Target/Control Evaluation of the Central Colorado Mountains River Basin Winter Cloud Seeding Program

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EXECUTIVE SUMMARY

The Central Colorado Mountains River Basin Program (CCMRBP) has been evaluated by North American Weather Consultants using target/control regression equations that are typical of those applied to other cloud seeding programs of this type. These regression equations are based on two different types of SNOTEL measurements: ***snow water content*** (SWE) and ***accumulation water year precipitation***. The 2020-21 season brought generally below normal precipitation and snowpack to central Colorado, although amounts were quite variable regionally. For the 2020-21 season, linear and multiple linear target/control evaluations yielded observed/predicted ratios of 1.03 and 1.01 for SNOTEL precipitation, respectively. Similar snowpack evaluations yielded ratios of 1.14 and 0.95 for SNOTEL snow, respectively. Two other types of snowpack evaluations yielded ratios ranging between 1.04 and 1.08. These numbers are suggestive of precipitation and snowpack increases that may reasonably be attributed to seeding operations. It is important to keep in mind that single-season results are subject to high variability in natural precipitation patterns, as well as other factors, and do not carry the same statistical significance as the long-term results. The long-term results (summarized on page 4-4 of the report) are suggestive of 2-5% increases in precipitation and snowpack due to seeding operations in this program. These composite results have been relatively consistent over time and carry much more significance than single season results.

1.0 INTRODUCTION AND BACKGROUND

A Weather Modification Act (Article 20) was enacted by the State of Colorado in 1972, regulating operational cloud seeding programs. This Act has gone through various amendments and a sunset review in 2011. These rules and regulations were revised in 2012 becoming effective on July 1, 2012. The 2012 revised rules and regulations for annual reports state: "The permit holder must compile annual reports in accordance with section 36-20-117(3), C.R.S. (2011). Annual reporting for ground-based winter operations shall include, at a minimum, target versus control analysis of precipitation or snow water equivalent. The permit holder must provide the Director with a written annual report that evaluates the weather modification operation within 90 days of concluding its operations season." The goal of these seeding programs is to increase the natural snowpack accumulation in the target areas.

1.1 The Winter Cloud Seeding Program in the Upper Colorado River Basin

A consortium of water users organized and financially supported winter cloud seeding in the Upper Colorado River Basin. The first season of seeding operations took place during the 2012 water year, with additional seasons of seeding operations through the 2021 water year. This project is being referred to as the Central Colorado Mountains River Basin Program (CCMRBP). Seeding evaluations in this report also include a couple of previous seasons (2003 and 2004 water years) with significant seeding operations in these same areas, in order to include as many seeded seasons as possible. Figures 1.1 and 1.2, maps obtained from Western Weather Consultants, show the target area and seeding site locations. Seeding operations were conducted during the November - March period during the 2020-21 season.

The Colorado River Water Conservation District acts as the fiscal and administrative representative of the Central Colorado Mountains River Basin Program (CCMRBP). Ground based silver iodide generators is the seeding method employed for this program.

1.2 Addition of Water Year 2021 Results to Earlier Study

NAWC, in its initial proposal, offered as an option an annual updating of the estimated results of the CCMRBP following the completion of each operational season. This option was subsequently exercised for the 2014 - 2020 water years. This report is submitted to fulfill a similar contract for the 2021 water year.

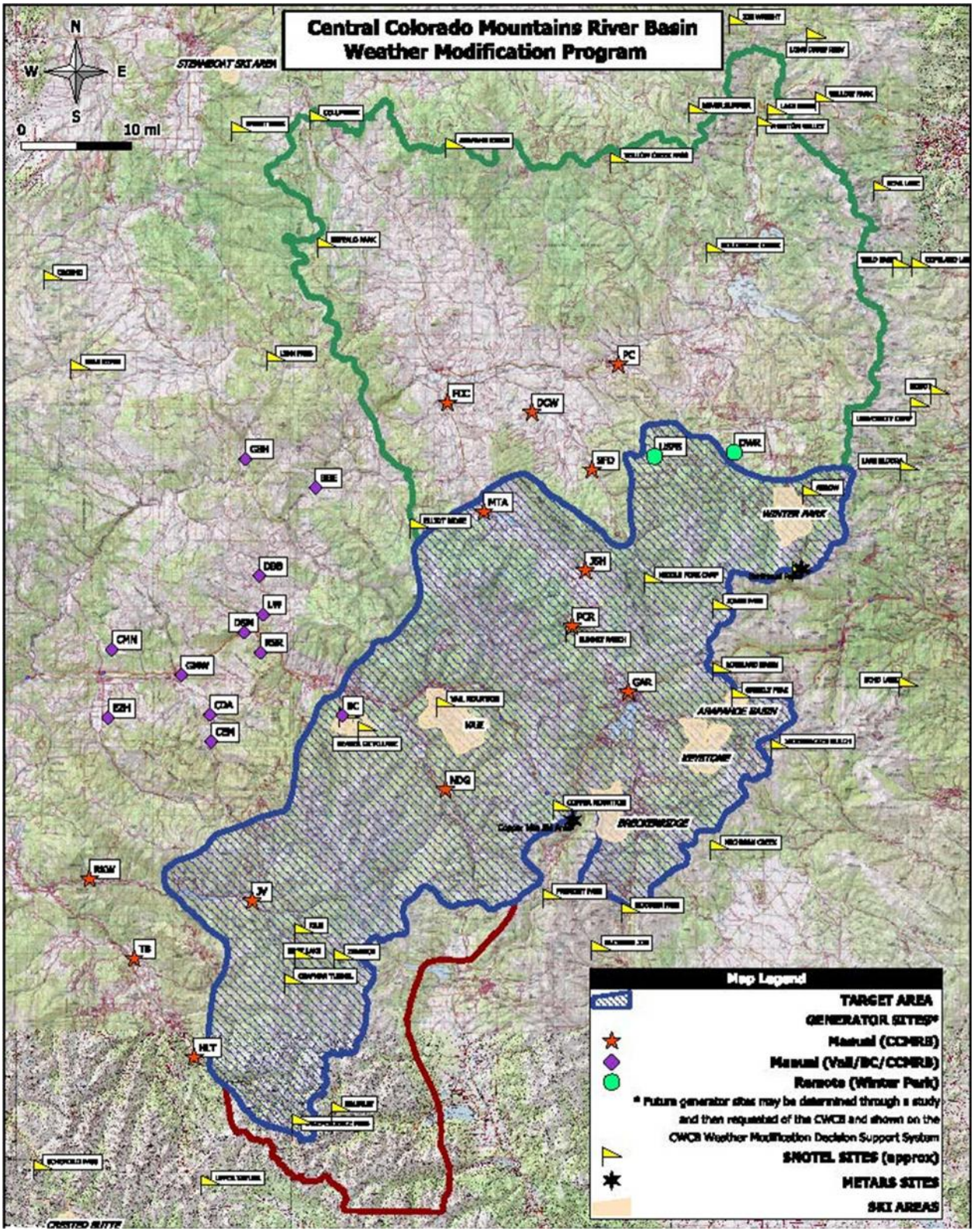

Figure 1.1 Central Colorado Mountains River Basin Weather Modification Program, including target area and seeding sites

