Idaho Collaborative Cloud Seeding Program
2021-22 Winter Season
End of Season Report

Prepared by

Idaho Power

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Evaluation of the Operational Upper Snake River Cloud Seeding Program in Idaho, 2021-2022 Winter Season

1.0 Introduction/History

The following report was prepared by Idaho Power following the end of cloud seeding operations for the WY2022 cloud seeding season.

Cloud seeding has occurred in the Snake River Basin, in one format or another, since the late 1980s. Early operations where primarily conducted by North American Weather Consultants (NAWC) using lower elevation manually controlled ground based generators (Table 1). These operations were taken over in the Upper Snake in 1996 by the High-Country RC&D (operated by Let It Snow-LIS), also using manual ground based generators. Beginning in the early 1990s, Idaho Power Company (IPC) begin investigating the potential of cloud seeding as part of its long-term water management strategy. After a comprehensive climatology study, a pilot project (WY1997) and considerable discussions with the State of Idaho, IPC begin cloud seeding operations in the Payette River Basin with seven higher elevation, satellite controlled (remote) ground based generators and one contract aircraft (operated by Weather Modification International – WMI). IPC slowly expanded its operations in the Payette Basin as it saw the effectiveness of its operations. In 2008, IPC began collaborating with the HC RC&D to enhance their program in the Upper Snake. This collaboration was a 5-year pilot project that was part of the Comprehensive Aquafer Management Plan (CAMP). The enhancement added remote ground based generators at high elevations in the Upper Snake region to augment the LIS manually controlled ground generators and IPC started working with the Western Wyoming RC&D to evaluate cloud seeding opportunities in western Wyoming. In 2011 IPC began working with the National Center for Atmospheric Research (NCAR) to develop a Weather Research and Forecasting model (WRF) based cloud seeding module (CSM) to provide guidance for cloud seeding operations and evaluate cloud seeding effectiveness. Beginning in 2013, IPC started working with the Big Wood Canal Company to use the Payette cloud seeding aircraft to seed in the Wood River Basin when it was not operating in the Payette. This effort was followed in 2015 by further expansion in the Boise, Wood and Upper Snake River Basins with additional remote ground generators and the addition of another aircraft for seeding in the Boise and Wood Basins. This expansion was made possible by collaborative effort with the Idaho Water Resources Board (IWRB), the counties and water users in the Boise and Wood Basins. 2016 saw further expansion in the Upper Snake with the addition of an aircraft and additional remote ground generators collaboratively supported by IPC, IWRB and water users. During January-March 2017, IPC participated in a National Science Foundation (NSF) funded research project in the Payette River Basin. The **S**eeded and **N**atural **O**rographic **W**intertime clouds-the **I**daho **E**xperiment (SNOWIE) research project aimed to improve the cloud seeding module as well as extend the scientific understanding of winter orographic clouds over complex terrain, and cloud seeding processes. Since the SNOWIE Project, numerous scientific journal articles have published based upon the SNOWIE research. Two of the higher impact articles where: 1) Preceding of the National Academy of Science, French et al 2018, Precipitation formation from orographic cloud seeding, stated "… first unambiguous evidence that glaciogenic seeding of a supercooled liquid cloud can enhance natural precipitation growth in a seeded cloud, leading to precipitation that would otherwise not fall within the targeted region." And 2) Bulletin of the American Meteorological Society, Tessendorf et all 2018, A transformational approach to winter orographic weather modification research The SNOWIE Project, "measurements from SNOWIE aim to address long-standing questions about the efficacy of cloud seeding, starting with documenting the physical chain of events following seeding."

Cloud seeding operations in the Snake River Basin have grown over approximately 30 years with an emphasis on creating more water for water users. A detailed breakout, by year since 2008, showing this growth for the Idaho Power/Idaho Collaborative Cloud Seeding program through the individual basins can be found in Figure 1 and Table 1 which shows the number of ground generators seeding the basins by year.

