Evaluation of the Operational Upper Snake River Cloud Seeding Program in Idaho, 2008-2009 Winter Season

Prepared for

High Country Resource Conservation and Development Council

by

Don A. Griffith
David P. Yorty

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

Report No. WM 09-04
Project No. 08-243

July 2009

TABLE OF CONTENTS

Section **Page**

Figure **Page**

Table **Page**

Table of Contents (continued)

Table **Page**

Evaluation of the Operational Upper Snake River Cloud Seeding Program in Idaho, 2008-2009 Winter Season

1.0 Introduction

An operational winter cloud seeding program has been conducted for several past winter seasons in eastern Idaho. A local group, Let it Snow headquartered in Clark County, has been the contractor selected to perform this work.

North American Weather Consultants (NAWC) was contacted by the High Country Resource Conservation and Development Council and subsequently by the Idaho Water Resource Board (IDWR) concerning the development of an evaluation method that could be used to assess the potential impact of cloud seeding in this area for the 2007-2008 winter season. Both groups elected to fund this evaluation. In the case of the IDWR, a separate task to perform this work was added to another contract that had been awarded to NAWC to conduct a weather modification feasibility study for the upper Snake River Basin in Idaho (Griffith, et al, 2008). A separate report was prepared by NAWC concerning this evaluation work and provided to the High Country Resource Conservation and Development Council during the summer of 2008 (Griffith and Yorty, 2008).

The High Country Resource Conservation and Development Council contracted with NAWC in January 2009 to perform a similar evaluation of this operational upper Snake River Basin cloud seeding program for the 2008-2009 winter season. The remainder of this report provides this evaluation. By and large the techniques developed in performance of the 2007-2008 evaluations have been utilized in this evaluation. Some of the background on the earlier work is reproduced in this report in order to make this a more stand-alone report.

2.0 Background

One commonly employed statistical technique that has been utilized in the evaluation of operational cloud seeding programs is the "target" and "control" comparison. This technique is described by Dr. Arnett Dennis in his book entitled “Weather Modification by Cloud Seeding (1980)”. This technique is based on the selection of a variable that would be affected by seeding (e.g., liquid precipitation, snowpack or streamflow). Records of the variable to be tested are acquired for an historical (not seeded) period of many years duration (20 years or more if possible). These records are partitioned into those located within the designated "target" area of the project and those in a nearby "control" area. Ideally the control sites should be selected in an area meteorologically similar to the target, but one that would be unaffected by the seeding (or seeding from other adjacent projects). The historical data (e.g., precipitation) in both the target and control areas are taken from past years that have not been subject to

cloud seeding activities in either area. These data are evaluated for the same seasonal period as that of the proposed or previous seeding. The target and control sets of data for the unseeded seasons are used to develop an equation (typically a linear regression) that estimates the amount of target area precipitation, based on precipitation observed in the control area. This regression equation is then applied to the seeded period to estimate what the target area precipitation would have been without seeding, based on that observed in the control area(s). This allows a comparison between the predicted target area natural precipitation and that, which actually occurred during the seeded period to determine if there are any differences potentially caused by cloud seeding activities.

This target and control technique works well where a good historical correlation can be found between target and control area precipitation. Generally, the closer the target and control areas are in terms of elevation and topography, the higher the correlation will be. Control sites that are too close to the target area, however, can be subject to contamination by the seeding activities. This can result in an underestimate of the seeding effect. For precipitation and snowpack assessments, a correlation coefficient (r) of 0.90 or better would be considered excellent. A correlation coefficient of 0.90 would indicate that over 80 percent of the variance (r^2) in the historical data set would be explained by the regression equation used to predict the variable (expected precipitation or snowpack) in the seeded years. An equation indicating perfect correlation would have an r value of 1.0.

3.0 Development of Target/Control Evaluation Method for the upper Snake River Basin

Figure 1 provides the approximate target area and associated ground generator seeding locations for the 2008-2009 upper Snake River cloud seeding program. The operations for the 2008-2009 winter season were upgraded considerably due to Idaho Power becoming a co-sponsor of this program. Improvements provided by Idaho Power last winter included

1. The installation of three remotely controlled, ground based silver iodide generators.
2. Siting and operation of a rawinsonde (weather balloon) release site.
3. Siting and operation of a radiometer site.

The utility of these ugrades will be discussed in a later section.

In performance of the earlier work in evaluating the 2007-2008 winter seeding program, NAWC examined several different types of data for possible use as target and control data for an evaluation of this program. NRCS SNOTEL sites, located in mountainous areas of the state, report both precipitation and snow water content data throughout the year. The SNOTEL sites were typically installed at prior manually observed snow course sites. The establishment of SNOTEL sites began in 1981 at most sites. Precipitation gage data, as well as manual snowcourse data, are available for most of these sites for years prior to 1981. These data were utilized along with the post-1981 SNOTEL data. The

manual snowcourse data at these sites was compared to the SNOTEL snow water data for the first 10 years or so after installation of the SNOTEL sites. Adjustments were made by the NRCS to the snowcourse data to match, in as much as possible, the SNOTEL data. Sites that continue to be operated as manual snowcourses provide snow water content measurements near the first of each month during the winter and spring. The measurements are normally made within a few days before or after the first of the month at these snowcourse locations. National Weather Service (NWS) co-op sites, generally in valley locations, provide monthly precipitation totals throughout the year. Evaluations of both precipitation and snow water content are viable using these different data sources. NAWC personnel entered available data from these sources into data files for additional analysis.

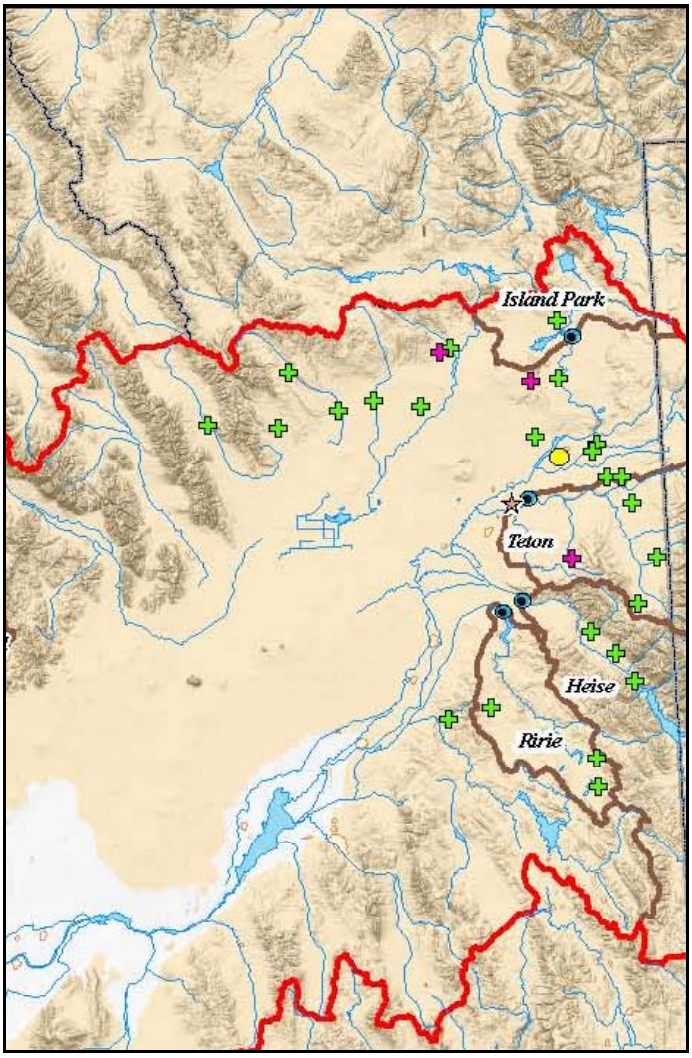

Figure 1. Map showing the target areas and seeding generator sites for the 2008-2009 upper Snake Operational Seeding Program (the three blue triangles are Idaho Power remote generators, the star is an Idaho Power rawinsonde release site and the yellow circle is an Idaho Power radiometer site)

For the precipitation evaluation (December – March period), both SNOTEL precipitation data (as well as pre-1981 gage data) and valley co-op site data were examined. The co-op data was considered only for sites with a good stable record and with minimal missing data. Estimates were made in a few cases for months with 3 or more missing days, using data from nearby sites (it turned out for other reasons that none of the valley co-op sites were included in the final equations anyway). Double-mass plots, an engineering technique where data are accumulated sequentially for two locations and plotted on a graph, were produced for both the SNOTEL and co-op sites and sites. Questionable sites were eliminated based on these plots. Figure 2 provides an example of a plot of December through March precipitation data with a break in the relationship between two stations (Giveout and Pine Creek Pass). This plot indicates questionable data at one of the sites. Comparison of the Giveout site with another site (Sheep Mountan) indicates a stable relationship (Figure 3). It was therefore concluded that the Pine Creek Pass site had some discontinuity in its data, and it was among those excluded from the development of the regression equations.