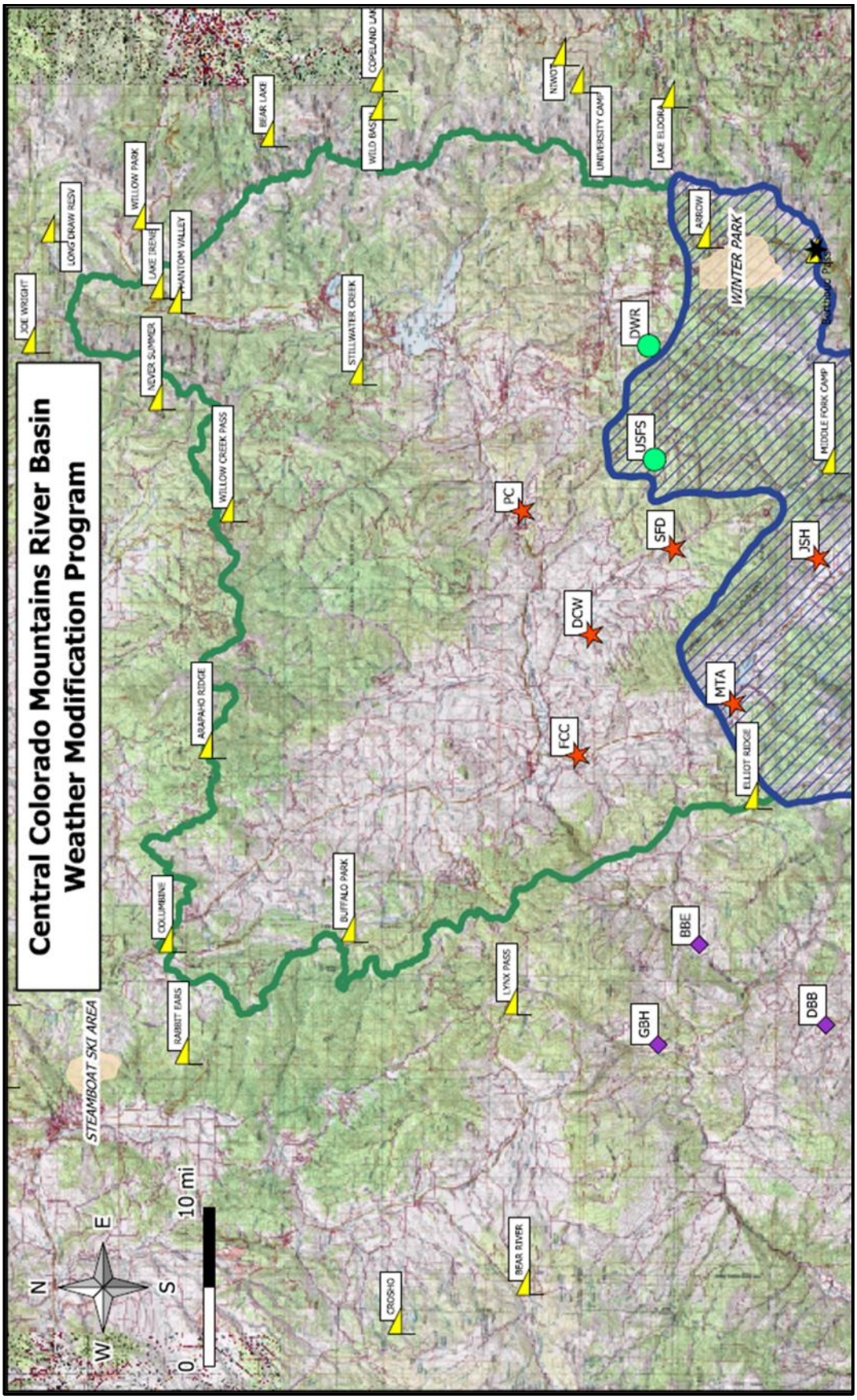

Figure 1.2a Northern half of the map in Figure 1.1, showing more detail

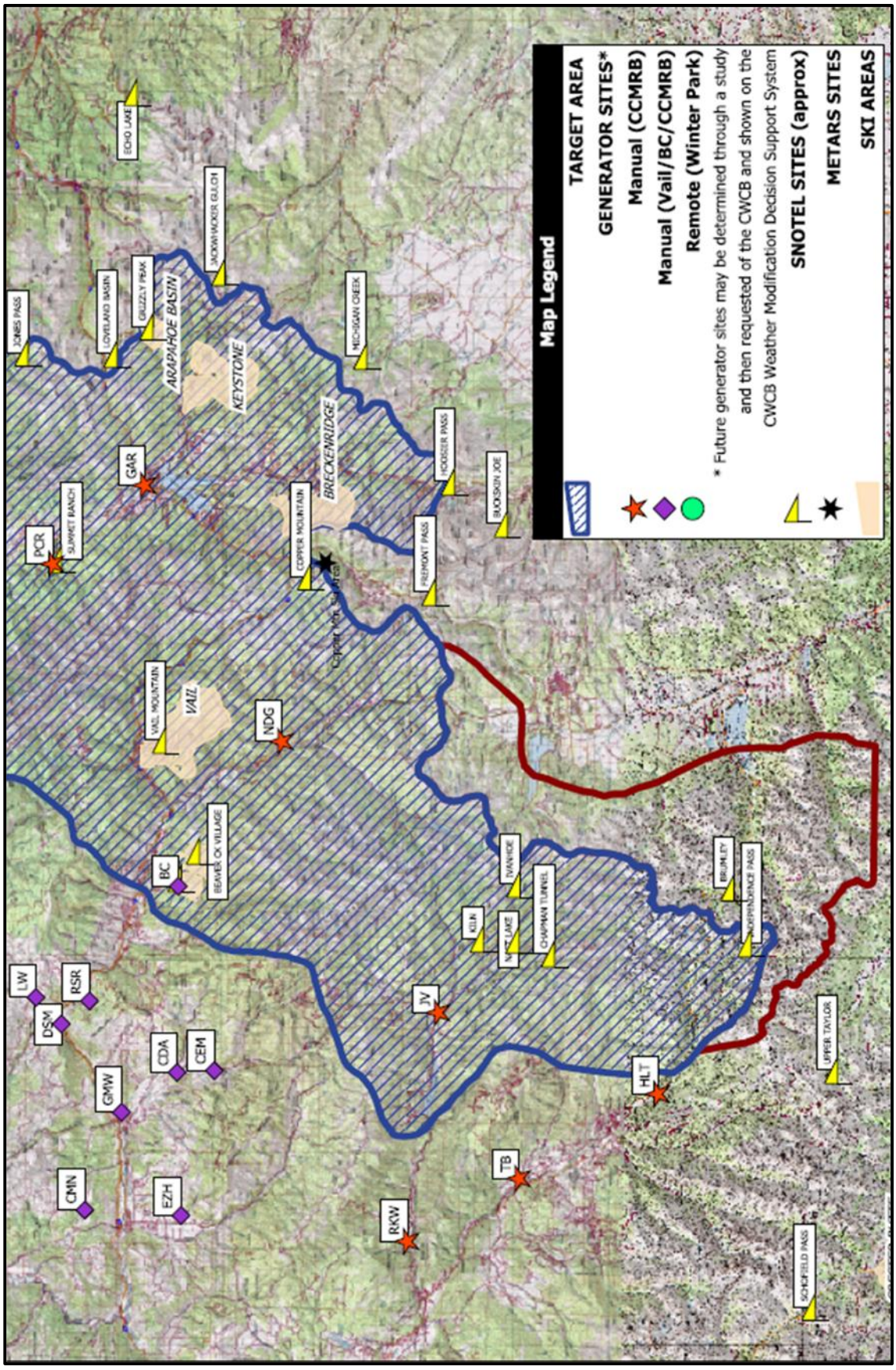

Figure 1.2b Southern half of the map in Figure 1.1, showing more detail

2.0 SUMMARY OF REGRESSION EQUATION DEVELOPMENT

This section provides a short summary of the work done on the original report which was delivered to GRC in May 2013 (Griffith and Yorty, 2013). This summary includes: 1) a background on the target/control evaluation approach, 2) selection of target and control sites, and 3) development of regression equations.

The historical target/control evaluation approach (Dennis, 1980) is a target and control comparison in which a "control area" is selected such that it should not be impacted by cloud seeding. The selection of target and control sites is ideally made prior to the beginning of seeding operations. A historical period is selected during which regression analyses can relate measurements such as precipitation, snow water equivalent, or streamflow to similar measurements in the "target area."

There are two basic precipitation measurement types at SNOTEL sites in the mountainous western U.S.: ***snow water content*** (SWE), which is the weight of the snow currently on the snow "pillow" (flat measurement surface at the site). This value fluctuates up and down with time as snow falls or melts. The other is a ***precipitation*** gauge measurement, the liquid equivalent of all precipitation, whether it falls as rain or snow. This latter measurement gauge accumulates the total water year precipitation beginning October 1. Most of these mountain sites essentially receive all snow in the winter season, but the numbers between the two measurements can differ due to either snow melt occurring, or precipitation gauge catch efficiency being less than 100%, or factors affecting the amount of snow that accumulates on the snow pillow (such as drifting, etc).

The historical regression period for developing the equations should exclude any periods with previous seeding in either the control or target areas. These regression relationships are then used to predict the amount of natural precipitation, etc., in the target area during seeding periods (from the control area measurements) for comparison to the observed precipitation in the target area. Results are often stated as a ratio of actual/predicted amounts. Ratios greater than 1.0 suggest an increase in precipitation or snow water content that may be attributed to the cloud seeding activities. The confidence in relating ratios greater than 1.0 to the seeding activities becomes more significant with increasing numbers of seeded seasons that maintain an average ratio greater than 1.0.

NAWC developed comprehensive data sets of precipitation and SWE observations for numerous official reporting sites (primarily from the Natural Resources Conservation Service [NRCS]) from western Colorado and some surrounding states. NAWC also developed a list of all historical seeding programs in the state of Colorado dating back to 1960. Individual sites were then considered for inclusion as either a target or control site. The desire was to develop data sets with as long as possible historical periods before any seeding in the target area. Some possible control sites were eliminated from consideration due to possible "contamination" from earlier cloud seeding programs. Detailed quality control procedures were then applied to all potential target or control sites which resulted in the removal of several potential target and control sites from consideration. A group of target sites was then established. Different control sites (as well as groupings of control sites) were then correlated with these target sites using linear and

multiple-linear regression techniques. The goal was to select those control sites that yielded the highest correlations with the target sites.

Linear and multiple-linear regressions based upon November – March precipitation and March 1st snow water content were developed, with the goal of obtaining the best correlations for each set of data. These sets include Snow Telemetry (SNOTEL) November through March precipitation (Section 2.1); SNOTEL-only SWE for March 1 (Section 2.2); long-term snow evaluation with mixed data types (Section 2.3); and a long-term snow evaluation using only the still active snow course sites, March 1 data (Section 2.4). March 1 SWE was used due to the greater frequency of snow melt problems that can impact the SWE values after this date, in spite of the fact that the seeding program continues through early April. For each of these data sets both a linear and multiple linear regression equation was developed, resulting in a total of 8 regression equations. These equations were developed considering only historical data (that prior to any seeding), with the seeded-season data evaluated after the fact, to avoid any bias. It would have been more desirable to develop these equations prior to any seeding activities but that was not possible in this situation. This proposed final set of target and control sites and the resulting regression equations were finalized in February 2013. NAWC then applied these equations, summarized in the following sections, to the seeded seasons in order to provide estimates of the effects of the seeding up through the current season. The results are presented in Section 3.0. Appendix A contains the detailed historical and seeded data in each of these equations, from which the results are derived.

Figures 2.1 and 2.2 show the locations of the target and control sites, respectively. Site data is listed in Tables 2-1 and 2-2 corresponding to the labels on the maps. These tables also indicate which evaluation type(s) each site is associated with. Appendix A contains the various control and target site data utilized by the equations shown in this section of the report. The regression equations are based on the historical (non-seeded) season portion of this data, and the results (shown in Section 3.0) are based on the corresponding data for the seeded seasons. The observed/predicted ratios shown in the report are based on the corresponding columns as shown in the appendix, e.g., dividing the observed target area average values by those predicted by the equation.

The following section of the report (Section 3.0) contains some graphs to help the reader visualize the historical (non-seeded) data contained in the linear regression equations, in comparison to the later seeded data on which the evaluation results are based.

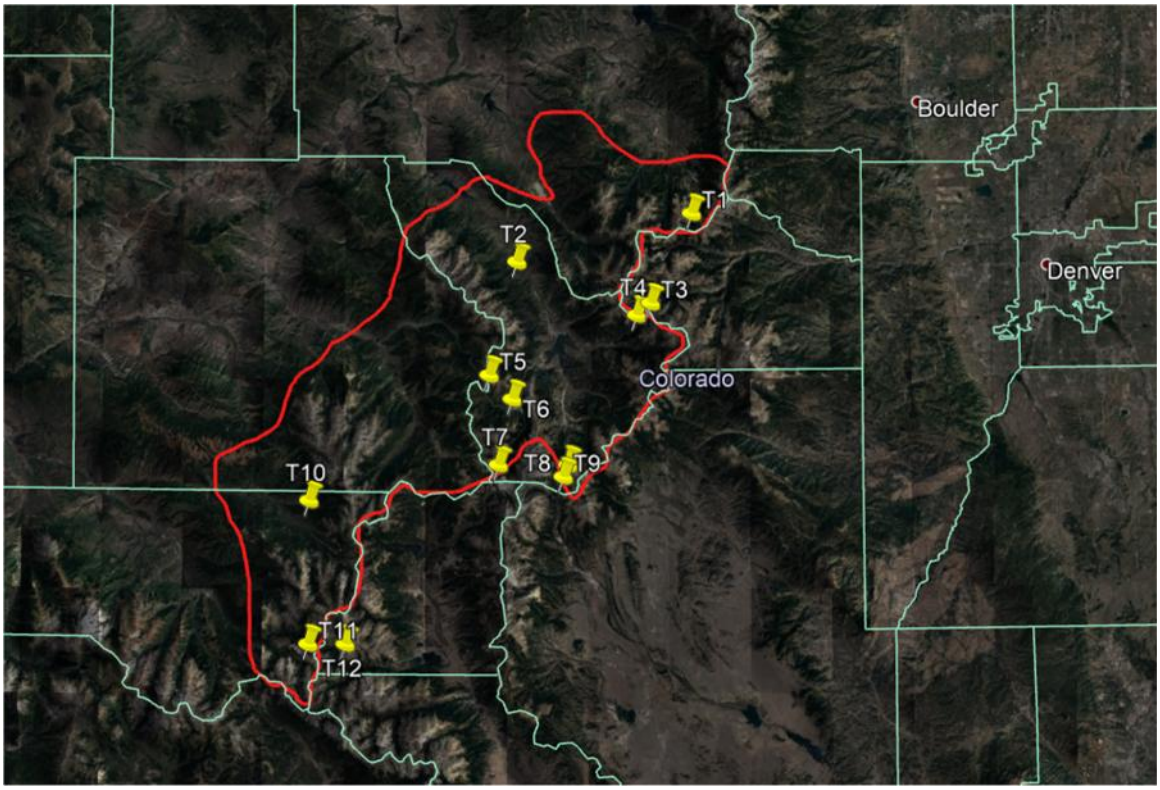

Figure 2.1 Map of target area and target sites (site numbers correspond to Table 2-1)

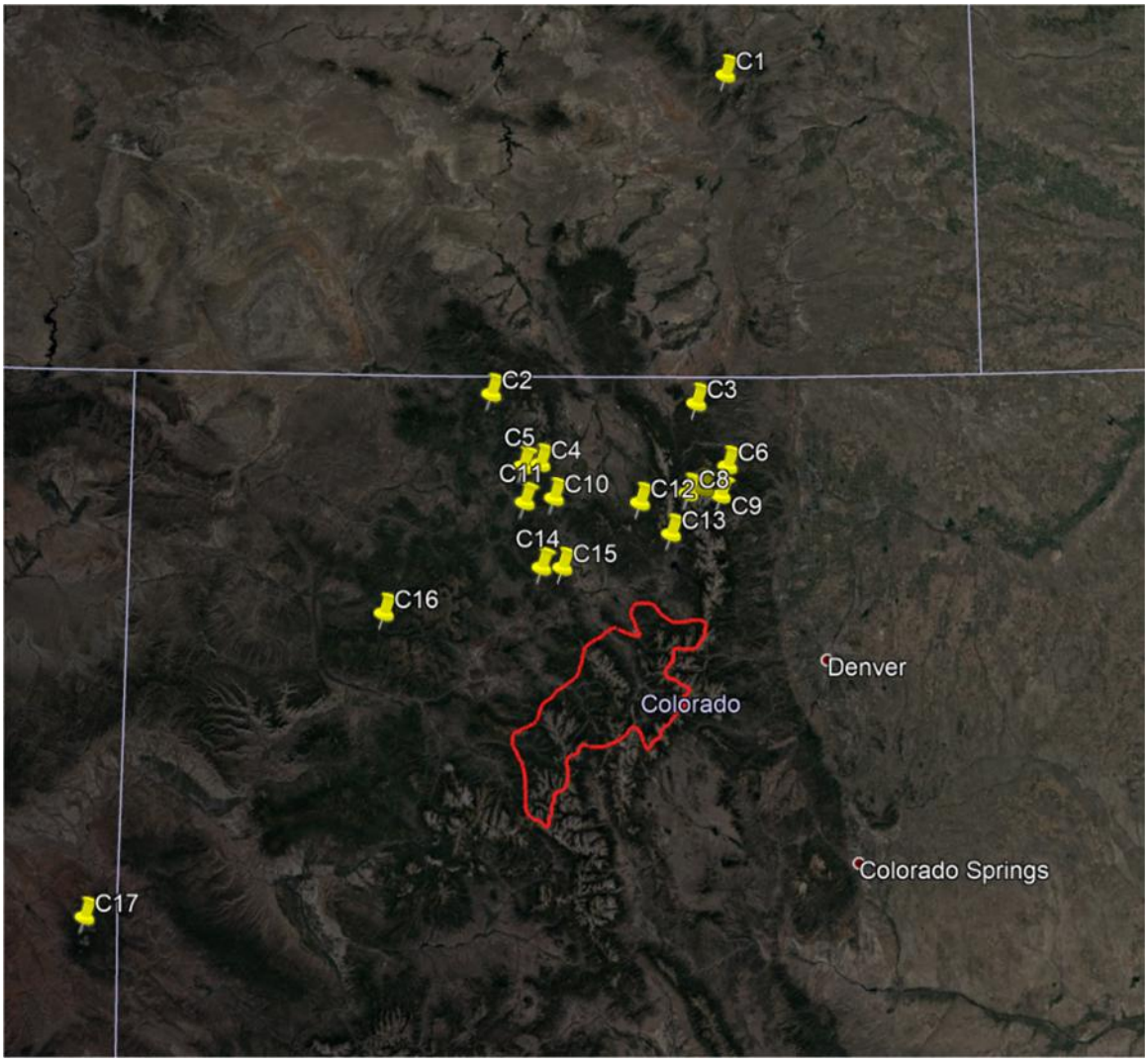

Figure 2.2 Map of control sites (site numbers correspond to Table 2-2)