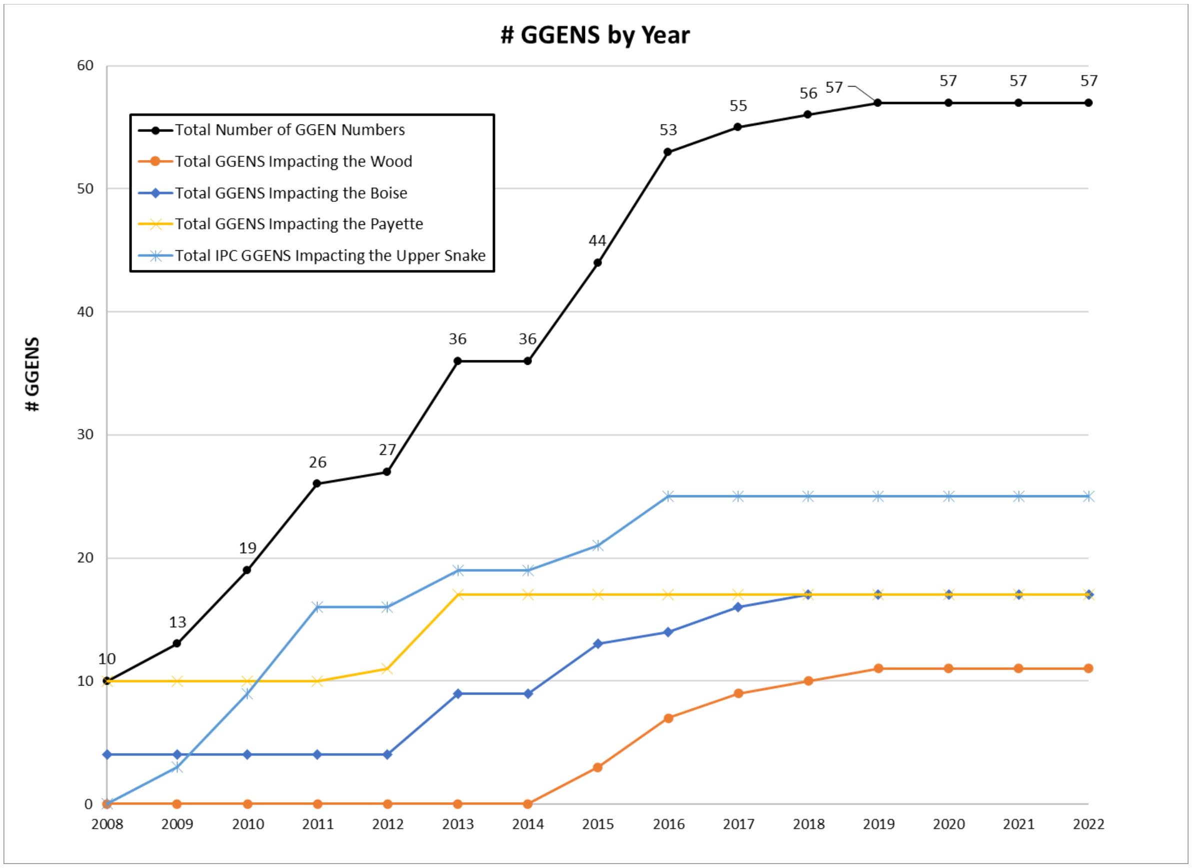

Figure 1: Number of IPC ground generators (GGENS) seeding basins by year since 2008.

Table 1: Years clouds seeding conducted in the Snake River Basin and the company's that conducted the operations (Since 1997).

Water Year	Payette	Boise	Wood	Northern Upper Snake	Southern/Eastern Upper Snake
1997	AI	*	*	LIS	*
1998	*	*	*	LIS	*
1999	*	*	*	LIS	*
2000	*	*	*	LIS	*
2001	*	*	*	LIS	*
2002	*	NAWC	*	LIS	LIS
2003	IPC	NAWC	*	*	LIS
2004	IPC	NAWC	*	LIS	LIS
2005	IPC	NAWC	*	*	LIS
2006	IPC	*	*	LIS	*
2007	IPC	*	*	LIS	*
2008	IPC	NAWC	*	LIS	LIS
2009	IPC	NAWC	*	LIS	LIS
2010	IPC	*	*	LIS/IPC	LIS/IPC
2011	IPC	NAWC	*	LIS/IPC	LIS/IPC
2012	IPC	NAWC	*	LIS/IPC	LIS/IPC
2013	IPC	*	IPC	LIS/IPC	LIS/IPC
2014	IPC	NAWC	IPC	LIS/IPC	LIS/IPC
2015	IPC	IPC	IPC	LIS/IPC	LIS/IPC
2016	IPC	IPC	IPC	LIS/IPC	LIS/IPC
2017	IPC	IPC	IPC	LIS/IPC	LIS/IPC
2018	IPC	IPC	IPC	LIS/IPC	LIS/IPC
2019	IPC	IPC	IPC	LIS/IPC	LIS/IPC
2020	IPC	IPC	IPC	LIS/IPC	LIS/IPC
2021	IPC	IPC	IPC	LIS/IPC	LIS/IPC
2022	IPC	IPC	IPC	LIS/IPC	LIS/IPC