For the snow water content evaluations (April 1st), both SNOTEL snow water data (including NRCS-adjusted pre-1981 snowcourse data for these sites) and data from current snowcourse sites were considered. Double-mass plots were made in this case also with questionable sites eliminated. Control site combinations best correlated with sites located in the target area were selected.

An historical period beginning in 1961 was selected on which to base the development of the regression equations. NAWC had conducted winter seeding programs in the target area shown in Figure 1 during the 1989, 1993 and 1995 water years (Risch, et al, 1995). Subsequent winter cloud seeding programs were conducted during the 1997 through 2007 water years by the Let it Snow organization. These seeded seasons were excluded from the data set, which resulted in 30 years of data on which the regression equations would be developed. Sites without records going back to 1961 were not considered. In addition, the target area was divided into a "northern" portion (areas north of the Ashton area) and "eastern" portion (south and east of the Ashton area) due to significant climatological and terrain differences between these two areas. These two areas are indicated on Figure 4. Regression equations for precipitation and snow water content were considered for each portion; it was discovered that a precipitation evaluation was not feasible for the eastern portion. This is because there is only one precipitation measurement site (Pine Creek Pass) in this portion of the target and double-mass plots showed poor precipitation data reliability at that SNOTEL site (refer to Figures 2 and 3).

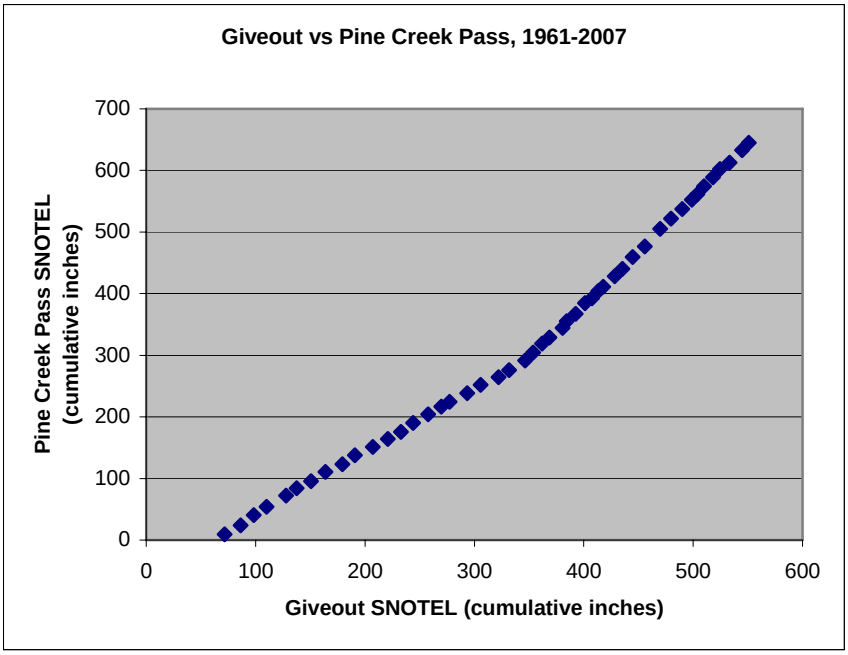

Figure 2 Pine Creek Pass plotted against the Giveout SNOTEL (plot shows very poor agreement)

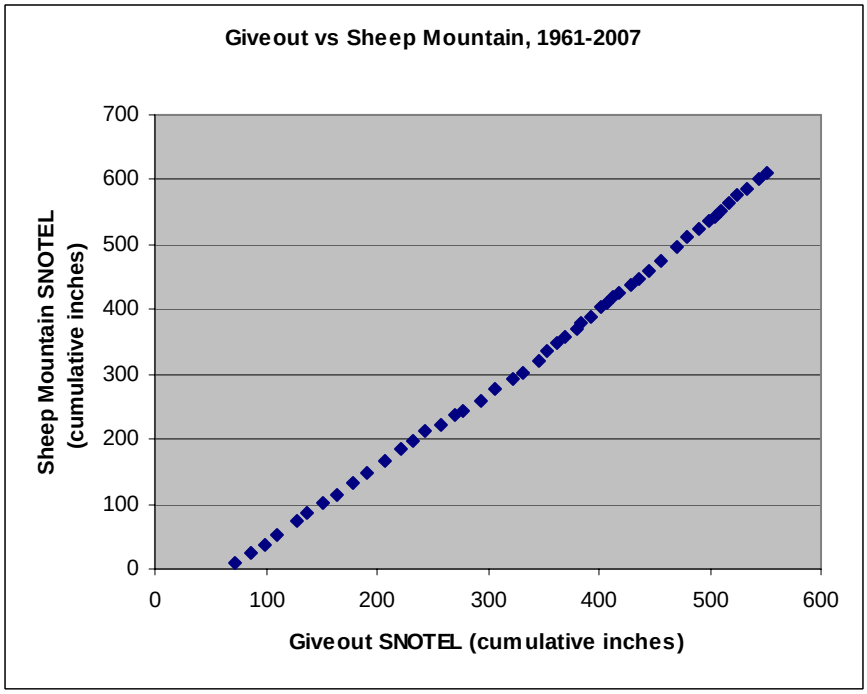

Figure 3 Sheep Mountain plotted against the Giveout SNOTEL (plot shows relatively good agreement)

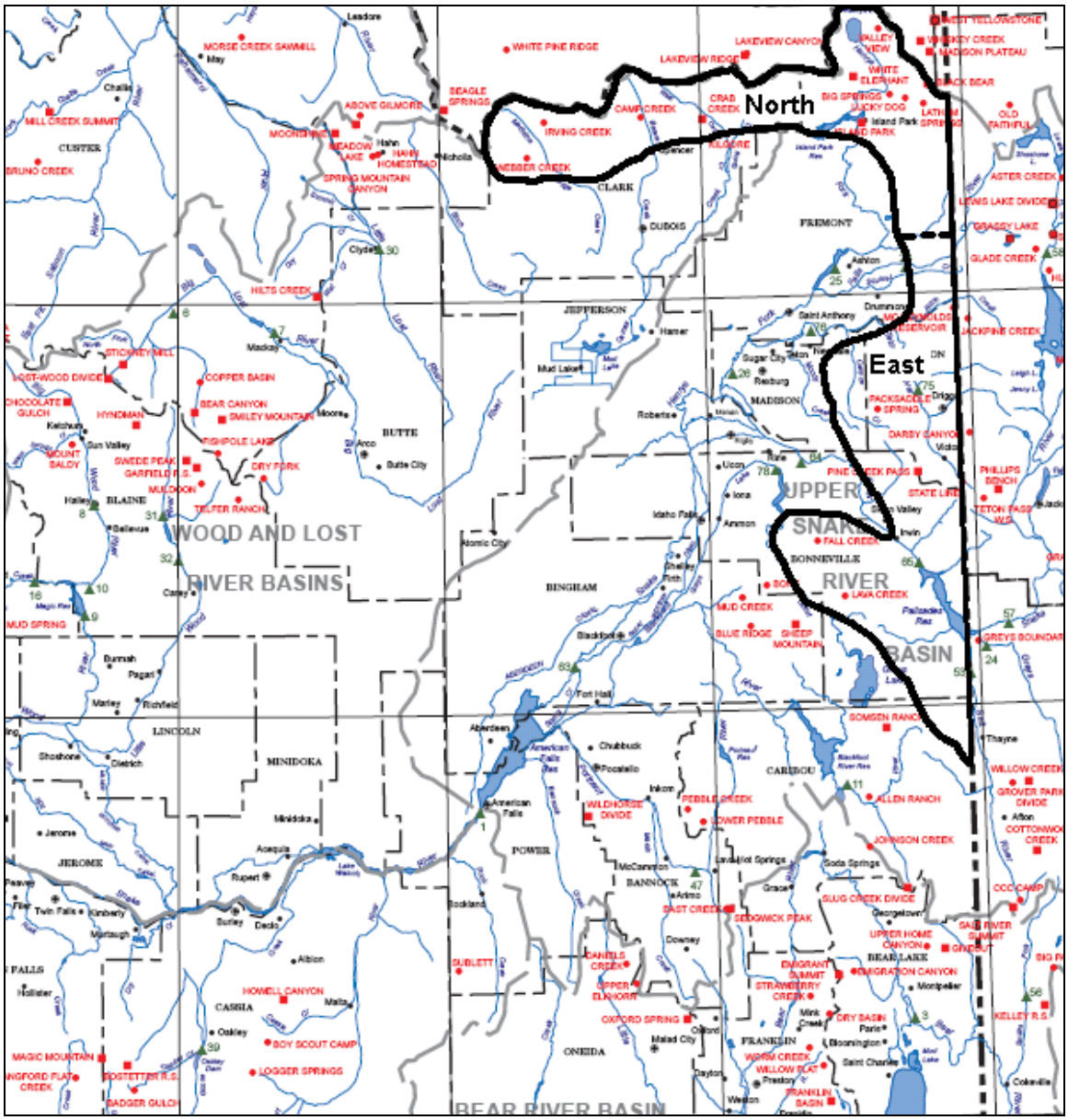

Figure 4 Target area division between "north" and "east", overlain on a map with NRCS SNOTEL and manual snowcourse site locations

Table 1 contains a list of sites excluded from consideration due to the double-mass plot analyses. Table 2 provides target and control sites selected for the evaluations, as well as the resulting linear and multiple linear equations. Figures 5 through 7 provide the locations of the target and control sites for the North target precipitation and snow water content, and the East target snow water content regression equations.