Table 2-1 Target Sites for Central Colorado Program Evaluation
Evaluation types: P = SNOTEL precipitation; S = SNOTEL snow; M = mixed snow evaluation; SC = snow course evaluation

Map Ref	Site Name	Latitude (deg)	Longitude (deg)	Elevation (ft)	Eval Type
T1	Berthoud Summit	39.80	-105.78	11300	P, S
T2	Summit Ranch	39.72	-106.16	9400	P, S
T3	Grizzly Peak	39.65	-105.87	11100	P, S
T4	Snake River	39.63	-105.90	10000	M, SC
T5	Shrine Pass	39.53	-106.22	10700	M, SC
T6	Copper Mountain	39.49	-106.17	10550	P, S
T7	Fremont Pass	39.38	-106.20	11400	P, S, M
T8	Blue River	39.38	-106.05	10500	SC
T9	Hoosier Pass	39.36	-106.06	11400	P, S, M
T10	Kiln	39.32	-106.61	9600	P, S
T11	Independence Pass	39.08	-106.61	10600	P, S, M
T12	Twin Lakes Tunnel	39.08	-106.53	10450	M, SC

Table 2-2 Control Sites for Central Colorado Program Evaluation
Evaluation types: P = SNOTEL precipitation; S = SNOTEL snow; M = mixed snow evaluation; SC = snow course evaluation

Map Ref	Site Name	Latitude (deg)	Longitude (deg)	Elevation (ft)	Eval Type(s)
C1	Windy Peak, WY	42.28	-105.58	7900	P, S
C2	Elk River, CO	40.85	-106.97	8700	P, S
C3	Deadman Hill, CO	40.81	-105.77	10220	S
C4	Tower, CO	40.54	-106.68	10500	P
C5	Dry Lake, CO	40.53	-106.78	8400	S
C6	Joe Wright, CO	40.53	-105.59	10120	S
C7	Willow Park, CO	40.43	-105.73	10700	P
C8	Lake Irene, CO	40.41	-105.82	8720	M
C9	Deer Ridge, CO	40.40	-105.63	9000	M, SC
C10	Columbine, CO	40.39	-106.60	9160	P, S
C11	Yampa View, CO	40.37	-106.77	8200	M, SC
C12	Park View, CO	40.37	-106.10	9160	SC
C13	Stillwater Creek, CO	40.23	-105.92	8720	M
C14	Lynx Pass, CO	40.08	-106.67	8880	P, S
C15	Gore Pass, CO	40.08	-106.55	9400	M, SC
C16	Burro Mountain, CO	39.87	-107.58	9400	P, M, SC
C17	La Sal Mountain, UT	38.48	-109.27	9560	P, S
C18	Chamita, NM	36.95	-106.65	8400	P

2.1 SNOTEL-Only Precipitation Evaluation, November – March Data

Historical period (for both SNOTEL precipitation and snow evaluations, limited to non-seeded years): Water years 1983-1984, 1986-1994, 1996-2002, 2006-2009 (22 seasons); November – March Precipitation Totals

Target SNOTEL sites: Berthoud Summit; Copper Mountain; Fremont Pass; Grizzly Peak; Summit Ranch; Hoosier Pass; Independence Pass; Kiln.

SNOTEL precipitation (November – March seasonal totals):

Control SNOTEL Sites: Columbine; Tower; Elk River; Lynx Pass; Willow Park; Burro Mountain; LaSal Mountain (Utah); Windy Peak (Wyoming); Chamita (New Mexico).

Linear Regression Equation:

T = 0.849C – 0.444 (Equation 1, SNOTEL precipitation linear)

In this equation, T is the predicted target site average of total November – March precipitation, and C is the control site average.

The r-value for Equation 1 is 0.907 (r^2 = 0.823), and the standard deviation of the seeded year observed/predicted ratios is 0.084. This equation and associated historical and seeded data is depicted graphically in Figure 3.1 of the following section.

Multiple Linear Regression Equation:

T = 0.560(Control Group 1) + 0.227 (Control Group 2) – 0.148

(Equation 2, SNOTEL precipitation multiple linear)

In this equation, Control Group 1 is the average of Columbine, Tower, Elk River, Willow Park, and Windy Peak (Wyoming). Control Group 2 is the average of Lynx Pass, Burro Mountain, LaSal Mountain (Utah), and Chamita (New Mexico). All values used in the equation are the November – March precipitation totals at the corresponding sites.

The r-value for Equation 2 is 0.915 (r^2 = 0.837), and the standard deviation of the historical year observed/predicted ratios is 0.071. This is lower than the standard deviation of 0.084 for these seeded season ratios which was obtained in the corresponding linear regression (Equation 1).

2.2 SNOTEL-Only Snow Evaluation, March 1 Data

Historical period (for both SNOTEL precipitation and snow evaluations, limited to non-seeded years): Water years 1983-1984, 1986-1994, 1996-2002, 2006-2009 (22 seasons); March 1 snow water equivalent data

Target SNOTEL sites: Berthoud Summit; Copper Mountain; Fremont Pass; Grizzly Peak; Summit Ranch; Hoosier Pass; Independence Pass; Kiln.

Control SNOTEL sites: Joe Wright; Dry Lake; Lynx Pass; Elk River; Columbine; Deadman Hill; LaSal Mountain (Utah); Windy Peak (Wyoming).

Linear Regression Equation:

T = 1.001C – 1.830 (Equation 3, SNOTEL snow linear)

In this equation, T is the predicted target area average snow water content, and C is the control average. The r-value for Equation 3 is 0.913 (r^2 = 0.834), and the standard deviation of seeded year observed/predicted ratios is 0.159. This equation and associated historical and seeded data is depicted graphically in Figure 3.2 of the following section.

Multiple Linear Regression Equation:

T = 0.408(Control Group 1) + 0.419(Control Group 2) + 0.055(LaSal Mountain) + 0.075(Windy Peak) –1.831 (Equation 4, SNOTEL snow multiple linear)

In this equation, Control Group 1 is the average of the Joe Wright and Deadman Hill values, and Control Group 2 is the average of Dry Lake, Lynx Pass, Elk River, and Columbine. All values used in the equation are the March 1 snow water equivalent values at the corresponding sites.

The r-value for Equation 4 is 0.920 (r^2 = 0.846), and the standard deviation of seeded year observed/predicted ratios is 0.093.

2.3 Long-Term Snow Evaluation with Mixed Data Types (SNOTEL, estimated SNOTEL, and snow course), March 1 data

Historical period: 1951-2002, 2006-2009 (56 seasons, limited to non-seeded years).

Target area SNOTEL sites, also containing NRCS pre-SNOTEL estimates: Fremont Pass, Hoosier Pass, Independence Pass

Target area active snow course sites: Twin Lakes Tunnel, Shrine Pass, Snake River

Control Area SNOTEL sites, also containing NRCS pre-SNOTEL estimates: Lake Irene SNOTEL, Stillwater Creek SNOTEL

Control area active snow course sites: Burro Mountain, Gore Pass, Deer Ridge, Yampa View

Linear Regression Equation:

T = 0.946C + 0.582 (Equation 5, Mixed Data Snow Linear)

where T is the predicted target area March 1 average snow water content, and C is the control average. The r-value for Equation 5 is 0.935 (r^2 = 0.874), and the standard deviation of seeded year observed/predicted ratios is 0.065.

Multiple Linear Regression Equation (using each control as an independent variable):

T = 0.196(Lake Irene SNOTEL) + 0.167(Stillwater Creek SNOTEL) + 0.131(Burro Mountain snow course) + 0.030(Gore Pass snow course) + +0.118(Deer Ridge snow course) + 0.248 (Yampa View snow course) + 0.182 (Equation 6, Mixed Data Snow Multiple Linear)

In this equation, T is the predicted target average snow water content, and each coefficient is multiplied by the Mar 1 snow water content value at its corresponding snow measurement site. The r-value for Equation 6 is 0.937, and the standard deviation of seeded year observed/predicted ratios is 0.076.

2.4 Active Snow Course-Only Snow Evaluation, March 1 data

Historical period: 1957-2002, 2006-2009 (50 seasons, limited to non-seeded years)

Target area snow course sites: Twin Lakes Tunnel, Shrine Pass, Snake River, Blue River

Control snow course sites: Gore Pass, Deer Ridge, Burro Mountain, Park View, Yampa View

Linear Regression Equation:

T = 0.972C – 0.075 (Equation 7, Snow Course-only Snow Linear)

In this equation, T is the predicted target area March 1 average snow water content, and C is the control average. The r-value for Equation 7 is 0.929 (r2 = 0.863), and the standard deviation of seeded year observed/predicted ratios is 0.085.

Multiple Linear Regression Equation (using each control as an independent variable):

T = 0.231(Gore Pass) + 0.223(Deer Ridge) + 0.161(Burro Mountain) – 0.010 (Park View) + 0.311 (Yampa View) – 0.079 (Equation 8, Snow course-only Snow Multiple Linear)

In this equation, T is the predicted target average snow water content, and each coefficient is multiplied by the Mar 1 snow water content value at its corresponding snow course site. The r-value for Equation 8 is 0.937, and the standard deviation of seeded year observed/predicted ratios is 0.095.

3.0 RESULTS FROM THE 2020-2021 WINTER SEASON AND ALL SEASONS

The regression equations described in Section 2.0 were used to evaluate the current winter season, as well as providing estimated results from all seeded seasons beginning with the 2003 water year. Indications for the current season ranged from increases of 1% to 8% that may potentially be attributed to seeding operations, based on the various regression equations (excluding outliers in the SNOTEL snow evaluation). These numbers are shown as observed/predicted ratio values in the top two rows of Table 3-1.

Table 3-1
Summary of Observed/Predicted Ratios

	SNOTEL Precipitation	SNOTEL Snow	Mixed Snow	Snow Course
Linear WY 21	1.03 (Equation 1)	1.14 (Equation 3)	1.05 (Equation 5)	1.05 (Equation 7)
Multiple Linear WY 21	1.01 (Equation 2)	0.95 (Equation 4)	1.08 (Equation 6)	1.04 (Equation 8)
Linear Long-Term W.Y. 03,04,12-21	1.04 (Equation 1)	1.12[1] (1.08) (Equation 3)	1.02 (Equation 5)	1.03 (Equation 7)
Multiple Linear Long-Term W.Y. 03,04,12-21	1.02 (Equation 2)	1.02[1] (0.99) (Equation 4)	1.05 (Equation 6)	1.00 (Equation 8)

[1] The SNOTEL snow linear evaluation includes some outlier values of + 55% for water year 2015 and + 35% for 2016. Value in parenthesis shows result when these two seasons are excluded from the average, which for consistency is shown for both the linear and multiple linear evaluation of SNOTEL snow.

The operational period for this program is currently permitted from November through mid-April, although actual operational start/end dates vary from season to season. Table 3-1 summarizes the results for the current winter season (upper two rows of the table) as well as for the combination of all seeded seasons (lower two rows) for the four different data sets, each with a linear and a multiple linear regression equation estimate. The values in the table are ratios of observed values, divided by the corresponding predicted values that are generated by the regression equations using the control site values. Values over 1.0 indicate that more precipitation or snow water content occurred than was predicted from the corresponding regression equation. The lower two rows are long-term results, based on averages of the seeded water years of 2003-2004, and 2012-2021. ***The seeded water years of 2005, 2010, and 2011 were excluded from these averages since it was NAWC's understanding that cloud seeding during these water years was primarily conducted to impact the Winter Park area, not the entire CCMRBP target area.*** There was no seeding conducted in water years 2006-2009, which were

therefore included as part of the historical (non-seeded) data set in the regression equations. Appendix A provides detailed information on these evaluations.