* = No cloud seeding conducted
IPC = Idaho Power Company
NAWC = North American Weather Consultants
LIS = Let it Snow
AI = Atmospherics Inc

2.0 2021-22 Winter Season Meteorological Conditions

In the western United Sates, conditions in the Pacific Ocean appear to have a significant impact on winter temperatures and the type and amount of precipitation received in each region. El Niño Southern Oscillation (ENSO) is one of the primary indicators of the temperature of Tropical Pacific waters. El Niño is the warm phase of ENSO and indicates that the 3-month average sea surface temperatures in the central and east-central Equatorial Pacific regions are 0.5 degrees C above or warmer than normal and generally indicates warmer than normal and drier than normal winter conditions in the Snake River Plain. ENSO-neutral indicates that the 3-month average sea surface temperatures in the central and east-central Equatorial Pacific regions are between 0.5 and -0.5 degrees C and do not typically indicate either warmer/cooler or wetter/drier than normal temperatures/precipitation. La Niña is the cool phase of ENSO and indicates that the 3-month average sea surface temperatures in the central and east-central Equatorial Pacific regions are 0.5 or more degrees C cooler than normal and generally indicates milder than normal and wetter than normal winter conditions in the Snake River Plain.

During the fall of 2021, observations were indicating the tropical Pacific Ocean had transitioned from to cool neutral conditions to weak La Niña (Figure 2).

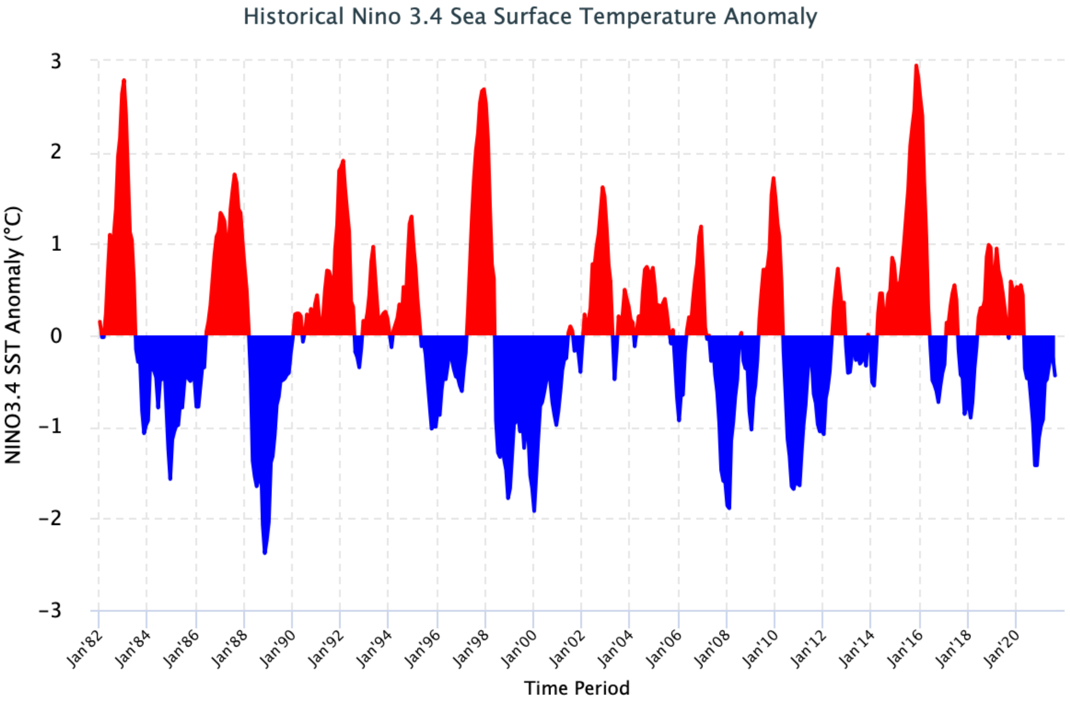

Figure 2: SST anomalies of the tropical Pacific (figure by NOAA).