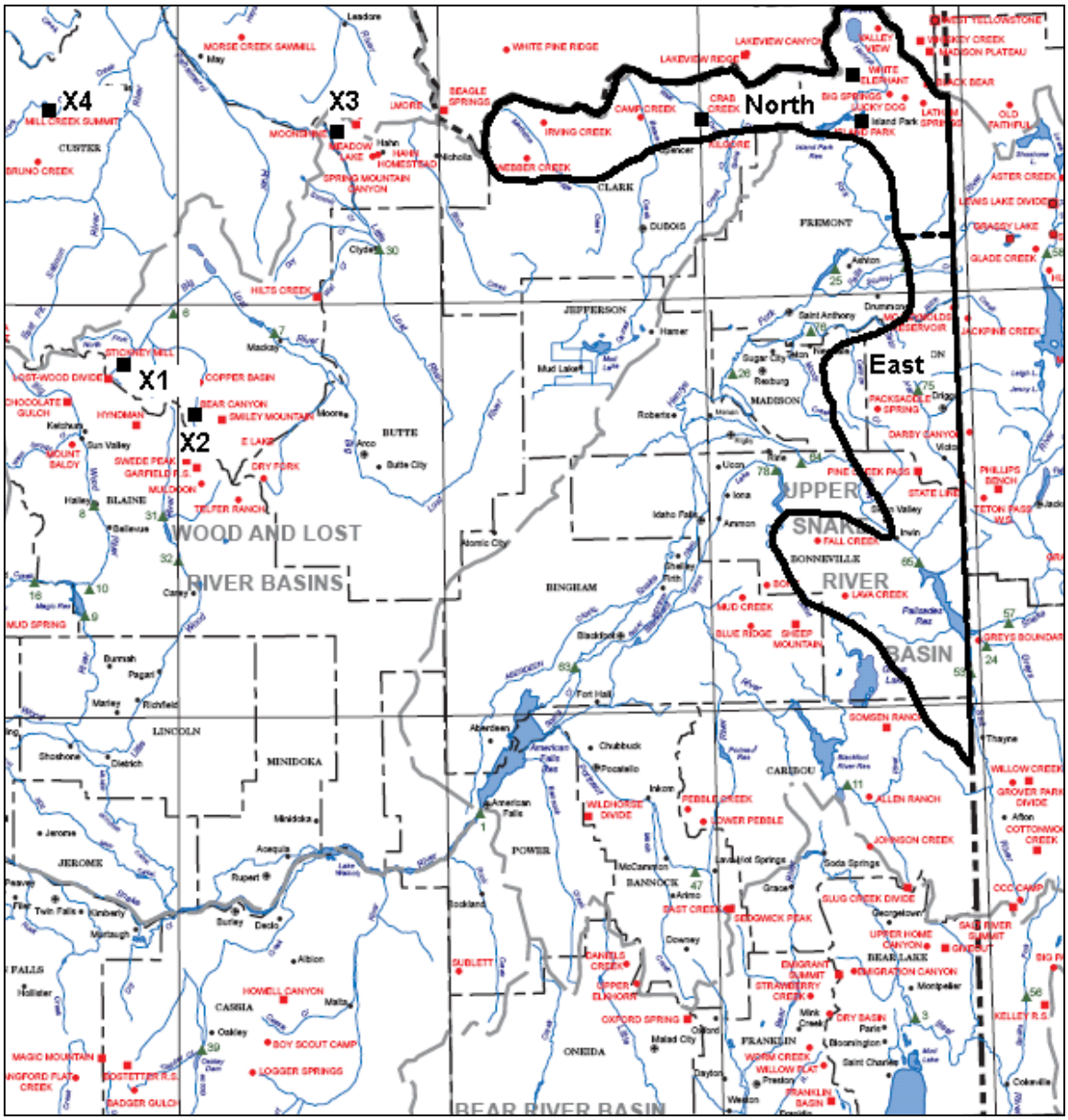

Figure 5 Map with final precipitation evaluation sites for the North target highlighted as black squares (control sites labeled to correspond with Table 2)