It should be noted that the precipitation and snow water content evaluations represent slightly different seasonal periods (i.e., March 1 snowpack would only include any seeding effects prior to that date). The 2021 water year results were positive in these evaluations (e.g. observed/predicted ratios greater than 1.0), except for the multiple linear regression for SNOTEL snow which showed a single season observed/predicted ratio of essentially 0.95. The SNOTEL snow linear evaluation result, in contrast, remains a high outlier as in some previous seasons, although the reasons for this are not clear. Evaluations using the multiple linear regression equation provide significantly lower estimates than those obtained using linear regression equation in this case. Single-season results for these evaluations carry little statistical significance, and focus should be placed on the overall results for multiple seeded seasons. Confidence in the evaluation results will improve with additional seeded seasons. For most of the evaluations (when high/low outliers are excluded), composite results for all the seeded seasons range from approximately 1.02 to 1.05 which is suggestive of a 2 - 5% positive seeding effect. Considering that four different combinations of data sources were used with varying target and control sites, we believe that the target/control equations as a whole are good representations of conditions in the target and control areas. The addition of future seeded seasons to the results should improve the accuracy of the seeding indications. This concept is discussed in Section 4.0.

The linear regression equations (the odd-number equations as detailed in Section 2 of the report) and corresponding results can be displayed graphically, including data points for both the historical non-seeded and seeded seasons. The multiple linear (even-numbered) equations are mathematically more complex and cannot be displayed in this way. The following scatterplots display the data points along with the corresponding regression equations and their R^2 values, to provide a visual comparison of the historical and seeded season data. The amount of natural season-to-season variability between the control vs. target area precipitation and SWE data is apparent in these plots, which is the primary reason that detection of seeding effects can be challenging for these programs.

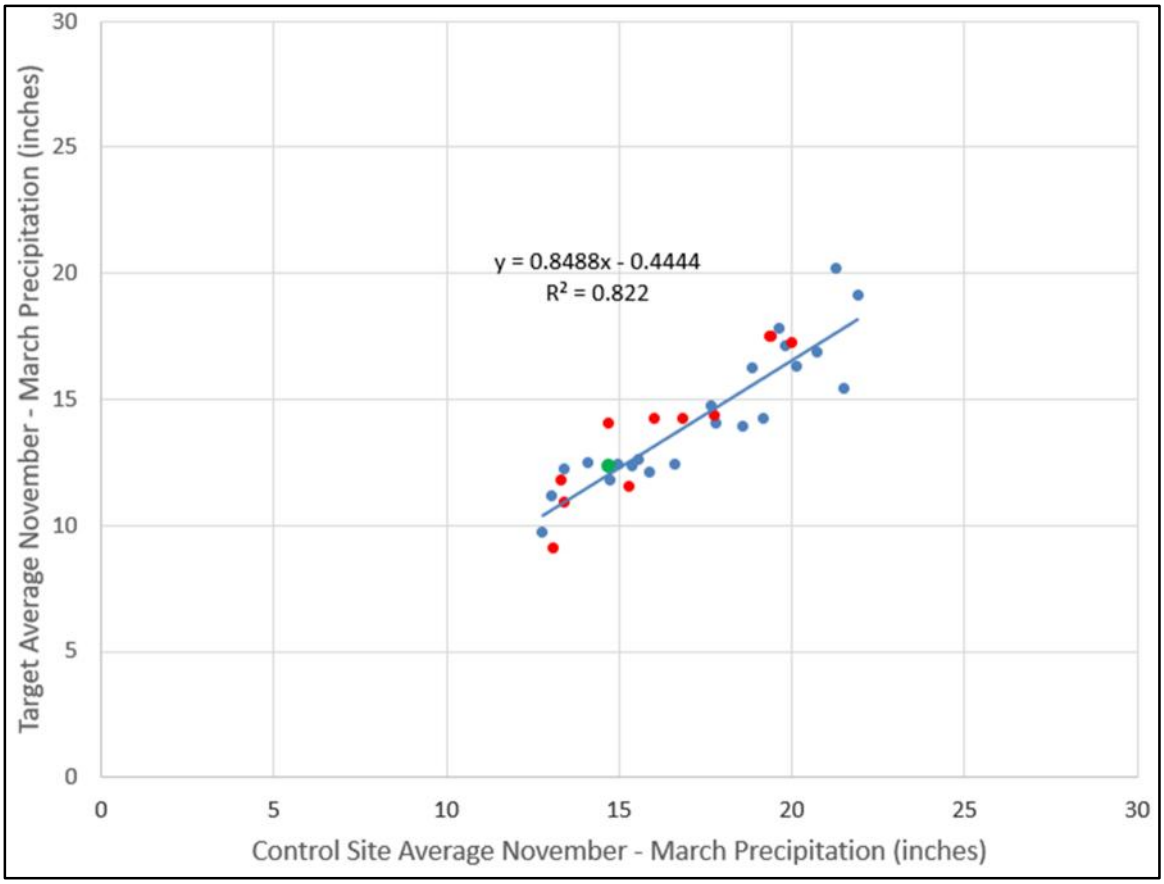

Figure 3.1 SNOTEL linear precipitation evaluation scatterplot, showing the historical data (blue dots) and corresponding regression equation, as well as seeded season data (red dots; 2021 displayed in green). This is based on Equation 1 as shown in the previous section of the report.

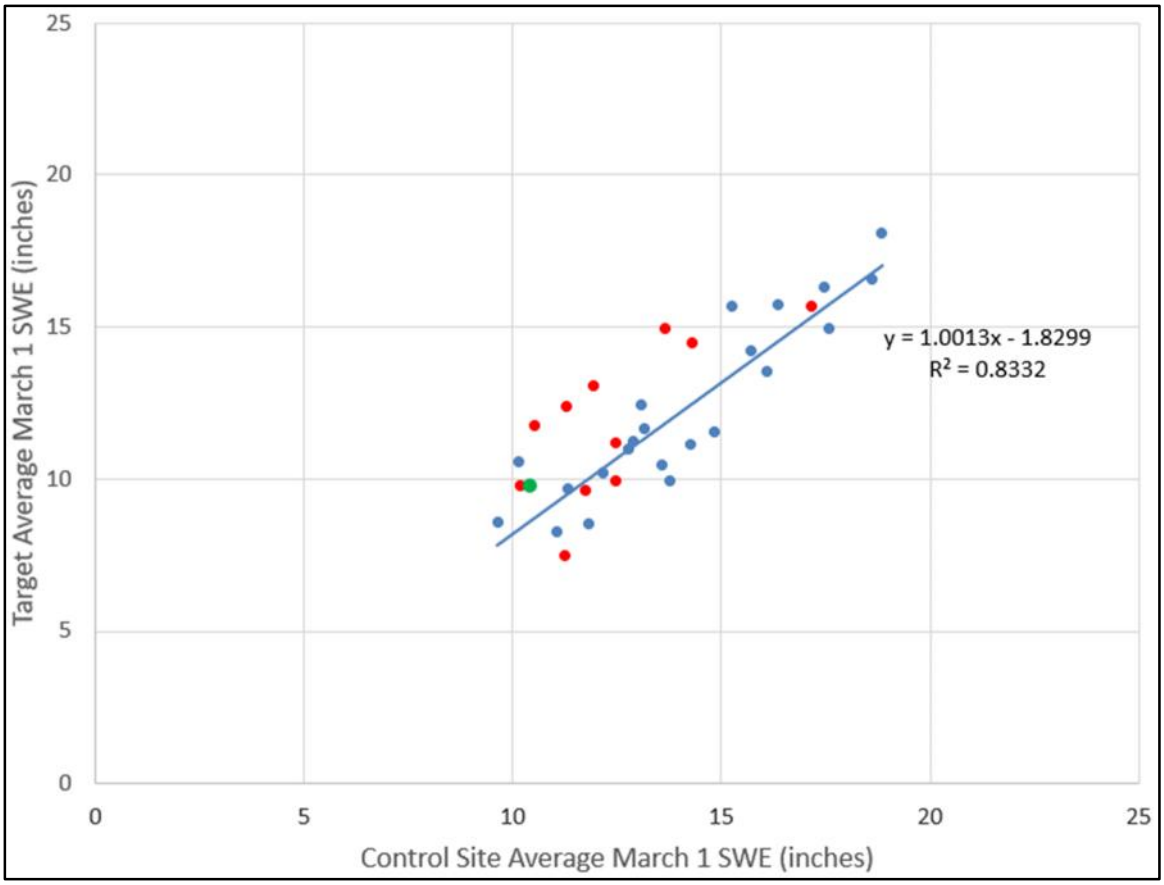

Figure 3.2 SNOTEL linear snow evaluation scatterplot, showing the historical data (blue dots) and corresponding regression equation, as well as seeded season data (red dots, 2021 shown in green). This is based on Equation 3 as shown in the previous section of the report.

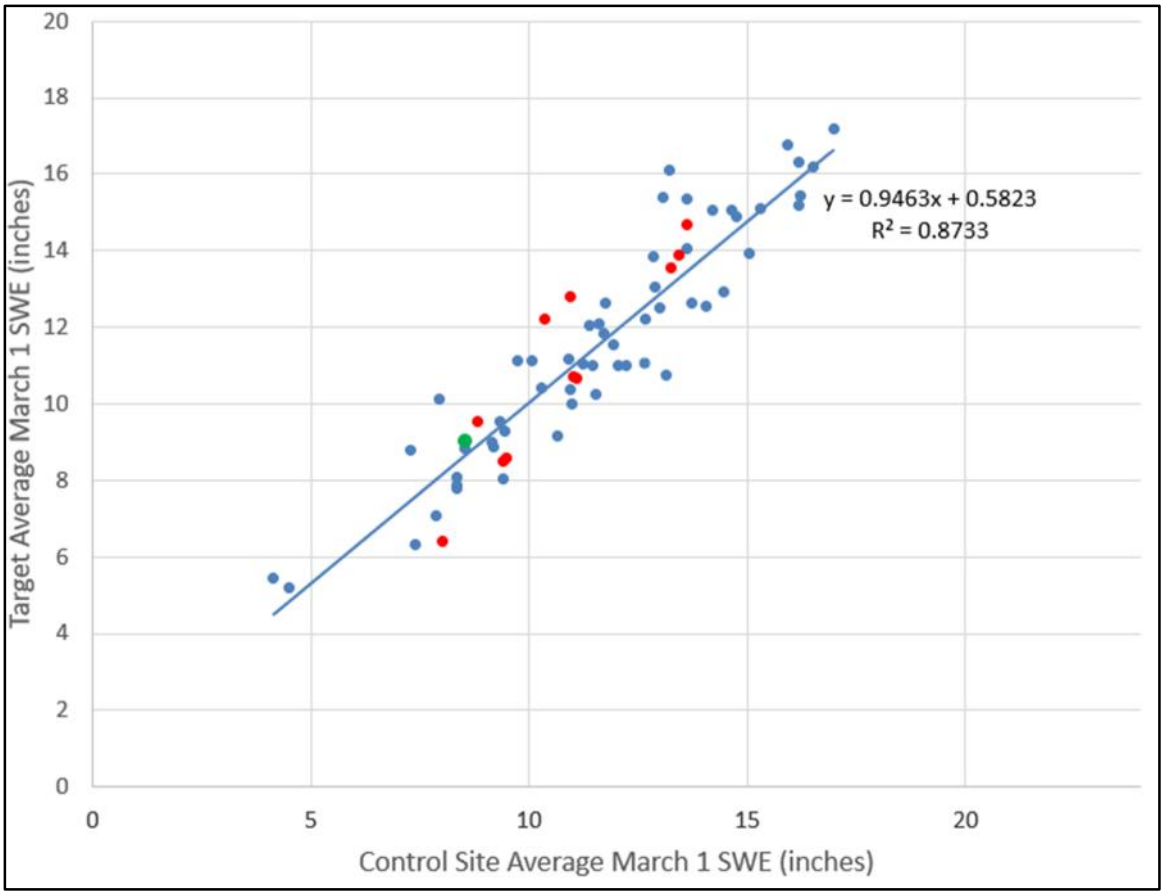

Figure 3.3 Mixed snow data linear regression evaluation scatterplot, showing the historical data (blue dots) and corresponding regression equation, as well as seeded season data (red dots, 2021 shown in green). This plot corresponds to Equation 5 as shown in the previous section of the report.

