American Weather Consultants, Inc as presented in their annual reports to The High Country Resource Conservation and Development Council. Methods employed are taken from these previous results and applied without modification. This analysis shows little to no positive effects from cloud seeding in the North area for April 1st SWE. The NAWC analysis indicates a **9.07% increase** for the linear regression and **8.83% increase** for the multiple linear regression for the eastern target area.

The analysis from the new target control indicates a **0.91% increase** for the linear regression and **2.37% increase** for the multiple linear regression for the northern target area, additionally the eastern target area indicated a **<u>2.08% increase</u>** for the linear regression and **<u>1.21% increase</u>** for the multiple linear regression.

Looking at the 19 year (1997-2015) averaged values, there is little difference between the two methods, with both linear and multiple-linear regressions indicating **~2.0% increase** in the northern target area and **~8.5% increase** in the eastern target area for the duration of the project.

Conclusion

Conditions throughout the season were not as favorable for cloud seeding as seen in previous years, with temperatures being significantly higher than normal. These higher than normal conditions prevented the use of ground based generators during significant stretches of the seasons (** many times conditions would have been favorable for aircraft operations when not favorable for ground based operations). While conditions were not as favorable as desired, both sets of analysis indicated good results in the eastern target area. The northern area results was a mixed bag with the NAWC analysis indicating negative effects from the program and the new target control indicated mild increase. The location of two of the NAWC control sites being right on the edge of the Wood River cloud seeding operations likely skewed these results and are what prompted us to look at the development of a new/updated target control analysis.