September 2021 model predictions indicated the likelihood of continuing a weak La Niña through the cloud seeding season and then beginning to transition back to neutral conditions (Figure 3).

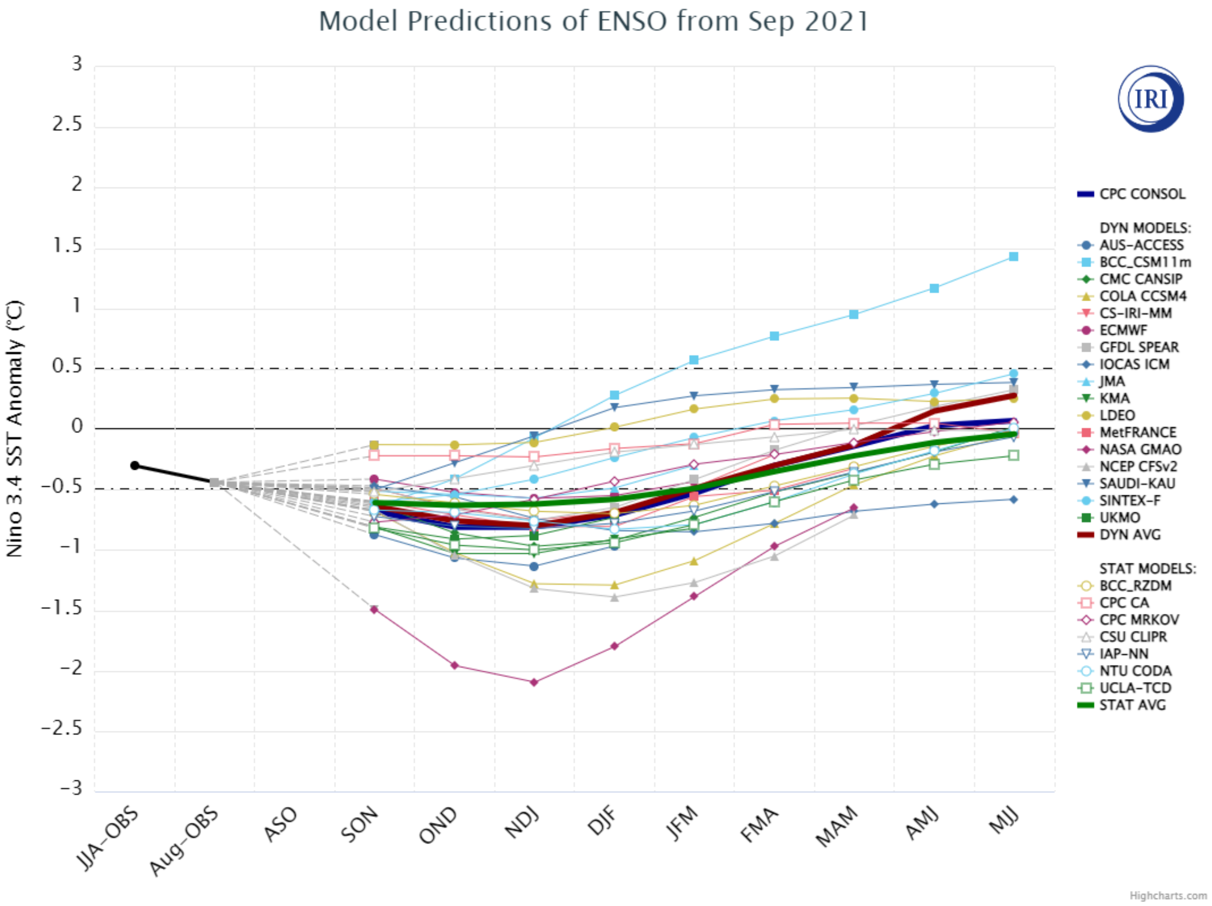

Figure 3: ENSO forecast plume from the International Research Institute for Climate and Society and the NOAA Climate Prediction Center showing the ENSO forecast during the fall of 2021.