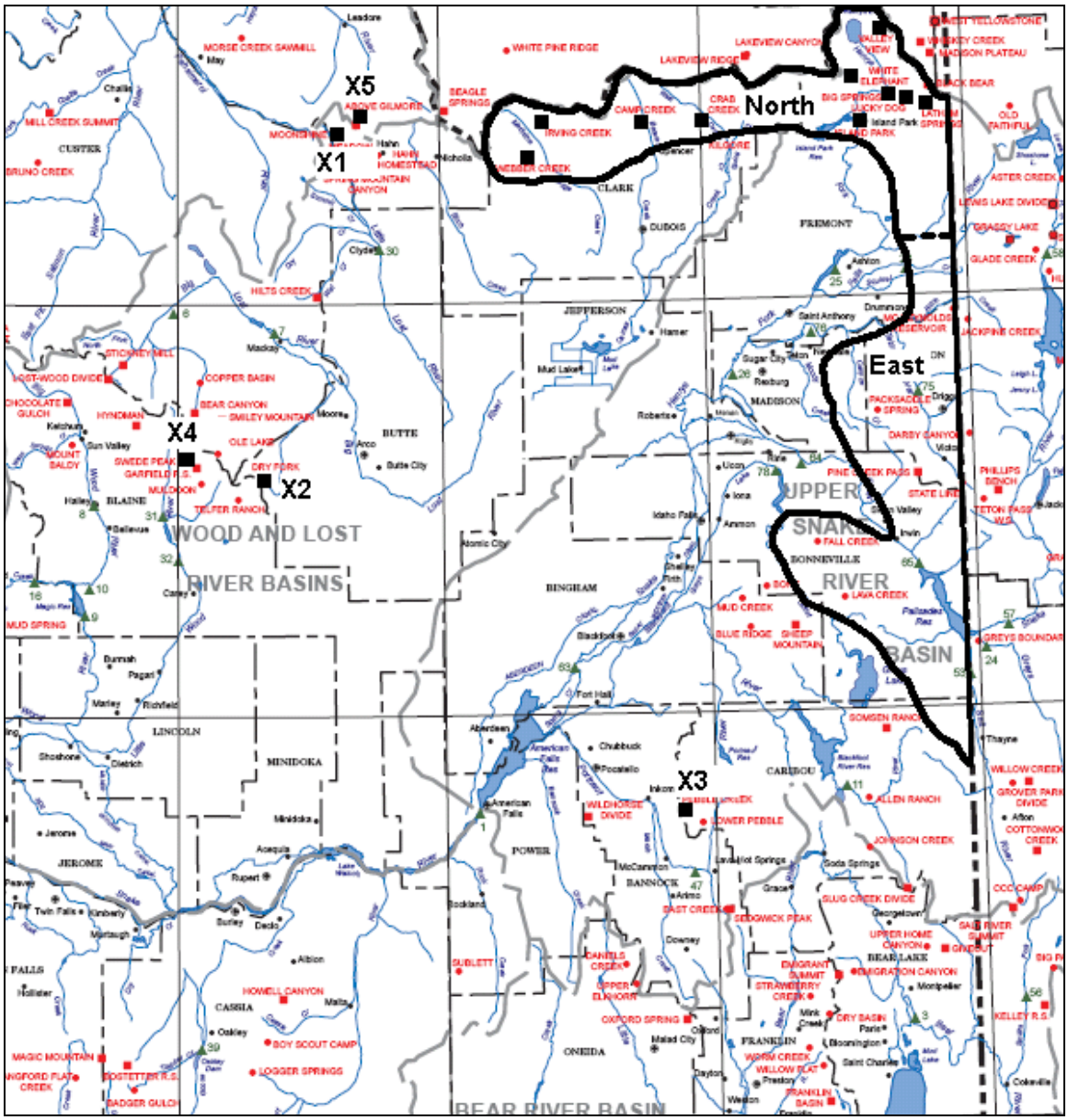

Figure 6 Map with final snowpack evaluation sites for the North target area

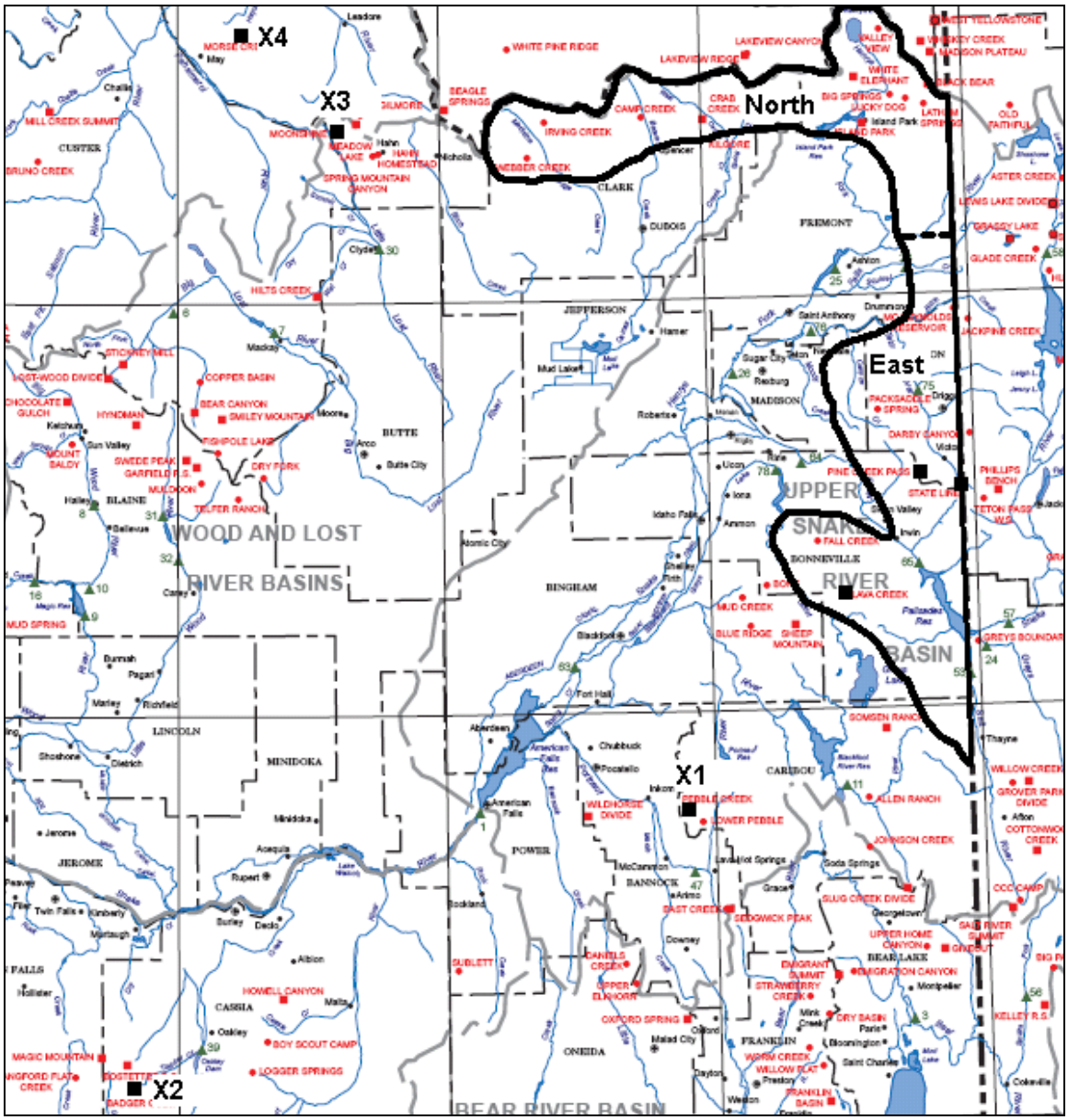

Figure 7 Map with final snowpack evaluation sites for the East target area

Table 1
Sites Excluded Based on Double Mass Plots

Dec-Mar Precip (SNOTEL)
Howell Canyon
Hilts Creek
Pine Creek Pass
Beagle Springs

Dec-Mar Precip (NWS Co-op)
Hamer 4NW
Dubois Exp Station

April 1 Snow (SNOTEL)
Bear Canyon
Oxford Spring

April 1 Snow (Snowcourse)
Langford Flat Creek
Daniels Creek
Bone

The difference between a linear and a multiple-linear equation is that for a linear equation all the potential control sites data for a specific season are averaged together. An equation is then developed between the single control area average values by season versus the single average target area values. Multiple-linear equations are those that allow the regression technique to consider individual site data instead of an average to correlate with the average target area values. In this manner, the regression technique weights the individual correlation of each control site with the target area average to obtain the best correlation.

In this analysis there were only very small differences indicated in the use of linear versus multi-linear equations. This conclusion is based on the very high and similar r values found using either technique. Recall that a perfect correlation would have an r value of 1.0. Therefore, the r values of .95 achieved in this analysis are considered quite high. This means that use of the selected control sites to predict the natural target area precipitation or snow water content for the 2008-2009 winter season should provide a good estimate. These high correlations should strengthen our ability to detect any differences that might be attributed to the seeding program.

Table 2
Regression Equations

North Target – December through March Precipitation:

Control (X)	Target (Y)
Stickney Mill SNOTEL (X_1)	Crab Creek SNOTEL
Bear Canyon SNOTEL (X_2)	White Elephant SNOTEL
Moonshine SNOTEL (X_3)	Island Park SNOTEL
Mill Creek Summit SNOTEL (X_4)	

Linear: $Y = 1.05(X) + 3.9$ ($r = 0.94$)
Multiple Linear: $Y = 0.56(X_1) + 0.21(X_2) + 0.21(X_3) + 0.12(X_4) + 4.5$ ($r = 0.95$)

North Target – April 1st Snowpack:

Control (X)	Target (Y)
Moonshine SNOTEL (X_1)	Crab Creek SNOTEL
Dry Fork snowcourse (X_2)	Island Park SNOTEL
Pebble Creek snowcourse (X_3)	White Elephant SNOTEL
Swede Peak SNOTEL (X_4)	Lucky Dog snowcourse
Above Gilmore snowcourse (X_5)	Big Springs snowcourse
	Valley View snowcourse
	Camp Creek snowcourse
	Irving Creek snowcourse
	Webber Creek snowcourse
	Latham Springs snowcourse

Linear: $Y = 1.05(X) + 3.4$ ($r = 0.95$)
Multiple Linear: $Y = 0.54(X_1) + 0.10(X_2) + 0.19(X_3) + 0.19(X_4) + 0.03(X_5) + 3.6$ ($r = 0.96$)

East Target – April 1 Snowpack:

Control (X)	Target (Y)
Pebble Creek snowcourse (X_1)	Pine Creek Pass SNOTEL
Badger Gulch snowcourse (X_2)	Lava Creek snowcourse
Moonshine SNOTEL (X_3)	State Line snowcourse
Morse Creek Sawmill snowcourse (X_4)	

Linear: $Y = 1.05(X) + 2.4$ ($r = 0.95$)
Multiple Linear: $Y = 0.30(X_1) + 0.28(X_2) + 0.25(X_3) + 0.15(X_4) + 2.82$ ($r = 0.95$)

4.0 2008-2009 Winter Season Precipitation

Precipitation in Idaho during the period from October 1, 2008 through April 1, 2009 was near to slightly below normal. Figure 8 provides a map of the Oct. 1, 2008 through April 1, 2009 percent of normal precipitation by drainage basin in Idaho. Figure 9 provides the April 1, 2009 snowpack water content by drainage basin in Idaho.