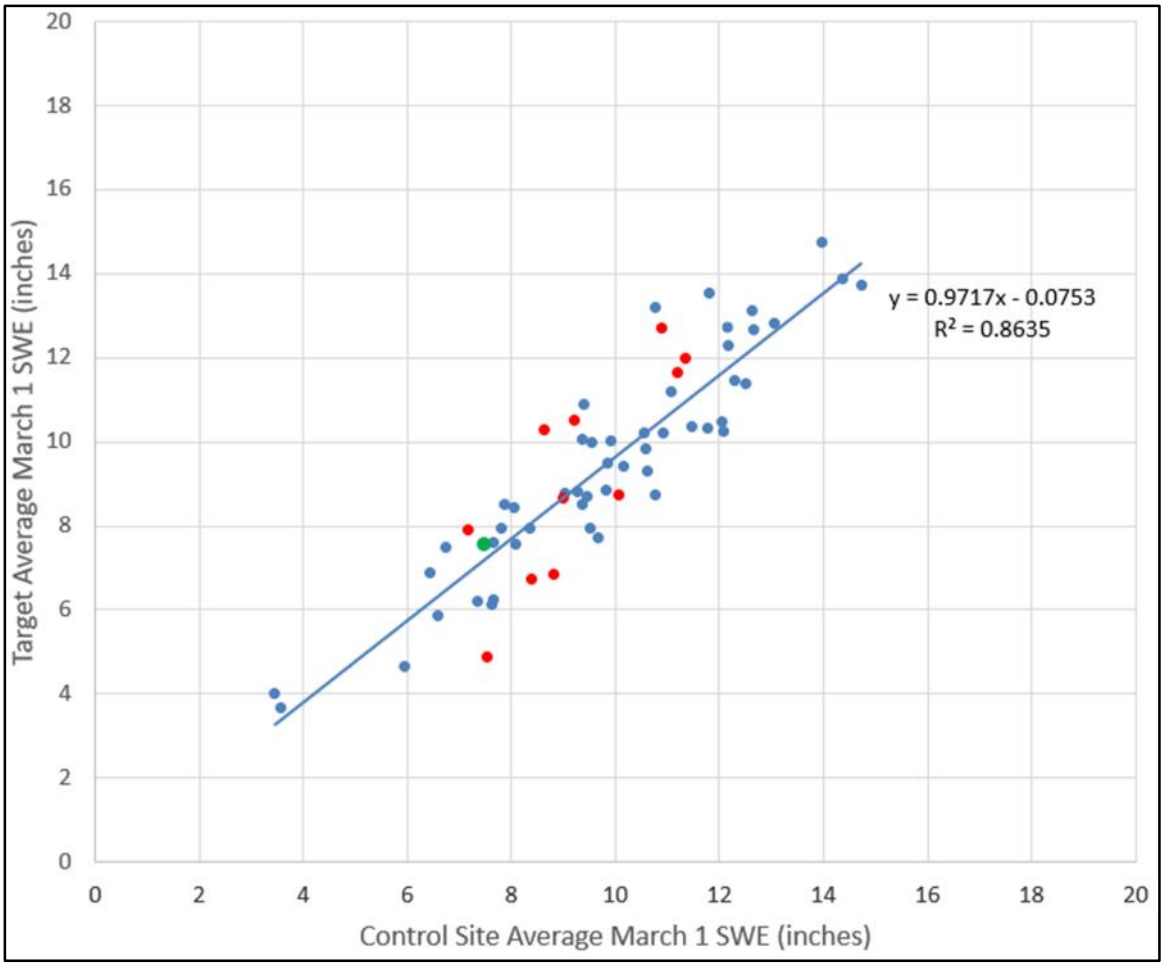

Figure 3.4 Snowcourse only snow linear regression evaluation scatterplot, showing the historical data (blue dots) and corresponding regression equation, as well as seeded season data (red dots, 2021 shown in green). This plot corresponds to Equation 7 as shown in the previous section of the report.

4.0 DISCUSSION OF RESULTS

4.1 Water Year 2021

The observed precipitation for Water Year 2021 was very close to that predicted by the regression equations, for the December – March precipitation data as summarized in Table 3-1 of the previous section (101% to 103% of the predicted values). The indicated results for the three different snow water content data sets as of March 1st ranged from 0.95(5% less than predicted by the regression equation) to 1.14 (14% more than predicted). These results were both low/high outliers respectively, compared to the remained of the evaluation results. Results for the SNOTEL-only snow (linear equation) continue to be higher than other comparative analyses, with a composite result of 1.12 for all the seeded seasons; all the other evaluation types, both linear and multiple linear, show composite results between 1.00 and 1.05 as shown in Table 3-1. Overall, the bulk of the results are suggestive of long-term precipitation and snowpack increases of about 2-5% due to seeding.

Season to season changes in dominant large-scale meteorological features such as persisting upper-level high (ridges) and low (trough) positions and the location of the jet stream impact the distribution of precipitation over the western United States. This natural seasonal weather variability influences the natural predictive relationships between control and target sites and can have significant impacts on single-season evaluation results. For this reason, among others, the regression equations provide imperfect predictions. If they were perfect predictions of the target area precipitation and snowfall, the correlation coefficient and r values would be 1.0. In exceptionally good correlations between target and control areas, we sometimes see r values in the 0.90 to 0.95 range. More common are values in the 0.80 to 0.89 range, which we still consider representative of good correlations. The lower the correlation, the higher the variability in the predictions. Because of this, a significant amount of single-season variability in ratios of observed over predicted precipitation and snow water content is expected in the target/control analyses. There are several underlying reasons for such variability, including:

Persistent upper-air circulation patterns during a winter season may impact target and control sites differently since control sites are typically located upwind of the target sites. If there is a persistent weather pattern that favors either the target or control areas, this can inadvertently affect the results of the target/control evaluation. It is assumed that over time the natural variability associated with such persistent seasonal patterns will become less significant as more seeded season data are accumulated; however, these patterns can (and frequently do) significantly affect single season evaluation results produced by these equations.

Variable spring snow melt may deplete the snow water content differently at control and target sites, especially if there are differences in terms of elevation or aspect (e.g. natural slope of the land in that area). These differences may lead to over- or under-predictions of target area snow water content.

Precipitation observations (SNOTEL) at high elevations, especially near timberline, may be influenced by strong winds during storms such that the amount of precipitation observed is

less than what occurred. Again, this could result in over or under predictions depending on its relative impact on target and control sites. This situation could advantage or disadvantage the target area predictions, as well as the observed target area precipitation. In the case of high winds during storms, experience in the conduct of the Upper Gunnison River program (Griffith, et al, 2011) suggests ***snow water content*** observations are not substantially influenced by high winds, whereas reductions frequently occur in ***precipitation*** measurements at high elevation sites near or above timberline.

Due to these factors, which can all strongly affect single-season results, combined results from all seeded seasons (section 4.2) are the focus of the evaluation efforts.

4.2 Combined Results for all Seeded Seasons

The combined results for the seeded water years of 2003, 2004, and 2012-2021 were displayed in the lower two rows of the results table (Table 3-1). These results are still quite variable in terms of seeding effect indications, although the bulk of the ratios (after eliminating the low and high outliers) range from 1.02 to 1.05 which suggests positive seasonal increases of precipitation/snowfall of approximately 2 to 5%. The variability in the results may be reflective of the twelve particular seeded seasons available for analysis thus far and may also reflect limitations associated with the number and location of available target and control sites. However, these composite seeded season ratios are all 1.0 or greater, with somewhat reduced variability compared to earlier analyses that contained a smaller number of seeded seasons. This decrease of the variability in the long-term results is to be expected as more seeded seasons are added to the evaluations.

Experience with other long-term winter orographic cloud seeding programs indicates the target/control modeling results of seeding are variable in the early years of these seeding programs. For example, some programs begin by indicating positive results while other programs can begin with the indications of negative (no effects) in their early years. The results can be highly affected by season to season variations in the natural precipitation and snowfall patterns, and the general trend is that the results tend to stabilize after approximately 15 seeded seasons (Silverman 2007). Even though it may take a number of years to reach stabilization, a trend is typically established after some intermediate period (e.g., 5-10 years) that provides a fairly reasonable estimate of the seeding effects from well-designed and executed winter cloud seeding programs. With twelve total seeded seasons now included in these analyses, confidence in positive effects of the program is reasonably good.

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APPENDIX A

HISTORICAL REGRESSION PERIOD AND SEEDED SEASON DATA

Table A-1
SNOTEL December - March Precipitation Linear Regression (Equation 1)

Historical regression period					
Water Year	Control Average	Target Average	Target Predicted	Obs/Pred ratio	Obs minus Predicted
1983	18.6	13.9	15.3	0.91	-1.40
1984	21.9	19.1	18.1	1.05	0.98
1986	21.5	15.4	17.8	0.87	-2.37
1987	13.0	11.2	10.6	1.05	0.58
1988	19.2	14.2	15.8	0.90	-1.59
1989	17.7	14.7	14.6	1.01	0.17
1990	15.0	12.5	12.3	1.02	0.19
1991	16.6	12.5	13.7	0.91	-1.20
1992	15.4	12.4	12.6	0.98	-0.25
1993	20.7	16.9	17.2	0.98	-0.29
1994	14.7	11.8	12.1	0.98	-0.23
1996	21.3	20.2	17.6	1.15	2.60
1997	20.1	16.3	16.6	0.98	-0.31
1998	15.9	12.1	13.0	0.93	-0.89
1999	14.1	12.5	11.5	1.08	0.96
2000	17.8	14.1	14.6	0.96	-0.57
2001	15.5	12.6	12.7	0.99	-0.13
2002	12.8	9.7	10.4	0.93	-0.68
2006	19.8	17.1	16.4	1.05	0.76
2007	13.4	12.2	10.9	1.12	1.32
2008	19.6	17.8	16.2	1.10	1.62
2009	18.9	16.3	15.6	1.05	0.71
Historical Mean	17.4	14.3	14.3	1.00	0.00
Seeded Period					
Water Year	Control Average	Target Average	Target Predicted	**Obs/Pred ratio**	Obs minus Predicted
2003	16.0	14.3	13.2	**1.08**	1.11
2004	15.3	11.6	12.5	**0.92**	-0.99
2012	13.1	9.1	10.7	**0.85**	-1.59
2013	13.4	10.9	10.9	**1.00**	-0.02
2014	19.4	17.5	16.0	**1.10**	1.53

2015	14.7	14.1	12.0	**1.17**	2.06
2016	17.8	14.4	14.6	**0.98**	-0.29
2017	19.3	17.5	16.0	**1.10**	1.52
2018	13.3	11.8	10.8	**1.09**	0.93
2019	20.0	17.2	16.5	**1.04**	0.71
2020	16.8	14.2	13.8	**1.03**	0.40
2021	14.7	12.4	12.0	**1.03**	0.37
Mean (03, 04,12-20)	16.2	13.7	13.3	**1.04**	0.48

Summary Output For Regression Equation (1)					
Regression Statistics					
Multiple R	**0.906615475**				
R Square	**0.821951619**				
Adjusted R Square	0.8130492				
Standard Error	1.182615272				
Observations	22				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	129.1294167	129.12941	92.32901932	6.1627E-09
Residual	20	27.97157765	1.3985788		
Total	21	157.1009943			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	**-0.444423161**	1.559832373	-0.2849172	0.77863697	-3.698174963
X Variable 1	**0.848769801**	0.088332558	9.6087990	6.1627E-09	0.6645114

Table A-2

SNOTEL Dec – Mar Precipitation Multiple Linear Regression (Equation 2)

Historical regression period						
Water Year	Ctrl 1	Ctrl 2	Target Average	Target Predicted	Obs/Pred ratio	Obs minus Predicted
1983	19.6	17.4	13.9	14.8	0.94	-0.83
1984	24.4	18.8	19.1	17.8	1.08	1.34
1986	25.6	16.4	15.4	17.9	0.86	-2.49
1987	13.0	13.1	11.2	10.1	1.11	1.09
1988	22.6	14.8	14.2	15.9	0.89	-1.68
1989	20.4	14.3	14.7	14.5	1.01	0.20
1990	19.1	9.8	12.5	12.8	0.97	-0.34
1991	17.9	15.0	12.5	13.3	0.94	-0.84
1992	16.3	14.3	12.4	12.2	1.01	0.15
1993	22.8	18.2	16.9	16.8	1.01	0.11
1994	17.0	11.9	11.8	12.1	0.98	-0.26
1996	26.8	14.3	20.2	18.1	1.11	2.07
1997	23.8	15.5	16.3	16.7	0.98	-0.41
1998	17.5	13.8	12.1	12.8	0.95	-0.68
1999	17.7	9.6	12.5	12.0	1.04	0.53
2000	22.1	12.4	14.1	15.0	0.94	-0.97
2001	18.1	12.3	12.6	12.8	0.99	-0.19
2002	14.6	10.5	9.7	10.4	0.93	-0.71
2006	24.5	13.9	17.1	16.7	1.02	0.38
2007	15.9	10.3	12.2	11.1	1.10	1.15
2008	22.0	16.7	17.8	15.9	1.12	1.88
2009	22.7	14.0	16.3	15.8	1.03	0.49