Forecasts were indicating an increased likelihood of above normal temperatures through the cloud seeding period with the season's precipitation being near to a little above normal through the basin. These conditions came together to provide a cloud seeding season temperature that averaged 0.8 degrees below normal in the Upper Snake reaches and 0.1 degrees below normal in the Middle and Lower Snake reaches. Precipitation was fairly uniform across the basin with the Upper Snake reaches averaging 77% of normal, while the Middle and Lower Snake reaches saw an average of 79% of normal precipitation (Figure 4, Tables 2, 3, and 4).

Tables 2, 3 and 4 were created using data sourced from the National Weather Service's Pacific Northwest River Forecast Center (https://www.nwrfc.noaa.gov/rfc/).

Table 2: Water Year 2022 Monthly Divisions Average Mean Areal Precipitation October 1, 2021 through April 30, 2022 Snake River

	Oct		Nov		Dec		Jan		Feb		Mar		Apr	
DIVISION NAME	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM
Henrys Fork River Basin	2.96	128	2	63	3.92	104	1.2	34	0.33	13	1.15	39	2.24	83
Upper Snake Tributaries	3.93	189	1.35	50	3.5	115	1.91	65	0.23	11	1.11	41	2.92	118
Upper Snake River Basin abv American Falls Dam	3.13	198	1.2	56	3	117	1.5	65	0.29	17	0.89	43	2.09	104
Middle Snake Tributaries	4.01	274	1.03	46	3.4	116	1.3	53	0.23	12	0.63	29	2.08	110
Malheur-Owyhee-Boise River Basins	2.5	228	0.88	46	2.11	91	1.09	56	0.16	11	0.55	30	1.77	115
Payette River Basin	3.58	183	2.16	57	5.29	111	2.8	69	0.42	14	1.07	31	3.31	122
Snake River Basin abv Hells Canyon Dam	2.86	213	1.07	54	2.62	102	1.38	63	0.24	14	0.68	35	1.94	110

Table 3: October 1, 2021 to April 30, 2022 Water Year Precipitation Precent Normal Snake River

DIVISION NAME	OBSERVED (in)	NORMAL (in)	DEPARTURE (in)	PERCENT of NORMAL
Henrys Fork River Basin	13.8	21	-7.2	66
Upper Snake Tributaries	14.9	18.1	-3.2	82
Upper Snake River Basin abv American Falls Dam	12.1	14.4	-2.3	84
Middle Snake Tributaries	12.7	15	-2.4	84
Malheur-Owyhee-Boise River Basins	9.1	12.1	-3	75
Payette River Basin	18.6	23.6	-5	79
Snake River Basin abv Hells Canyon Dam	10.8	13.5	-2.7	80

Table 4: Water Year 2022 Monthly Departures from Normal Mean Areal Temperatures (Deg F) Snake River

DIVISION NAME	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Seasonal
Henrys Fork River Basin	0.7	4.6	4.7	-1.8	-4.8	-0.2	-4.2	-0.4
Upper Snake Tributaries	-0.9	4.1	3	-2.5	-5.2	-0.9	-5	-1.3
Upper Snake River Basin abv American Falls Dam	-0.1	4.4	4	-2.7	-5.2	0.1	-4.3	-0.8
Middle Snake Tributaries	-0.1	4.4	2.4	-1.3	-2.8	1.8	-4.2	-0.2
Malheur-Owyhee-Boise River Basins	0.2	4.2	2.1	-0.7	-1.3	2.2	-3.4	0.3
Payette River Basin	1	3.8	2.5	-0.7	-2.6	1.6	-5	-0.1
Snake River Basin abv Hells Canyon Dam	0.2	4.2	2.8	-1.8	-3.5	1.3	-4	-0.3