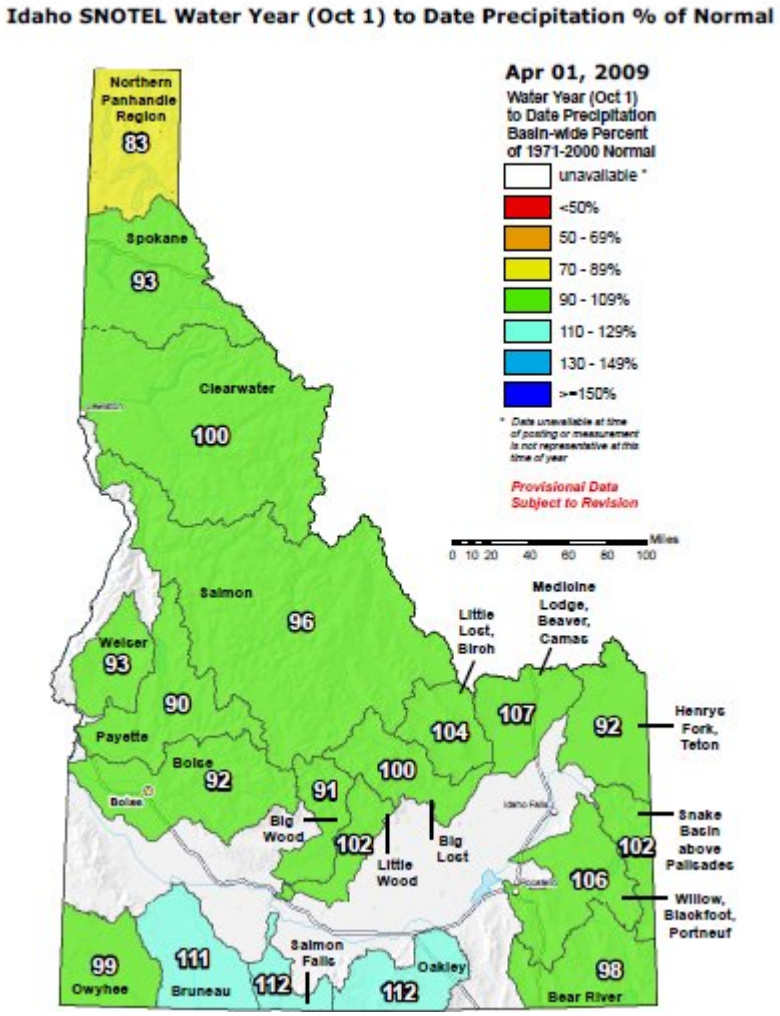

Figure 8 October 1, 2008 through April 1, 2009 Precipitation Percent of Normal by Drainage Basin in Idaho

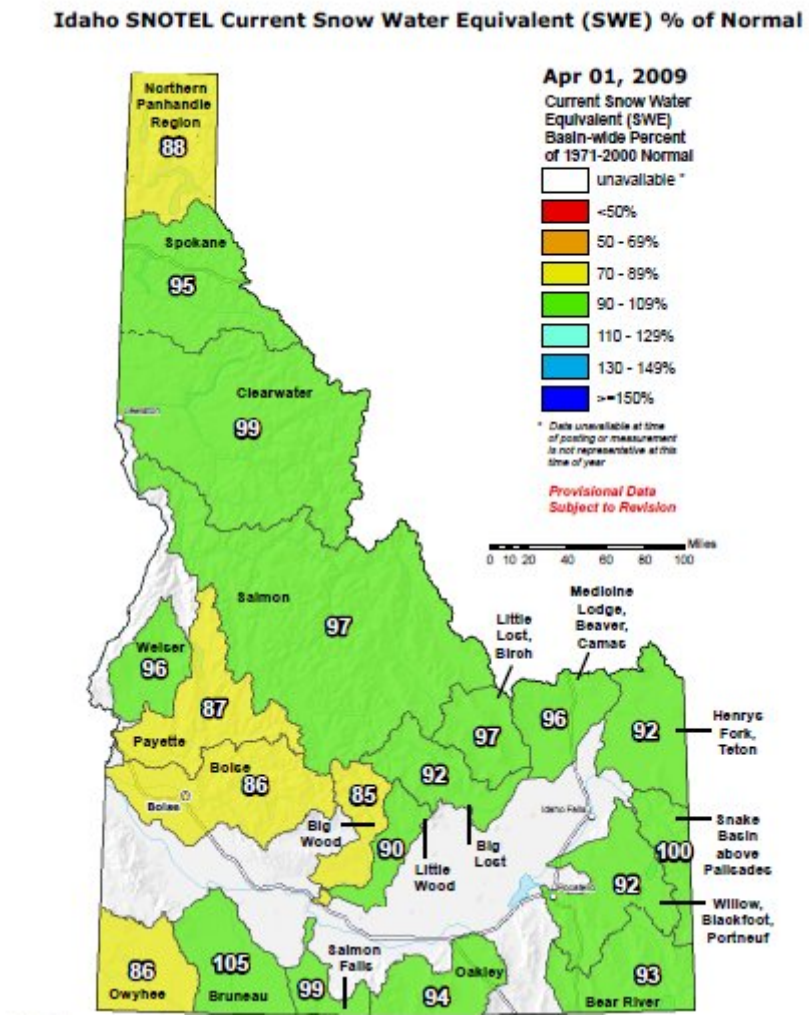

Figure 9 April 1, 2009 Snow Water Content Percent of Normal by Drainage Basin in Idaho

5.0 Results

The next step in this work was to collect the relevant target and control data from the 2008-2009 winter season once the winter season ended on March 31, 2009. The target and control station information was inserted into the appropriate equation provided in Table 2. In this manner, predictions of the average natural December-March target precipitation (for the North target area) or average target area April 1st snow water content (for both the North and East target areas) were obtained. These predicted amounts were then compared to the observed (actual) precipitation or snow water content values to see if there were any indicated differences that potentially could be attributed to the cloud seeding program. Calculations were also made for the historical seeded winter seasons of 1997-2008. The North and East areas were not always seeded during this historical period. Appendix B provides the historical seeding information provided to us by the High Country Resource Conservation and Development Council. Data found in this Appendix indicates that the amount of seeding conducted varied from periods as short as three months to as long as six months. Also, the number of seeding generators for the same target area varied from year to year. One would therefore expect varying indications of the effects of seeding from year to year. Also, estimates of any seeding effects in the months of April and May are not covered since our analyses are based either upon December through March precipitation or April 1st snow water contents. Based upon data provided in Appendix B, the water years that were considered seeded for the North area were 1997-2002, 2004, and 2006-2009 (twelve seeded seasons). The water years considered to be seeded for the East area were 2002-2005 and 2008-2009 (six seeded seasons).

Tables 3 provides the linear and multi-linear equation method calculated values and results for all of the seeded seasons. Summarized results for the snow water equivalent evaluations are shown in Table 9 and for the precipitation data evaluations in Table 10.

Table 3 North Target, April 1st Snow Water Content, <u>Linear Regression</u> Equation Results

Seeded Years:					
YEAR	XOBS	YOBS	YCALC	RATIO	EXCESS
1997	18.22	25.02	22.55	1.11	2.47
1998	11.44	15.16	15.43	0.98	-0.27
1999	15.58	20.15	19.77	1.02	0.38
2000	10.96	16.21	14.93	1.09	1.28
2001	5.54	8.78	9.24	0.95	-0.46
2002	9.88	14.90	13.79	1.08	1.11
2003	#VALUE!	11.91	#VALUE!	#VALUE!	#VALUE!
2004	8.18	15.22	12.01	1.27	3.21
2006	18.02	19.94	22.34	0.89	-2.40
2007	5.96	9.57	9.68	0.99	-0.11
2008	13.70	18.73	17.80	1.05	0.93
2009	12.00	15.93	16.02	0.99	-0.09
Mean*	**11.8**	**16.3**	**15.8**	**1.03**	**0.55**

Table 4 North Target, April 1st Snow Water Content, Multiple-Linear Regression Equation Results

Seeded Years:									
YEAR	Moonshine	Dry Fork	Pebble Creek	Swede Peak	Above Gilmore	YOBS	YCALC	RATIO	EXCESS
1997	14.80	20.40	18.40	24.00	13.50	25.02	22.20	1.13	2.82
1998	8.90	11.80	14.30	14.20	8.00	15.16	15.32	0.99	-0.16
1999	13.00	18.20	15.80	19.90	11.00	20.15	19.65	1.03	0.50
2000	8.30	12.40	11.90	13.40	8.80	16.21	14.48	1.12	1.73
2001	3.70	5.40	6.40	7.70	4.50	8.78	9.01	0.97	-0.23
2002	5.90	11.30	12.40	12.20	7.60	14.90	12.91	1.15	1.99
2003	4.70	10.20	7.50	14.70	mm	11.91	#VALUE!	#VALUE!	#VALUE!
2004	7.00	6.10	10.90	10.30	6.60	15.22	12.27	1.24	2.95
2006	14.30	19.90	19.90	23.50	12.50	19.94	22.04	0.90	-2.10
2007	5.80	4.10	6.80	6.70	6.40	9.57	9.95	0.96	-0.38
2008	12.60	12.80	17.60	15.00	10.50	18.73	18.28	1.02	0.45
2009	10.40	11.70	14.80	13.70	9.40	15.93	16.16	0.99	-0.23
Mean*	**9.5**	**12.2**	**13.6**	**14.6**	**9.0**	**16.3**	**15.7**	**1.04**	**0.67**