Historical Mean	20.2	14.0	14.35	14.35	1.00	0.00
Seeded Period						
Water Year	Ctrl 1	Ctrl 2	Target Average	Target Predicted	**Obs/Pred ratio**	Obs minus Predicted
2003	20.0	11.0	14.3	13.6	**1.05**	0.69
2004	18.4	11.4	11.6	12.8	**0.90**	-1.22
2012	15.5	10.1	9.1	10.8	**0.84**	-1.74
2013	15.7	10.6	10.9	11.1	**0.99**	-0.14
2014	26.0	11.1	17.5	17.0	**1.03**	0.58
2015	17.4	11.3	14.1	12.2	**1.16**	1.91
2016	20.6	14.2	14.4	14.6	**0.98**	-0.29
2017	22.9	14.9	17.5	16.1	**1.09**	1.43
2018	17.0	8.7	11.8	11.4	**1.04**	0.42
2019	22.7	16.7	17.2	16.3	**1.05**	0.89
2020	20.2	12.6	14.2	14.0	**1.01**	0.20
2021	17.8	10.9	12.4	12.3	**1.01**	0.12
Mean (03, 04,12-20)	19.5	11.9	13.7	13.5	**1.02**	0.24
Summary Output for Regression Equation (2)						
Regression Statistics						
Multiple R	**0.915150292**					
R Square	**0.837500057**					
Adjusted R Square	0.8203948					
Standard Error	1.15914902					
Observations	22					

ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	2	131.57209	65.78604587	48.96155906	3.18497E-08	
Residual	19	25.528903	1.343626452			
Total	21	157.10099				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	**-0.14772211**	1.544636	-0.095635546	0.924811519	-3.380683445	3.085239229
Ctrl 1	**0.560350867**	0.0815615	6.870288936	1.48686E-06	0.389640695	0.73106104
Ctrl 2	**0.227424984**	0.1175804	1.934208571	0.068121987	-0.018673662	0.473523629

Table A-3
SNOTEL March 1 SNOTEL Snow Linear Regression (Equation 3)

Historical regression period					
Water Year	Control Average	Target Average	Target Predicted	Obs/Pred ratio	Obs minus Predicted
1983	13.8	9.9	11.9	0.83	-2.00
1984	17.5	16.3	15.6	1.04	0.66
1986	17.6	15.0	15.8	0.95	-0.79
1987	10.1	10.6	8.3	1.27	2.24
1988	14.8	11.6	13.0	0.89	-1.46
1989	13.6	10.5	11.8	0.89	-1.30
1990	11.8	8.5	10.0	0.85	-1.51
1991	11.1	8.3	9.2	0.89	-0.98
1992	11.3	9.7	9.5	1.02	0.17
1993	16.1	13.5	14.3	0.95	-0.75
1994	13.2	11.7	11.3	1.03	0.34
1996	18.9	18.1	17.0	1.06	1.04
1997	18.6	16.6	16.8	0.99	-0.21
1998	12.8	11.0	10.9	1.01	0.06
1999	12.9	11.3	11.1	1.02	0.19
2000	14.3	11.2	12.4	0.90	-1.28
2001	12.2	10.2	10.4	0.98	-0.17
2002	9.6	8.6	7.8	1.10	0.78
2006	15.3	15.7	13.5	1.17	2.26
2007	13.1	12.5	11.3	1.11	1.20
2008	16.4	15.8	14.6	1.08	1.21
2009	15.7	14.2	13.9	1.02	0.31
Historical Mean	14.1	12.3	12.3	1.00	0.00
Seeded Period					
Water Year	Control Average	Target Average	Target Predicted	**Obs/Pred ratio**	Obs minus Predicted
2003	12.5	11.2	10.7	**1.05**	0.54
2004	12.5	10.0	10.6	**0.94**	-0.67
2012	11.8	9.6	9.9	**0.97**	-0.32
2013	11.3	7.5	9.4	**0.79**	-1.97
2014	17.2	15.7	15.4	**1.02**	0.35
2015	11.3	12.4	9.5	**1.31**	2.93
2016	10.5	11.8	8.7	**1.35**	3.05
2017	13.6	15.0	11.8	**1.26**	3.13

2018	10.2	9.8	8.4	**1.17**	1.39
2019	11.9	13.1	10.1	**1.29**	2.95
2020	14.3	14.5	12.5	**1.16**	2.00
2021	10.4	9.8	8.6	**1.14**	1.20
Mean (03, 04,12-21)	12.3	11.7	10.5	**1.12**	1.21
Summary Output for Regression Equation (3)					
Regression Statistics					
Multiple R	**0.91278024**				
R Square	**0.83316777**				
Adjusted R Square	0.82482616				
Standard Error	1.21294912				
Observations	22				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	146.949357	146.9493	99.88091683	3.19563E-09
Residual	20	29.42491151	1.471245		
Total	21	176.3742685			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	**-1.82989388**	1.436783778	-1.273604	0.217407067	-4.826970934
X Variable 1	**1.00127329**	0.100187	9.994044	3.19563E-09	0.792286968

Table A-4
SNOTEL March 1 SNOTEL Snow Multiple Linear Regression (Equation 4)

Historical regression period								
Water Year	Ctrl 1	Ctrl 2	Ctrl 3	Ctrl 4	Target Average	Target Predicted	Obs/Pred ratio	Obs minus Predicted
1983	14.8	14.7	16.5	5.0	9.9	11.7	0.85	-1.72
1984	19.3	19.4	15.8	7.7	16.3	15.6	1.05	0.70
1986	22.0	19.2	11.6	8.2	15.0	16.4	0.91	-1.46
1987	12.6	9.6	13.2	4.4	10.6	8.4	1.26	2.18
1988	15.1	18.0	9.4	7.2	11.6	12.9	0.90	-1.35
1989	13.6	16.9	10.6	3.5	10.5	11.6	0.90	-1.15
1990	12.9	14.6	5.1	5.7	8.5	10.2	0.83	-1.70
1991	12.1	12.5	9.3	5.1	8.3	9.2	0.90	-0.96
1992	11.6	12.4	9.7	8.4	9.7	9.2	1.05	0.46
1993	16.1	17.5	17.9	8.9	13.5	13.7	0.99	-0.15
1994	16.5	13.9	10.8	6.0	11.7	11.8	0.99	-0.07
1996	21.7	22.7	10.0	6.6	18.1	17.6	1.03	0.52
1997	17.4	22.9	13.2	9.3	16.6	16.3	1.02	0.31
1998	13.8	14.6	10.3	5.9	11.0	10.9	1.01	0.10
1999	16.1	14.9	6.0	5.5	11.3	11.7	0.96	-0.44
2000	13.3	17.8	10.7	5.6	11.2	12.0	0.93	-0.88
2001	12.4	14.4	8.4	6.8	10.2	10.2	1.00	-0.01
2002	9.8	12.1	6.1	3.1	8.6	7.8	1.10	0.81
2006	15.6	19.5	7.3	5.8	15.7	13.5	1.16	2.19
2007	15.5	14.8	8.0	6.6	12.5	11.6	1.07	0.86
2008	17.2	19.5	12.3	6.5	15.8	14.5	1.09	1.28
2009	15.8	19.2	10.7	6.5	14.2	13.7	1.03	0.47

Historical Mean	15.2	16.4	10.6	6.3	12.3	12.3	1.00	0.00
Seeded Period								
Water Year	Ctrl 1	Ctrl 2	Ctrl 3	Ctrl 4	Target Average	Target Predicted	**Obs/Pred ratio**	Obs minus Predicted
2003	11.6	14.9	8.5	5.1	11.2	10.0	**1.12**	1.24
2004	10.6	14.8	10.5	4.4	10.0	9.6	**1.04**	0.36
2012	14.6	13.4	8.8	6.8	9.6	10.7	**0.90**	-1.09
2013	10.4	12.4	11.1	3.4	7.5	8.4	**0.88**	-0.98
2014	19.4	20.2	8.4	6.0	15.7	15.4	**1.02**	0.27
2015	13.3	12.9	7.5	5.2	12.4	9.8	**1.26**	2.58
2016	12.4	14.9	13.2	6.2	11.8	10.6	**1.11**	1.13
2017	17.8	18.4	14.9	9.0	15.0	14.6	**1.02**	0.33
2018	14.6	13.1	6.4	5.0	9.8	10.3	**0.95**	-0.57
2019	14.6	16.6	12.6	7.2	13.1	12.3	**1.06**	0.77
2020	16.8	20.2	9.3	8.6	14.5	14.6	**0.99**	-0.15
2021	13.8	13.9	7.4	4.5	9.8	10.4	**0.95**	-0.57
Mean (03, 04,12-21)	14.1	15.5	9.9	6.0	11.7	11.4	**1.02**	0.28
Summary Output for Regression Equation (4)								
Regression Statistics								
Multiple R	**0.92048247**							
R Square	**0.84728798**							

Adjusted R Square	0.81135574							
Standard Error	1.25872182							
Observations	22							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	4	149.4398	37.359949	23.580161	9.48068E-07			
Residual	17	26.934471	1.5843806					
Total	21	176.37427						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**-1.83056385**	1.5319122	-1.1949535	0.2485104	-5.06262067	1.401492971	-5.062620	1.401492971
Ctrl 1	**0.40792321**	0.1433774	2.84510189	0.0111894	0.105422991	0.710423424	0.105422	0.710423424
Ctrl 2	**0.41906185**	0.1238599	3.38335313	0.0035328	0.157739896	0.680383807	0.157739	0.680383807
Ctrl 3	**0.05487288**	0.0919299	0.59689943	0.5584411	-0.13908243	0.248828194	-0.139082	0.248828194
Ctrl 4	**0.07494782**	0.2135834	0.35090653	0.7299694	-0.37567443	0.525570065	-0.375674	0.525570065

Table A-5
Mixed March 1 Snow Evaluation Linear Regression (Equation 5)

Historical regression period					
Water Year	Control Average	Target Average	Target Predicted	Obs/Pred ratio	Obs minus Predicted
1951	13.2	16.1	13.1	1.23	3.04
1952	16.5	16.2	16.2	1.00	-0.03
1953	11.2	11.1	11.2	0.99	-0.16
1954	7.3	8.8	7.5	1.18	1.32
1955	9.4	8.0	9.5	0.85	-1.44
1956	16.2	15.4	15.9	0.97	-0.51
1957	13.6	14.1	13.5	1.04	0.58
1958	11.7	12.6	11.7	1.08	0.93
1959	12.7	12.2	12.6	0.97	-0.32
1960	10.1	11.1	10.1	1.10	1.02
1961	7.4	6.3	7.6	0.84	-1.25
1962	17.0	17.2	16.6	1.03	0.55
1963	8.5	8.8	8.7	1.02	0.18
1964	7.9	7.1	8.0	0.88	-0.96
1965	15.3	15.1	15.0	1.00	0.07
1966	8.3	7.9	8.5	0.93	-0.58
1967	11.4	12.1	11.3	1.06	0.73
1968	11.9	11.6	11.9	0.97	-0.32
1969	12.0	11.0	12.0	0.92	-0.95
1970	14.2	15.1	14.0	1.07	1.03
1971	14.1	12.6	13.9	0.90	-1.34
1972	11.7	11.8	11.7	1.01	0.16
1973	10.6	9.2	10.6	0.86	-1.46
1974	12.6	11.1	12.5	0.89	-1.44
1975	13.0	12.5	12.9	0.97	-0.37
1976	10.9	11.2	10.9	1.02	0.27
1977	4.2	5.5	4.5	1.21	0.96
1978	16.2	15.2	15.9	0.96	-0.68
1979	14.5	12.9	14.3	0.91	-1.34
1980	14.8	14.9	14.5	1.02	0.34
1981	4.5	5.2	4.8	1.07	0.34
1982	12.9	13.9	12.7	1.09	1.11
1983	9.2	9.0	9.3	0.97	-0.27
1984	14.6	15.1	14.4	1.04	0.64
1985	11.0	10.0	11.0	0.91	-0.96
1986	15.0	14.0	14.8	0.94	-0.86
1987	7.9	10.1	8.1	1.25	2.04
1988	12.2	11.0	12.2	0.91	-1.14