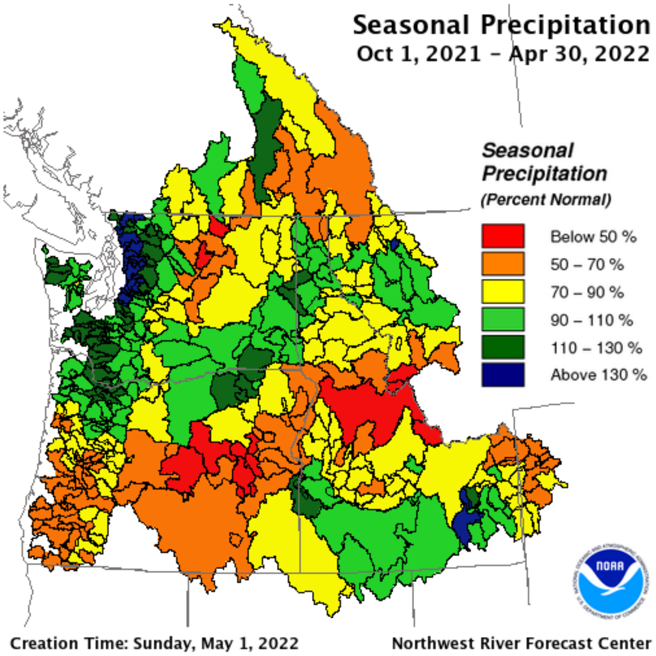

Figure 4: Seasonal Precipitation (Oct 1, 2021–April 30, 2022) for the Pacific Northwest (figure by the Northwest River Forecast Center) shows below normal seasonal precipitation across most of the basin with a few sub-basins at or near normal.

3.0 Cloud Seeding Operations

During the WY2021 cloud seeding season, in the Central Mountains IPC operated 32 remote ground-based cloud seeding generators, 2 cloud seeding aircraft (operated by WMI), 1 automated surface observing system (ASOS), 2 radiometers and 11 high resolution precipitation gauges focusing on the Payette, Boise and Wood River Basins. (Figure 5). In the Upper Snake Basin, the High-Country RC&D (HC RC&D) operated 25 manual ground based cloud seeding generators (operated by Let It Snow), IPC operated 1 cloud seeding aircraft (operated by WMI) and 25 remote ground based cloud seeding generators, 1 ASOS, 2 radiometers and 2 high resolution precipitation gauges (Figure 6 and 7). As part of the collaborative efforts in the Upper Snake Basin, IPC provides its weather and cloud seeding operations forecasts and other scientific support to Let It Snow in support of its operation of manual ground generators.