Table 5 North Target, December – March Precipitation, Linear Regression Equation Results

Seeded Years:					
YEAR	XOBS	YOBS	YCALC	RATIO	EXCESS
1997	17.13	25.13	21.89	1.15	3.24
1998	8.75	15.10	13.10	1.15	2.00
1999	12.40	18.67	16.93	1.10	1.73
2000	10.65	15.67	15.10	1.04	0.57
2001	4.70	7.57	8.85	0.85	-1.29
2002	9.50	13.80	13.89	0.99	-0.09
2003	10.43	11.53	14.86	0.78	-3.33
2004	10.53	16.33	14.97	1.09	1.37
2006	14.78	20.07	19.42	1.03	0.64
2007	7.68	10.97	11.98	0.92	-1.01
2008	11.95	17.90	16.46	1.09	1.44
2009	12.55	15.23	17.09	0.89	-1.86
Mean	**10.9**	**15.7**	**15.4**	**1.02**	**0.29**

Table 6 North Target, December – March Precipitation,
Multiple-Linear Regression Equation Results

Seeded Years:								
YEAR	Stickney Mill	Bear Canyon	Moonshine	Mill Creek Summit	YOBS	YCALC	RATIO	EXCESS
1997	12.80	19.20	13.20	23.30	25.13	21.29	1.18	3.84
1998	6.10	11.20	7.80	9.90	15.10	13.10	1.15	2.00
1999	8.00	14.60	10.50	16.50	18.67	16.24	1.15	2.43
2000	7.20	12.10	10.60	12.70	15.67	14.83	1.06	0.84
2001	3.30	5.10	4.90	5.50	7.57	9.11	0.83	-1.54
2002	6.30	11.40	7.60	12.70	13.80	13.55	1.02	0.25
2003	6.80	12.50	7.50	14.90	11.53	14.31	0.81	-2.78
2004	7.60	13.20	9.90	11.40	16.33	14.98	1.09	1.35
2006	11.40	19.10	12.60	16.00	20.07	19.47	1.03	0.59
2007	4.60	7.40	6.80	11.90	10.97	11.49	0.95	-0.53
2008	8.00	13.40	11.80	14.60	17.90	16.03	1.12	1.87
2009	8.90	15.30	9.90	16.10	15.23	16.72	0.91	-1.49
Mean	**7.6**	**12.9**	**9.4**	**13.8**	**15.7**	**15.1**	**1.04**	**0.57**

Table 7 East Target, April 1st Snow Water Content,
Linear Regression Equation Results

Seeded Years:					
YEAR	XOBS	YOBS	YCALC	RATIO	EXCESS
2002	10.58	12.47	13.48	0.92	-1.01
2003	6.35	12.87	9.06	1.42	3.81
2004	9.13	12.47	11.96	1.04	0.50
2005	8.65	11.67	11.47	1.02	0.20
2008	14.03	17.53	17.09	1.03	0.45
2009	11.70	15.73	14.66	1.07	1.08
Mean	**10.1**	**13.8**	**13.0**	**1.06**	**0.84**

Table 8 East Target, April 1st Snow Water Content,
Multiple-Linear Regression Equation Results

Seeded years:								
YEAR	Pebble Creek	Badger Gulch sc	Moonshine	Morse ck sawmill sc	YOBS	YCALC	RATIO	EXCESS
2002	12.40	15.80	5.90	8.20	12.47	13.64	0.91	-1.17
2003	7.50	4.20	4.70	9.00	12.87	8.76	1.47	4.11
2004	10.90	13.00	7.00	5.60	12.47	12.28	1.02	0.19
2005	12.50	9.80	6.90	5.40	11.67	11.79	0.99	-0.13
2008	17.60	16.80	12.60	9.10	17.53	17.24	1.02	0.30
2009	14.80	10.20	10.40	11.40	15.73	14.37	1.09	1.36
Mean	**12.6**	**11.6**	**7.9**	**8.1**	**13.8**	**12.7**	**1.08**	**1.05**

Tables 9 and 10 summarize the results obtained using the historical target/control methodology for April 1st snow water content, aka snow water equivalent (SWE), and December through March precipitation. A reminder, there were/are not enough high elevation precipitation stations in the East target to establish December through March precipitation regression equations. Results are shown for both the linear and multiple-linear regression equations.

Table 9 Results for April 1st Snow Water Content

Target	Predicted Apr. 1 SWE	Observed Apr. 1 SWE	Ratio Predicted/Observed SWE	Observed minus Predicted SWE (inches)
North Linear Eq. WY 2009	16.0	15.9	0.99*	-0.09
North Linear Eq. WY 1997-2009	15.8	16.3	1.03*	0.55
North Multi-Linear Eq. WY 2009	16.2	15.9	0.99	-0.23
North Multi-Linear Eq. WY 1997-2009	15.4	14.7	1.04	0.29
East Linear Eq. WY 2009	14.7	15.7	1.07	1.08
East Linear Eq. WY 2002-05, 2008-09	13.0	13.8	1.06	0.84
East Multi-Linear Eq. WY 2009	14.4	15.7	1.09	1.36
East Multi-Linear Eq. WY 2002-05, 2008-09	12.7	13.8	1.08	1.05

* Missing data in WY 2003, not included in calculations.

Table 10 Results for December – March Precipitation, North Area

Target	Predicted Dec. – Mar. Precipitation (inches)	Observed Dec. – Mar. Precipitation (inches)	Ratio Predicted/Observed Dec. – Mar. Precipitation	Observed minus Predicted Dec. – Mar. Precipitation (inches)
North Linear Eq. WY 2009	17.1	15.2	0.89	-1.86
North Linear Eq. WY 1997-2009	15.4	15.7	1.02	0.29
North Multi-Linear Eq. WY 2009	16.7	15.2	0.91	-1.49
North Multi-Linear Eq. WY 1997-2009	15.1	15.7	1.04	0.57

6.0 Discussion

We used the same target and control sites and regression equations as those developed for the previous winter's evaluations. There were no missing data for the 2008-2009 winter season. Therefore, there should be no question of bias on NAWC's part since the target and control sites were selected prior to the beginning of the 2008-2009 winter season (e.g., this represents an *a priori* analysis). It is noted that the linear and the multi-linear regression techniques provide very similar estimates. This is a desirable result that indicates stability in the target and control relationships. Discussion of the results are broken down into the North and East target areas.

6.1 North Target Area

The ratios of observed over calculated April 1st snow water content for WY 2009 using the linear and multi-linear equations suggest a 1% decrease in water content. Such a small indicated difference is considered insignificant. This single-season result is not indicative of a seeding effect for WY 2009. Results for all of the seeded seasons, WY 1997-2009, suggest average increases in water content of 3-4%. The average estimated increases in the April 1st snow water content for all the seeded seasons range from 0.29 to 0.55 inches.

The ratios of observed over calculated December through March precipitation using the linear and multi-linear equations suggest a 9-11% decrease in water content for

WY 2009. NAWC does not believe that cloud seeding can reduce precipitation. We attribute indications of negative results to inexact predictions from the historical regression equations used in this analysis. This also points out why we do not focus upon single season estimates. **We consider the average of results over a number of seasons to be more representative of the actual effects of cloud seeding.** Results for all of the seeded seasons, WY 97-09, suggest average increases in December through March precipitation of 2-4%. The average estimated increases in December through March precipitation for the entire seeded period (WY 97-09) range from 0.29 to 0.57 inches.

6.2 East Target Area

The ratios of observed over calculated April 1st snow water content for WY 2009 using the linear and multi-linear equations suggest a 7-9 % increase in water content. Results for all of the seeded seasons, WY 2002-2005, 2008-2009, suggest average increases in water content of 6-8%. The average estimated increases in April 1st snow water content for WY 2009 are in the range of 1.08 to 1.36 inches of additional water content. Similar estimates for the entire seeded period (WY 2002-05, 2008-2009) range from 0.84 to 1.05 inches.

6.3 Other Considerations

The estimated increases in snow water content or December through March precipitation are area averages and can be visualized as being spread over the target area. For example, the estimated average 0.29 to 0.55 inches of additional snow water content for the northern target area for the seeded seasons from WY 1997 to WY 2009 are assumed to be distributed equally over the target area. The results for the northern area April 1st snow water contents may be more representative of possible seeding effects since there were more target area gages available for inclusion in that analysis than in the precipitation analysis.