1989	13.1	10.7	13.0	0.83	-2.28
1990	9.2	8.9	9.3	0.96	-0.39
1991	8.4	7.8	8.5	0.92	-0.68
1992	9.4	9.3	9.5	0.98	-0.21
1993	13.7	12.7	13.6	0.93	-0.92
1994	11.0	10.4	10.9	0.95	-0.56
1995	9.8	11.1	9.8	1.13	1.31
1996	15.9	16.8	15.7	1.07	1.09
1997	16.2	16.3	15.9	1.03	0.42
1998	10.3	10.4	10.3	1.01	0.10
1999	11.5	11.0	11.4	0.96	-0.40
2000	11.5	10.2	11.5	0.89	-1.25
2001	9.3	9.6	9.4	1.02	0.15
2002	8.3	8.1	8.5	0.96	-0.38
2006	13.1	15.4	13.0	1.19	2.42
2007	11.6	12.1	11.6	1.04	0.51
2008	13.6	15.3	13.5	1.14	1.88
2009	12.9	13.0	12.8	1.02	0.24
Historical Mean	11.7	11.6	11.6	1.00	0.00
Seeded Period					
Water Year	Control Average	Target Average	Target Predicted	**Obs/Pred ratio**	Obs minus Predicted
2003	11.1	10.7	11.1	**0.96**	-0.44
2004	9.5	8.6	9.6	**0.90**	-0.96
2012	9.4	8.5	9.5	**0.90**	-0.96
2013	8.0	6.4	8.2	**0.79**	-1.75
2014	13.6	14.7	13.5	**1.09**	1.18
2015	10.4	12.2	10.4	**1.17**	1.81
2016	11.0	10.7	11.0	**0.97**	-0.29
2017	13.5	13.9	13.3	**1.04**	0.57
2018	8.8	9.5	8.9	**1.07**	0.59
2019	10.9	12.8	10.9	**1.17**	1.89
2020	13.3	13.6	13.1	**1.03**	0.43
2021	8.5	9.1	8.7	**1.05**	0.39
Mean (03, 04,12-21)	10.7	10.9	10.7	**1.02**	0.21
Summary Output for Regression Equation (5)					

Regression Statistics					
Multiple R	**0.93451111**				
R Square	**0.873311014**				
Adjusted R Square	0.870964922				
Standard Error	1.068992896				
Observations	56				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	425.3764831	425.3764831	372.2406844	6.85456E-26
Residual	54	61.70827384	1.142745812		
Total	55	487.0847569			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	**0.582328362**	0.590641467	0.985925293	0.328566888	-0.601837509
X Variable 1	**0.946263745**	0.049045626	19.29353996	6.85456E-26	0.8479331

* 2018 results were adjusted due to a data correction

Table A-6
Mixed March 1 Snow Evaluation Multiple Linear Regression (Equation 6)

Historical regression period										
Water Year	Lake Irene SN	Stillwater Creek SN	Burro Mtn sc	Gore Pass sc	Deer Ridge sc	Yampa View sc	Target Average	Target Predicted	Obs/ Pred ratio	Obs minus Predicted
1951	30.2	5.8	13.5	7.9	7.4	14.4	16.1	13.5	1.19	2.60
1952	31.6	10.4	20.5	11.2	6.6	18.8	16.2	16.6	0.98	-0.39
1953	22.0	6.3	12.5	8.9	4.2	13.5	11.1	11.3	0.98	-0.24
1954	15.8	4.0	11.5	4.0	1.0	7.3	8.8	7.5	1.17	1.28
1955	15.2	5.1	12.1	9.5	2.4	12.1	8.0	9.2	0.88	-1.13
1956	32.3	10.4	18.2	13.2	6.9	16.3	15.4	15.9	0.97	-0.46
1957	21.2	8.5	18.0	11.8	5.6	16.7	14.1	13.3	1.06	0.80
1958	22.4	6.3	19.3	8.2	1.8	12.4	12.6	11.7	1.08	0.93
1959	22.7	7.0	17.9	8.6	5.9	13.8	12.2	12.5	0.98	-0.28
1960	22.7	5.7	13.0	5.5	2.3	11.1	11.1	10.5	1.06	0.64
1961	15.5	3.8	10.9	3.9	2.0	8.3	6.3	7.7	0.82	-1.36
1962	30.9	9.0	22.7	14.3	7.9	17.0	17.2	16.3	1.06	0.90
1963	19.0	5.8	7.8	5.2	4.3	9.1	8.8	8.8	1.00	0.02
1964	15.0	4.5	9.8	5.8	2.2	9.9	7.1	8.0	0.88	-0.98
1965	28.5	10.5	19.0	13.5	5.0	15.2	15.1	14.8	1.02	0.35
1966	11.8	6.3	13.3	5.2	3.4	10.0	7.9	8.3	0.95	-0.44
1967	21.5	8.3	14.6	8.3	3.3	12.2	12.1	11.4	1.06	0.71
1968	22.6	6.0	15.1	8.7	3.6	15.6	11.6	12.1	0.95	-0.59
1969	19.5	8.3	16.1	9.9	3.1	15.3	11.0	12.0	0.92	-0.93
1970	26.5	9.3	15.3	10.5	8.2	15.5	15.1	14.1	1.07	1.01
1971	26.3	8.1	17.9	12.0	3.4	16.7	12.6	13.9	0.90	-1.38
1972	22.8	8.5	13.0	9.6	3.7	12.7	11.8	11.6	1.02	0.19

1973	17.8	5.3	15.1	7.8	5.7	12.1	9.2	10.4	0.88	-1.25
1974	22.6	8.7	14.3	8.2	4.8	17.1	11.1	13.0	0.85	-1.90
1975	20.6	7.5	18.6	10.8	4.3	16.1	12.5	12.7	0.98	-0.23
1976	20.5	7.7	13.8	9.3	3.0	11.2	11.2	10.7	1.05	0.48
1977	7.1	3.0	5.0	3.2	0.3	6.3	5.5	4.4	1.24	1.05
1978	30.7	9.1	19.5	13.0	7.8	16.9	15.2	15.8	0.96	-0.57
1979	25.6	10.1	16.8	12.4	5.9	15.9	12.9	14.1	0.92	-1.18
1980	27.6	8.7	15.4	10.6	9.5	16.7	14.9	14.6	1.02	0.25
1981	9.4	2.9	6.1	2.6	0.2	5.8	5.2	4.8	1.07	0.34
1982	24.1	5.8	15.4	10.9	4.1	16.8	13.9	12.9	1.08	0.99
1983	17.5	4.9	14.5	6.4	0.3	11.4	9.0	9.4	0.96	-0.40
1984	24.3	9.5	18.5	10.3	7.2	18.0	15.1	14.6	1.03	0.50
1985	19.1	7.5	15.6	8.5	3.1	12.1	10.0	10.8	0.92	-0.82
1986	30.7	10.5	17.7	11.7	6.0	13.6	14.0	14.7	0.95	-0.75
1987	15.3	4.0	10.9	5.1	4.4	7.9	10.1	7.9	1.28	2.23
1988	23.3	6.3	15.1	9.4	5.9	13.4	11.0	12.1	0.91	-1.06
1989	27.0	6.7	16.1	10.1	5.8	13.1	10.7	12.9	0.83	-2.20
1990	15.7	5.4	9.8	6.5	4.0	13.7	8.9	9.5	0.93	-0.62
1991	11.7	5.5	13.0	8.1	1.0	10.8	7.8	8.1	0.96	-0.33
1992	16.2	4.8	14.3	6.7	2.6	12.0	9.3	9.5	0.98	-0.21
1993	23.3	10.2	16.8	11.6	6.5	13.9	12.7	13.2	0.96	-0.56
1994	20.1	6.6	12.6	8.5	5.9	12.0	10.4	10.8	0.96	-0.41
1995	17.3	6.3	12.7	7.9	1.6	12.7	11.1	9.9	1.13	1.26
1996	27.1	9.8	18.9	13.2	5.6	21.0	16.8	15.9	1.06	0.89
1997	26.0	11.0	20.4	12.5	6.4	20.7	16.3	16.0	1.02	0.26
1998	17.3	6.0	13.7	9.0	4.1	11.7	10.4	10.0	1.04	0.41
1999	21.9	6.6	13.0	8.9	4.1	14.2	11.0	11.5	0.95	-0.53
2000	19.7	8.5	11.9	8.2	4.8	16.0	10.2	11.8	0.87	-1.56
2001	17.4	6.3	11.6	7.0	1.0	12.6	9.6	9.6	0.99	-0.06

2002	13.8	4.6	12.5	6.1	1.2	11.9	8.1	8.6	0.95	-0.46
2006	21.1	9.8	15.8	11.6	2.1	18.1	15.4	13.1	1.17	2.28
2007	19.6	8.3	13.7	7.4	6.3	14.4	12.1	11.7	1.03	0.35
2008	20.2	9.5	17.5	11.8	6.0	16.6	15.3	13.2	1.16	2.14
2009	21.6	8.9	15.8	12.1	3.6	15.4	13.0	12.6	1.04	0.46
Historical Mean	21.2	7.2	14.7	9.0	4.3	13.7	11.6	11.6	1.00	0.00
Seeded Period										
Water Year	Lake Irene SN	Stillwater Creek SN	Burro Mtn sc	Gore Pass sc	Deer Ridge sc	Yampa View sc	Target Average	Target Predicted	**Obs/ Pred ratio**	Obs minus Predicted
2003	19.1	8.7	14.4	8.4	2.2	13.8	10.7	11.2	**0.95**	-0.54
2004	13.3	6.1	14.4	6.7	3.2	13.2	8.6	9.5	**0.90**	-0.94
2012	14.1	5.7	10.0	9.6	6.8	10.2	8.5	8.8	**0.97**	-0.31
2013	11.9	4.4	10.2	8.2	0.8	12.5	6.4	8.0	**0.80**	-1.62
2014	25.7	10.2	12.1	11.6	9.2	13.0	14.7	13.2	**1.11**	1.51
2015	18.0	6.8	10.7	8.2	8.6	9.9	12.2	10.0	**1.23**	2.24
2016	15.9	7.7	12.5	10.3	5.2	14.5	10.7	10.7	**1.00**	-0.02
2017	24.0	11.1	12.1	11.8	8.5	13.2	13.9	12.9	**1.07**	0.93
2018*	15.9	6.4	8.1	9.4	3.6	9.6	9.5	8.5	**1.12**	1.02
2019	18.5	6.7	13.5	10.9	3.2	12.8	12.8	10.6	**1.21**	2.25
2020	21.5	9.3	11.6	14.1	7.4	15.7	13.6	12.7	**1.07**	0.92
2021	15.8	4.0	9.7	8.4	3.1	10.2	9.1	8.4	**1.08**	0.69
Mean (03, 04,12-21)	17.8	7.3	11.6	9.8	5.2	12.4	10.9	10.4	**1.05**	0.51

Summary Output for Regression Equation (6)										
Multiple R	**0.93701**									
R Square	**0.87800**									
Adjusted R Square	0.86306									
Standard Error	1.10123									
Observations	56									
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*		
Intercept	**0.18193**	0.766203	0.2374	0.813300	-1.35781	1.721674572	-1.357810358	1.72167457		
Lake Irene SN	**0.19624**	0.053067	3.6979	0.000549	0.089598	0.302885377	0.089598314	0.30288537		
Stillwater Cr SN	**0.16662**	0.147180	1.1321	0.263096	-0.12914	0.462396418	-0.129145587	0.46239641		
Burro Mtn sc	**0.13098**	0.085561	1.5309	0.132219	-0.04095	0.302931381	-0.040954298	0.30293138		
Gore Pass sc	**0.02984**	0.137576	0.2169	0.829158	-0.24662	0.306316188	-0.246625344	0.30631618		
Deer Ridge sc	**0.11787**	0.105025	1.1222	0.267206	-0.09318	0.3289275	-0.093187433	0.3289275		
Yampa View sc	**0.24764**	0.091095	2.7185	0.009042	0.06458	0.430709907	0.064582109	0.43070990		

Table A-7
Snowcourse-Only March 1 Evaluation Linear Regression (Equation 7)