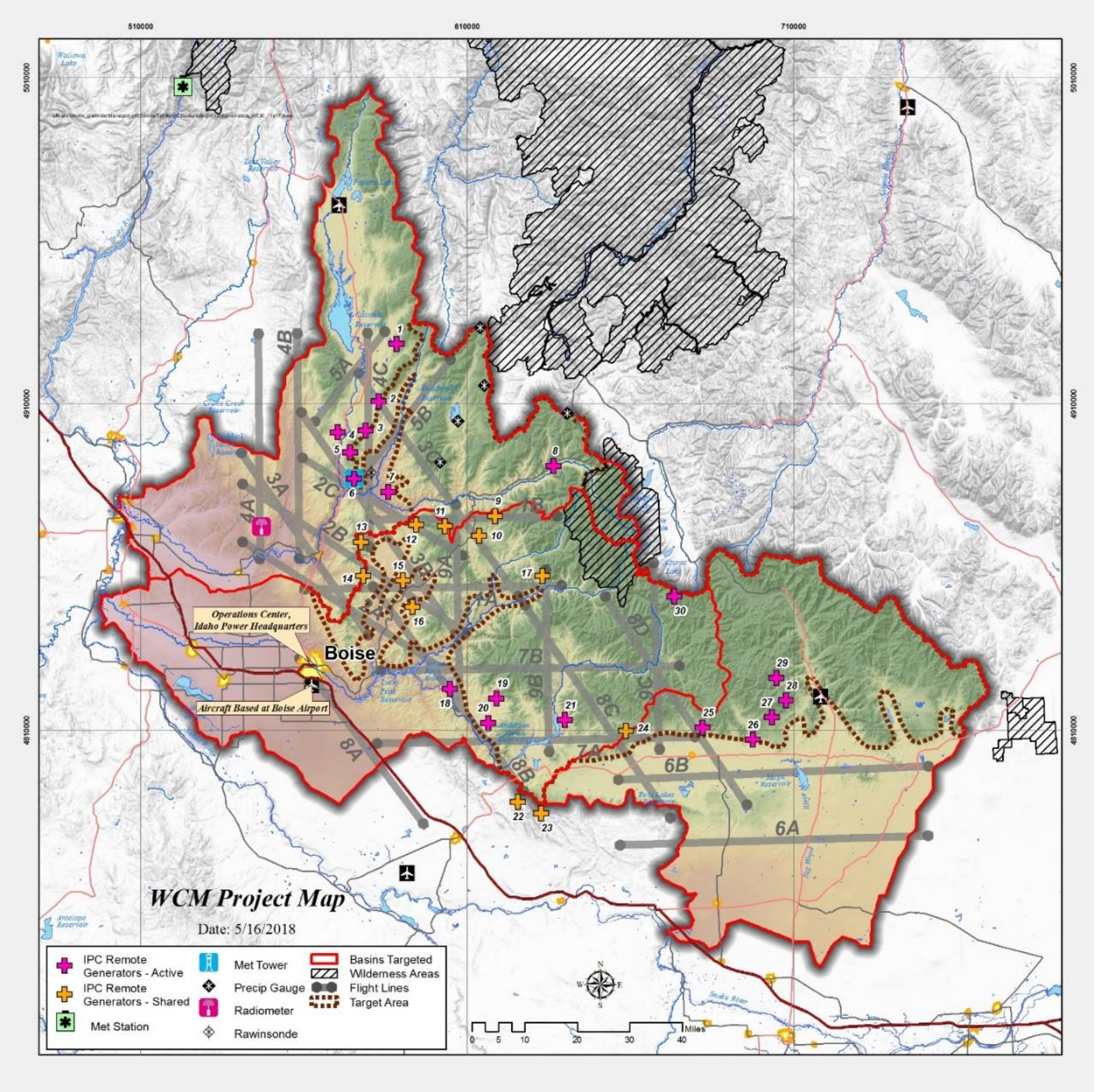

Figure 5: Central Mountains Cloud Seeding Project

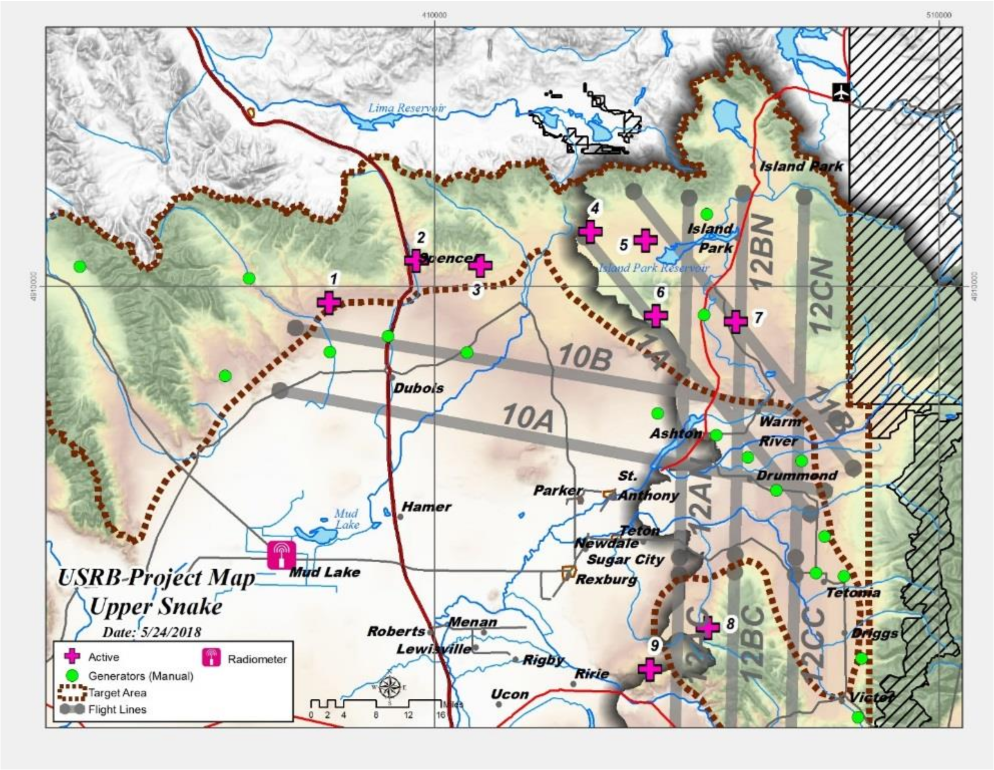

Figure 6: Northern Upper Snake Cloud Seeding Project

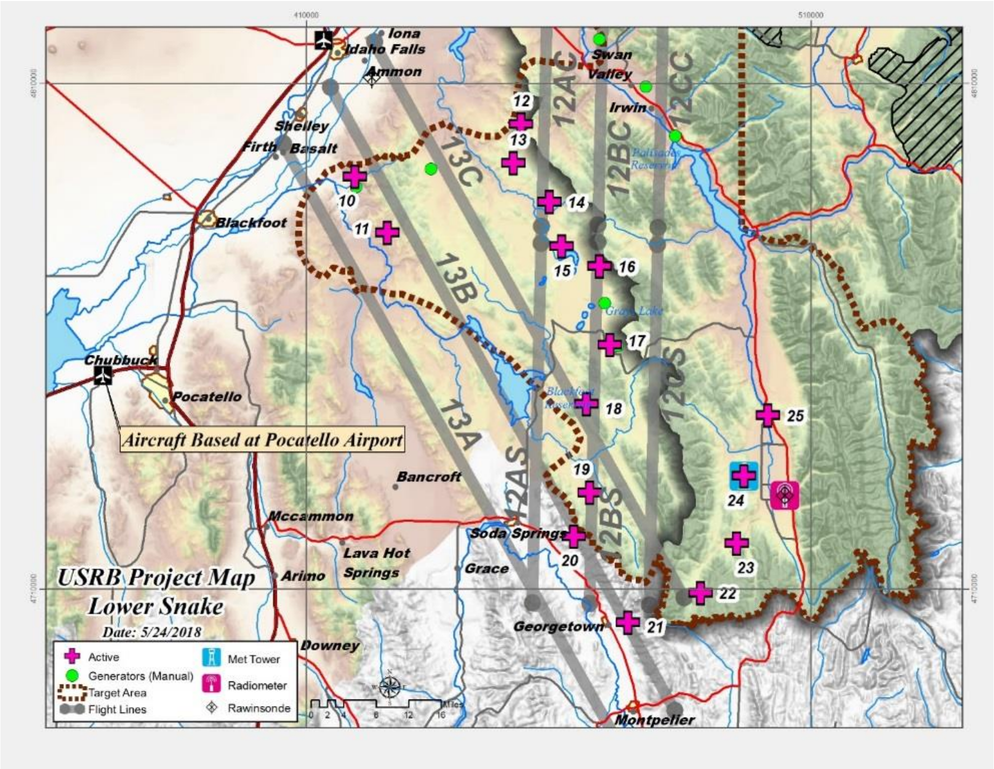

Figure 7: Southern Upper Snake Cloud Seeding Project

3.1 Ground Generator Operations