6.4 Notable Changes

Idaho Power decided to augment the Eastern Snake River Basin cloud seeding program beginning with the 2008-2009 winter season. This augmentation was primarily in the form of additional seeding and observational equipment to the program. Three remotely operated, ground based silver iodide generators were added to the program. A radiosonde release site was installed near St. Anthony, Idaho. Weather balloons were released from this site during storm periods. These observations provide measurements of temperature, dew point and winds with height. A microwave radiometer was also installed for the winter season near Ashton, Idaho. This device senses a number of variables in the atmosphere above the site including the presence of supercooled cloud droplets, which are the targets of opportunity to increase precipitation. Figure 1 provides the locations of these additions.

NAWC completed a weather modification feasibility study for the Upper Snake River Basin in Idaho in October 2008 (Griffith, et al, 2008). The Idaho Water Resource Board funded this study. This study covered the same areas of interest as those in this operational Eastern Snake River Basin seeding program. NAWC's study recommended both the rawinsonde releases during storm periods and the collection of icing meter or radiometer data. There were two primary questions of uncertainty identified in NAWC's study:

1. How frequent are atmospheric inversions during winter storm periods in this area and what are the altitudes of these inversions? Atmospheric inversions can restrict the transport of the silver iodide seeding material released from ground-based generators. Indirect evidence used by NAWC suggests that such inversions are rather frequent in this area. If inversions occur that limit transport of the ground based releases of silver iodide to at least the height of the -5^0 C level (the temperature at which silver iodide begins to function as an effective seeding agent) when supercooled water is present in the storm clouds, then seeding potential is lost.

2. Where and when does supercooled liquid water exist for prolonged periods of a few hours during winter storms in this area? This supercooled liquid water is the target of the seeding operations. Again, NAWC used some indirect evidence to discern when supercooled water might be occurring over the target areas.

The rawinsonde data can be used to answer the first question and the radiometer data can be used to answer the second question. Hopefully, Idaho Power will perform detailed analyses of these data sets to begin to answer these important questions. Also, another season or two of these types of observations would provide a more representative database from which answers to these questions could be based.

References

Dennis, A.S., 1980: Weather Modification by Cloud Seeding. *International Geophysical Series*, 24, Academic Press, New York, NY.

Griffith, D.A., D.P. Yorty and M.E. Solak: Weather Modification Feasibility Study for the Upper Snake River Basin in Idaho. NAWC report # WM 08-11 to Idaho Water Resouces.

Risch, D.A., J.R. Thompson and D.A. Griffith, 1995: Summary of Operations and Evaluation of a Cloud Seeding Program for Portions of the Upper Snake River Drainage in Idaho. North American Weather Consultants Report No. 95-10 to High Country RC & D.

Appendix A

Eastern Snake River Basin Detailed Seeding History

Cloud Seeding Archives

Region most likely impacted	County	Location	Hours Run 1996					Hours Run 1996-1997		
			Feb	Mar	Apr	Nov	Dec	Jan	Feb	Mar
North	Clark	Crooked Creek								
North	Clark	Kilgore								
North	Clark	Lone Pine	9.25	22.25	31.25	11	15.25			17
North	Clark	Lower Medicine Lodge	23.5	32	16.75	31.75	18			24
North	Clark	Radar	27.25	37.5	32.75	81.5	15			3
North	Clark	Sheep Station	21.75	33.5	24.25	52.75	15			3
North	Clark	Small								
North	Clark	Upper Medicine Lodge								
North	Clark	Warm Springs	32.5	36.25	13.75	25.25	16.25			6
East	Bonneville	Bone								
East	Bonneville	Gray's Lake	23.75	24.5						
East	Bonneville	Herman	24.25	6.5						
East	Bonneville	Pine Creek								
East	Bonneville	Sheep Creek								
East	Bonneville	Swan Valley	39.5	43						
North	Fremont	Ashton	28.5	66.25						
Both ?	Fremont	Fall River								
Both ?	Fremont	Green Timber								
North	Fremont	Herys Lake (Valley View)	22	51						
North	Fremont	Island Park (Last Chance)	37	60.25						
Both ?	Fremont	Lamont								
North	Fremont	Sadoris								
Both ?	Fremont	Squirrell								
North	Fremont	Swan Lake (Pine Haven)	47.75	43.25						
East	Madison	Green Canyon	30	60	4.75					
East	Madison	Kelly Canyon	13.5	4.5						
East	Teton	Driggs	72.25	45						
East	Teton	Felt								
East	Teton	Tetonia (Robison)	48	21.5	3					
East	Teton	Victor	19	75.5						

Cloud Seeding Archives

Region most likely impacted	County	Location	Hours Run 1998 Jan	Feb	Mar	Dec	Hours Run 1998-1999 Jan	Feb	Mar
North	Clark	Crooked Creek							
North	Clark	Kilgore		73.25	18.5	25.5	80	33	10.75
North	Clark	Lone Pine	20	9.75	5.5	15.5	32	1.5	10
North	Clark	Lower Medicine Lodge	51	48.5	11.5	28.5	46.25	49.5	9
North	Clark	Radar	42.5	24.5	19.75	16.5	52.25	21.75	12
North	Clark	Sheep Station	41.5	45	14.5	16.75	35.5	14.75	3.75
North	Clark	Small							
North	Clark	Upper Medicine Lodge		52	17		20.25	20	9.5
North	Clark	Warm Springs	34	61	12	11.75	59.5	34.5	5.5
East	Bonneville	Bone							
East	Bonneville	Gray's Lake							
East	Bonneville	Herman							
East	Bonneville	Pine Creek							
East	Bonneville	Sheep Creek							
East	Bonneville	Swan Valley							
North	Fremont	Ashton							
Both ?	Fremont	Fall River							
Both ?	Fremont	Green Timber							
North	Fremont	Herys Lake (Valley View)							
North	Fremont	Island Park (Last Chance)							
Both ?	Fremont	Lamont							
North	Fremont	Sadoris							
Both ?	Fremont	Squirrell							
North	Fremont	Swan Lake (Pine Haven)							
East	Madison	Green Canyon							
East	Madison	Kelly Canyon							
East	Teton	Driggs							
East	Teton	Felt							
East	Teton	Tetonia (Robison)							
East	Teton	Victor							

Cloud Seeding Archives

Region most likely impacted	County	Location	Hours Run 2000 Jan	Feb	Mar	Hours Run 2000-2001 Dec	Jan	Feb	Mar
North	Clark	Crooked Creek							
North	Clark	Kilgore	18.25	95	47.5	21	69	45	20
North	Clark	Lone Pine	41.75	49.25	18.75	30.75	69	21.5	12
North	Clark	Lower Medicine Lodge	10	89.5	36	25	70	45	12
North	Clark	Radar	14.75	62.25	19.25	26	64	46.5	3.5
North	Clark	Sheep Station	5.5	90.5	19.5	26.25	64.5	46.5	4
North	Clark	Small							
North	Clark	Upper Medicine Lodge	6.5	87.5	11	24	61.75	54.5	6.5
North	Clark	Warm Springs	27.5	65.75	36.5	24.25	37.5	14.75	
East	Bonneville	Bone							
East	Bonneville	Gray's Lake							
East	Bonneville	Herman							
East	Bonneville	Pine Creek							
East	Bonneville	Sheep Creek							
East	Bonneville	Swan Valley							
North	Fremont	Ashton							
Both ?	Fremont	Fall River							
Both ?	Fremont	Green Timber							
North	Fremont	Herys Lake (Valley View)							
North	Fremont	Island Park (Last Chance)							
Both ?	Fremont	Lamont							
North	Fremont	Sadoris							
Both ?	Fremont	Squirrell							
North	Fremont	Swan Lake (Pine Haven)							
East	Madison	Green Canyon							
East	Madison	Kelly Canyon							
East	Teton	Driggs							
East	Teton	Felt							
East	Teton	Tetonia (Robison)							
East	Teton	Victor							