Historical regression period					
Water Year	Control Average	Target Average	Target Predicted	Obs/Pred ratio	Obs minus Predicted
1957	12.3	11.5	11.9	0.97	-0.41
1958	9.4	10.9	9.0	1.20	1.84
1959	10.6	10.2	10.2	1.00	0.01
1960	7.9	8.5	7.6	1.12	0.92
1961	5.9	4.7	5.7	0.82	-1.02
1962	14.7	13.7	14.2	0.96	-0.50
1963	6.4	6.9	6.2	1.11	0.69
1964	6.6	5.9	6.3	0.93	-0.44
1965	12.7	12.7	12.2	1.03	0.42
1966	7.6	6.1	7.3	0.83	-1.22
1967	9.6	10.0	9.2	1.09	0.79
1968	9.8	9.5	9.5	1.00	-0.01
1969	10.8	8.8	10.4	0.84	-1.65
1970	11.8	13.5	11.4	1.19	2.13
1971	12.1	10.3	11.7	0.88	-1.41
1972	9.4	10.1	9.0	1.12	1.06
1973	9.7	7.7	9.3	0.83	-1.61
1974	10.6	9.9	10.2	0.97	-0.36
1975	11.5	10.4	11.1	0.94	-0.69
1976	9.0	8.8	8.7	1.01	0.09
1977	3.5	4.0	3.3	1.22	0.71
1978	13.0	12.8	12.6	1.02	0.23
1979	12.0	10.5	11.6	0.90	-1.15
1980	12.1	12.8	11.7	1.09	1.03
1981	3.6	3.7	3.4	1.08	0.27
1982	11.1	11.2	10.7	1.05	0.51
1983	7.8	7.9	7.5	1.05	0.40
1984	12.6	13.1	12.2	1.07	0.91
1985	9.4	8.5	9.0	0.94	-0.52
1986	12.5	11.4	12.1	0.94	-0.72
1987	6.7	7.5	6.5	1.16	1.03
1988	10.2	9.4	9.8	0.96	-0.37
1989	10.6	9.3	10.2	0.91	-0.94
1990	8.1	7.6	7.8	0.97	-0.20
1991	7.7	6.3	7.4	0.85	-1.12
1992	8.4	8.0	8.1	0.99	-0.10
1993	11.8	10.3	11.4	0.91	-1.03
1994	9.5	7.9	9.2	0.86	-1.25

1995	8.0	8.5	7.7	1.09	0.71
1996	14.0	14.7	13.5	1.09	1.24
1997	14.4	13.9	13.9	1.00	0.00
1998	9.3	8.8	8.9	0.98	-0.14
1999	9.4	8.7	9.1	0.96	-0.40
2000	9.8	8.9	9.5	0.93	-0.62
2001	7.7	7.6	7.4	1.03	0.23
2002	7.3	6.2	7.1	0.88	-0.85
2006	10.8	13.2	10.4	1.27	2.82
2007	9.9	10.0	9.6	1.05	0.46
2008	12.2	12.3	11.7	1.05	0.56
2009	10.9	10.2	10.5	0.97	-0.34
Historical Mean	9.5	9.5	9.5	1.00	0.00
Seeded Period					
Water Year	Control Average	Target Average	Target Predicted	**Obs/Pred ratio**	Obs minus Predicted
2003	9.0	8.7	8.7	**1.00**	-0.02
2004	8.8	6.9	8.5	**0.81**	-1.64
2012	8.4	6.8	8.1	**0.83**	-1.34
2013	7.5	4.9	7.2	**0.68**	-2.33
2014	10.9	12.7	10.5	**1.21**	2.20
2015	8.6	10.3	8.3	**1.24**	1.97
2016	10.1	8.8	9.7	**0.90**	-0.97
2017	11.3	12.0	10.9	**1.10**	1.06
2018	7.2	7.9	6.9	**1.14**	1.00
2019	9.2	10.5	8.9	**1.18**	1.64
2020	11.2	11.7	10.8	**1.08**	0.84
2021	7.5	7.6	7.2	**1.05**	0.38
Mean (03, 04,12-21)	9.1	9.0	8.8	**1.03**	0.23
Summary Output for Regression Equation (7)					
Regression Statistics					
Multiple R	**0.929261447**				
R Square	**0.863526837**				
Adjusted R Square	0.860683646				
Standard Error	0.970824397				
Observations	50				
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	286.2537495	286.2537495	303.7175029	2.14137E-22

Residual	48	45.24000048	0.94250001		
Total	49	331.49375			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	**-0.07531856**	0.566053365	-0.133059122	0.894702893	-1.213444467
X Variable 1	**0.971677793**	0.055755455	17.42749273	2.14137E-22	0.859574002

Table A-8

Snowcourse-Only March 1 Evaluation Multiple Linear Regression (Equation 8)

Historical regression period									
Water Year	Gore Pass	Deer Ridge	Burro Mtn	Park View	Yampa View	Target Average	Target Predicted	**Obs/Pred ratio**	Obs minus Predicted
1957	11.8	5.6	18.0	9.3	16.7	11.5	11.9	**0.96**	-0.47
1958	8.2	1.8	19.3	5.2	12.4	10.9	9.1	**1.19**	1.74
1959	8.6	5.9	17.9	6.6	13.8	10.2	10.4	**0.99**	-0.15
1960	5.5	2.3	13.0	7.5	11.1	8.5	7.2	**1.18**	1.32
1961	3.9	2.0	10.9	4.6	8.3	4.7	5.6	**0.84**	-0.89
1962	14.3	7.9	22.7	11.7	17.0	13.7	13.8	**0.99**	-0.11
1963	5.2	4.3	7.8	5.8	9.1	6.9	6.1	**1.12**	0.75
1964	5.8	2.2	9.8	5.2	9.9	5.9	6.4	**0.92**	-0.49
1965	13.5	5.0	19.0	10.6	15.2	12.7	11.9	**1.07**	0.80
1966	5.2	3.4	13.3	6.3	10.0	6.1	7.1	**0.86**	-0.96
1967	8.3	3.3	14.6	9.4	12.2	10.0	8.6	**1.16**	1.36
1968	8.7	3.6	15.1	6.2	15.6	9.5	10.0	**0.95**	-0.49
1969	9.9	3.1	16.1	9.5	15.3	8.8	10.2	**0.86**	-1.42
1970	10.5	8.2	15.3	9.5	15.5	13.5	11.4	**1.19**	2.13
1971	12.0	3.4	17.9	10.4	16.7	10.3	11.4	**0.90**	-1.19
1972	9.6	3.7	13.0	7.8	12.7	10.1	8.9	**1.13**	1.13
1973	7.8	5.7	15.1	7.7	12.1	7.7	9.1	**0.85**	-1.41
1974	8.2	4.8	14.3	8.5	17.1	9.9	10.4	**0.94**	-0.59
1975	10.8	4.3	18.6	7.5	16.1	10.4	11.3	**0.92**	-0.94
1976	9.3	3.0	13.8	7.8	11.2	8.8	8.4	**1.05**	0.40
1977	3.2	0.3	5.0	2.5	6.3	4.0	3.5	**1.15**	0.53
1978	13.0	7.8	19.5	8.0	16.9	12.8	13.0	**0.99**	-0.18
1979	12.4	5.9	16.8	9.2	15.9	10.5	11.7	**0.90**	-1.21
1980	10.6	9.5	15.4	8.5	16.7	12.8	12.1	**1.05**	0.64
1981	2.6	0.2	6.1	3.2	5.8	3.7	3.3	**1.11**	0.35
1982	10.9	4.1	15.4	8.2	16.8	11.2	11.0	**1.02**	0.21
1983	6.4	0.3	14.5	6.5	11.4	7.9	7.3	**1.09**	0.64
1984	10.3	7.2	18.5	9.1	18.0	13.1	12.4	**1.06**	0.68

1985	8.5	3.1	15.6	7.5	12.1	8.5	8.8	**0.97**	-0.29
1986	11.7	6.0	17.7	13.6	13.6	11.4	10.9	**1.04**	0.45
1987	5.1	4.4	10.9	5.4	7.9	7.5	6.3	**1.20**	1.25
1988	9.4	5.9	15.1	7.0	13.4	9.4	10.0	**0.95**	-0.53
1989	10.1	5.8	16.1	8.0	13.1	9.3	10.2	**0.92**	-0.85
1990	6.5	4.0	9.8	6.4	13.7	7.6	8.1	**0.93**	-0.53
1991	8.1	1.0	13.0	5.4	10.8	6.3	7.4	**0.84**	-1.17
1992	6.7	2.6	14.3	6.2	12.0	8.0	8.0	**0.99**	-0.09
1993	11.6	6.5	16.8	10.0	13.9	10.3	11.0	**0.94**	-0.68
1994	8.5	5.9	12.6	8.6	12.0	7.9	8.9	**0.89**	-0.97
1995	7.9	1.6	12.7	5.3	12.7	8.5	8.1	**1.05**	0.40
1996	13.2	5.6	18.9	11.1	21.0	14.7	13.7	**1.07**	1.02
1997	12.5	6.4	20.4	11.8	20.7	13.9	13.9	**1.00**	0.01
1998	9.0	4.1	13.7	7.9	11.7	8.8	8.7	**1.01**	0.10
1999	8.9	4.1	13.0	7.0	14.2	8.7	9.3	**0.93**	-0.65
2000	8.2	4.8	11.9	8.2	16.0	8.9	9.7	**0.91**	-0.87
2001	7.0	1.0	11.6	6.1	12.6	7.6	7.5	**1.01**	0.11
2002	6.1	1.2	12.5	5.0	11.9	6.2	7.3	**0.85**	-1.06
2006	11.6	2.1	15.8	6.2	18.1	13.2	11.2	**1.18**	2.01
2007	7.4	6.3	13.7	7.8	14.4	10.0	9.7	**1.04**	0.36
2008	11.8	6.0	17.5	8.9	16.6	12.3	11.9	**1.03**	0.40
2009	12.1	3.6	15.8	7.7	15.4	10.2	10.8	**0.95**	-0.59
Historical Mean	9.0	4.2	14.7	7.7	13.7	9.5	9.5	**1.000**	0.00
Seeded Period									
Water Year	Gore Pass	Deer Ridge	Burro Mtn	Park View	Yampa View	Target Average	Target Predicted	**Obs/Pred ratio**	Obs minus Predicted
2003	8.4	2.2	14.4	6.2	13.8	8.7	8.9	**0.97**	-0.26
2004	6.7	3.2	14.4	6.6	13.2	6.9	8.6	**0.80**	-1.70
2012	9.6	6.8	10.0	5.4	10.2	6.8	8.4	**0.80**	-1.66
2013	8.2	0.8	10.2	5.9	12.5	4.9	7.5	**0.66**	-2.57
2014	11.6	9.2	12.1	8.5	13.0	12.7	10.6	**1.20**	2.11

2015	8.2	8.6	10.7	5.7	9.9	10.3	8.5	**1.21**	1.77
2016	10.3	5.2	12.5	7.9	14.5	8.8	9.9	**0.88**	-1.17
2017	11.8	8.5	12.1	11.1	13.2	12.0	10.5	**1.14**	1.49
2018	9.4	3.6	8.1	5.2	9.6	7.9	7.1	**1.11**	0.75
2019	10.9	3.2	13.5	5.6	12.8	10.5	9.3	**1.13**	1.23
2020	14.1	7.4	11.6	7.2	15.7	11.7	11.5	**1.01**	0.12
2021	8.4	3.1	9.7	5.9	10.2	7.6	7.2	**1.04**	0.31
Mean (03, 04,12-21)	9.8	5.2	11.6	6.8	12.4	9.0	9.0	**1.00**	0.03

Summary Output for Regression Equation (8)	
Regression Statistics	
Multiple R	**0.9373969**
R Square	**0.8787130**
Adjusted R Square	0.8649304
Standard Error	0.9559131
Observations	50

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**-0.07875172**	0.70056861	-0.112411	0.911008706	-1.490654934	1.333151493	-1.490654934	1.333151493
Gore Pass	**0.23132813**	0.12680365	1.8243018	0.074901793	-0.024227834	0.486884094	-0.024227834	0.486884094
Deer Ridge	**0.225558945**	0.08692337	2.5949171	0.01280686	0.050376405	0.400741486	0.050376405	0.400741486
Burro Mtn	**0.160897624**	0.07768114	2.0712572	0.044230516	0.004341573	0.317453675	0.004341573	0.317453675
Park View	**-0.01000731**	0.11485827	-0.087128	0.930965475	-0.241488947	0.221474317	-0.241488947	0.221474317
Yampa View	**0.311306915**	0.07951141	3.9152483	0.000310292	0.151062204	0.471551627	0.151062204	0.471551627