Region most likely impacted	Cloud Seeding Archives County	Location	Hours Run 2001-2002 Dec	Jan	Feb	Mar	Apr	May	Hours Run 2002-2003 Nov	Dec	Jan	Feb	Mar	Apr
North	Clark	Crooked Creek												
North	Clark	Kilgore	71	29.5	30	18			1	82.75	55.5	30.5	19	16.5
North	Clark	Lone Pine	68.5	10	22	13.5			11.5	33.5	32.5	7	20.5	
North	Clark	Lower Medicine	65.5	10.5	13	9			4.5	23.25	33.5	13.5	8.5	10
North	Clark	Radar	53.5	16.25	17.5	9.5			7.25	48.5	28.75	24.25	5	
North	Clark	Sheep Station	52.5	14	17.5	9			7.25	46.75	27.25	26.25	5	
North	Clark	Small							8.5	48	40	27.75		
North	Clark	Upper Medicine	28.5	10.5										
North	Clark	Warm Springs	26.25		6.5				9	50	5.5	33		
East	Bonneville	Bone		80.75	30	58.25	39.25	18		134.25	45.42	102	78.75	
East	Bonneville	Gray's Lake								143.5	71	10.75	24.25	9.5
East	Bonneville	Herman												
East	Bonneville	Pine Creek	47	15.75	17.5	27.25	21		17	60.75	31	59.75	9	
East	Bonneville	Sheep Creek									37	27	43	
East	Bonneville	Swan Valley	26	45		34	9		18	92.5	36.5	59	20.5	
North	Fremont	Ashton												
Both ?	Fremont	Fall River							13	44	52	27	3	13
Both ?	Fremont	Green Timber							14.5	88	52.25	48.75	4	3.5
North	Fremont	Herys Lake												
North	Fremont	Island Park	23.25	55.75	18.5	3.5	32.5		6	61.25	53	55	19.25	2.75
Both ?	Fremont	Lamont												
North	Fremont	Sadoris	35.5	37	13	9	47.5		17.5	56.75	35	28.5		
Both ?	Fremont	Squirrell	65.5	58.5	13.25	26	10.25	4	9.25	148.5	80	35	11.5	
North	Fremont	Swan Lake												
East	Madison	Green Canyon												
East	Madison	Kelly Canyon	11	17.5	37	60.5				10.5	23	79.5	32	
East	Teton	Driggs	97.5	64	10	86		4.5	13.25	122.25	79.5	64.5	52	
East	Teton	Felt	41.5	52.5	21	37	28			116	76.5	36.5	56.5	
East	Teton	Tetonia								77.25	45.5	25		
East	Teton	Victor	40.5	27.5	22.5	20	22.5		9.25	11.5	67.25	68	29.25	11

Cloud Seeding Archives

Region most likely impacted	County	Location	Hours Run 2003-2004					Hours Run 2004-2005					
			Nov	Dec	Jan	Feb	Mar	Nov	Dec	Jan	Feb	Mar	Apr
North	Clark	Crooked Creek											
North	Clark	Kilgore	24.5	73	31	76.5	6.5						
North	Clark	Lone Pine		39	53.75								
North	Clark	Lower Medicine Lodge	24.5	58.5	11	39.5	5						
North	Clark	Radar	15.25	74.25	28	65							
North	Clark	Sheep Station	14	66	27.5	68.75							
North	Clark	Small		104	7.5	34.5							
North	Clark	Upper Medicine Lodge											
North	Clark	Warm Springs		80	10.5	74							
East	Bonneville	Bone		60	42.25	28.25		21.25	41.25	49	29.75	10.75	
East	Bonneville	Gray's Lake		117.75	97.5	49.5		21.25	60.75	28.25	73	75.75	14
East	Bonneville	Herman											
East	Bonneville	Pine Creek		101.5	107.5	43	6.5	17	17	36	33.5	16.5	
East	Bonneville	Sheep Creek		321	6	135	52	28.5	100	81.5	73	83	30
East	Bonneville	Swan Valley		79.5	18.25	89.5	6	12.5	15	18	48	28	15
North	Fremont	Ashton											
Both ?	Fremont	Fall River		10.5	34.25	52	16.5	16	64.5	50	9.5	24	21.5
Both ?	Fremont	Green Timber		45.75	42	72.5	2		60.5	45.5	42.5	42.5	27.5
North	Fremont	Herys Lake (Valley View)											
North	Fremont	Island Park (Last Chance)		65.5	35.75	58	4	7.5	33.5	26	10.25	57.75	7.5
Both ?	Fremont	Lamont						21.5	25.5	52.5	58.5	63	33.5
North	Fremont	Sadoris		54	50.5	43		9	27.5	86.5	44	16.5	21
Both ?	Fremont	Squirrell		24.25	7	44							
North	Fremont	Swan Lake (Pine Haven)											
East	Madison	Green Canyon											
East	Madison	Kelly Canyon		97	60.5	54.5				19.5	85		
East	Teton	Driggs		173.5	71	77	43.5	149	44	108.5			
East	Teton	Felt		66.5	46.5	114.5	32	8	47	62.5	23	47	17.75
East	Teton	Tetonia (Robison)		10.5	15	29		11	9	13	42	14	14.5
East	Teton	Victor		69.75	46.5	19			92	100	59	66.75	24

Cloud Seeding Archives

Region most likely impacted	County	Location	Hours Run 2005-2006					Hours Run 2006-2007			
			Nov	Dec	Jan	Feb	Mar	Nov	Dec	Jan	Feb
North	Clark	Crooked Creek							48.75	16.25	44
North	Clark	Kilgore	37	84.5	81	34	66	20	30.5	37	63.5
North	Clark	Lone Pine		11.5	16.25		17				
North	Clark	Lower Medicine Lodge	14	41	51	14.5	68.5		13	8	53
North	Clark	Radar	12.75	89.5	47	27.5	71		30.25	8.25	23.75
North	Clark	Sheep Station	11.75	88.5	47.75	24	68.5		30.25	8.75	17.5
North	Clark	Small							23	10	23
North	Clark	Upper Medicine Lodge	12	63	58	17	52.5				
North	Clark	Warm Springs		76			44				
East	Bonneville	Bone									
East	Bonneville	Gray's Lake									
East	Bonneville	Herman									
East	Bonneville	Pine Creek									
East	Bonneville	Sheep Creek									
East	Bonneville	Swan Valley									
North	Fremont	Ashton									
Both ?	Fremont	Fall River									
Both ?	Fremont	Green Timber									
North	Fremont	Herys Lake (Valley View)									
North	Fremont	Island Park (Last Chance)									
Both ?	Fremont	Lamont									
North	Fremont	Sadoris									
Both ?	Fremont	Squirrell									
North	Fremont	Swan Lake (Pine Haven)									
East	Madison	Green Canyon									
East	Madison	Kelly Canyon									
East	Teton	Driggs									
East	Teton	Felt									
East	Teton	Tetonia (Robison)									
East	Teton	Victor									

Summary for Seeding Operations in Eastern Idaho 2008-2009

County	Location	Nov-08	Dec-08	Jan-09	Feb-09	Mar-09	Apr-09	Total	Budget
Bingham	Wolverine Canyon		24	17	22.25	12	13.25	88.5	
Bonneville	Bone		33.5	21.5	10	0	0	65	
Bonneville	Gray's Lake	5.75	17.5	58.25	21	44.5	5.5	152.5	
Bonneville	Gray's Lake-2 Tingey	7.5	42.5	41.5	11	17.5	31.25	151.25	
Bonneville	Palisades		83.5	139.5	71.5	105.5	32	432	
Bonneville	Pine Creek		40	23	23.75	5.5	14.5	106.75	
Bonneville	Swan Valley		15	68	16.5	23	23.5	146	
Clark	Lone Pine		0	22.5	37.5	33.5	0	93.5	
Clark	Crooked Creek		40.75	6.25	23.5	31.5	6	108	
Clark	Lower Medicine Lodge		28.5	2.5	3.5	9.5	0	44	
Clark	Upper Medicine Lodge		11	9	7	13.5	7	47.5	
Clark	Radar		18	7	17.75	31.75	13.25	87.75	
Clark	Sheep Station		18	2.5	13.75	28.75	7.5	70.5	
Fremont	Cave Falls		17.5	29.25	24.75	0	29	100.5	
Fremont	Fall River		29.5	23.5	30	2.5	8	93.5	
Fremont	Island Park		18.75	19	18.5	3.5	22.25	82	
Fremont	Lamont-Martindale	6	27	62.5	70.5	26	53.5	245.5	
Fremont	Sadoris Hill		26	29	46.5	4	18	123.5	
Fremont	Shotgun		21.5	14	9	20.5	26.5	91.5	
Fremont	Lamont-Hill		17	33	5	0	0	55	
Teton	Felt-Smith	19.5	41.25	43	65.5	81.5	41.5	292.25	
Teton	Driggs		47	42	39.5	42	19	189.5	
Teton	Tetonia		24	45.5	21	22	16	128.5	
Teton	Victor		55.5	51.25	18.25	28	16.5	169.5	
	TOTALS	38.75	697.25	810.5	627.5	586.5	404	3164.5	5750
	Avg. Per Generator	1.61458	29.0521	33.7708	26.1458	24.4375	16.8333	131.854	

Summary for Remote Controlled Seeding Operations in Eastern Idaho 2008-2009

County	Location	Nov-08	Dec-08	Jan-09	Feb-09	Mar-09	Apr-09	Total
Clark	Kilgore		21.6	15.7	10.2	41.4	21.9	110.8
Fremont	Antelope		8.1	1.6	13.8	45.3	15.7	84.5
Madison	Kirkham		52.8	39.8	18.5	50.5	13.6	175.2
TOTALS		0	82.5	57.1	42.5	137.2	51.2	370.5

North American
Weather Consultants, Inc.

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

801-942-9005