Ground generators saw nearly 3,500 hours in the season, with 2183 hours in the western project and 1305 in the eastern project. Figure 8 shows the monthly trend as well as runtime hours by month, figure 9 shows a slightly different look at the ground generators operations with total hours by basin.

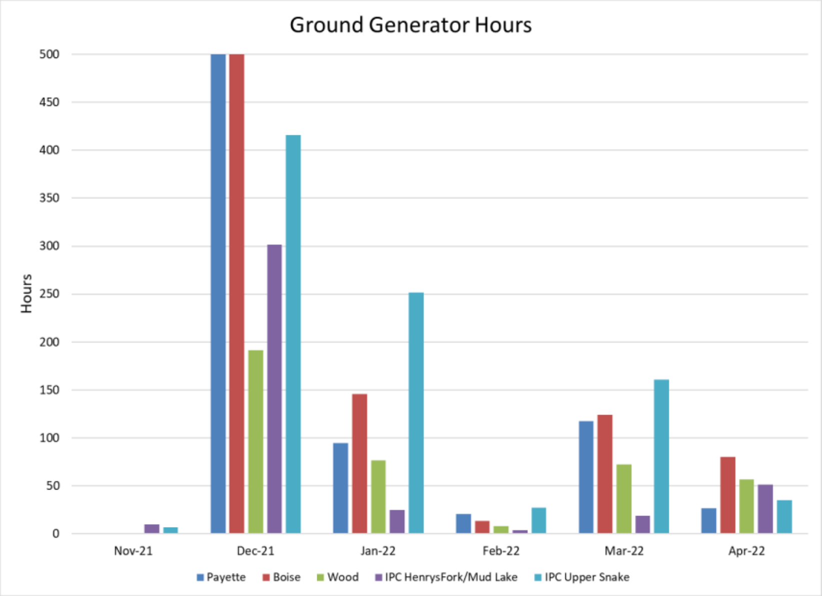

Figure 8: IPC Ground generator run time hours by month by basin

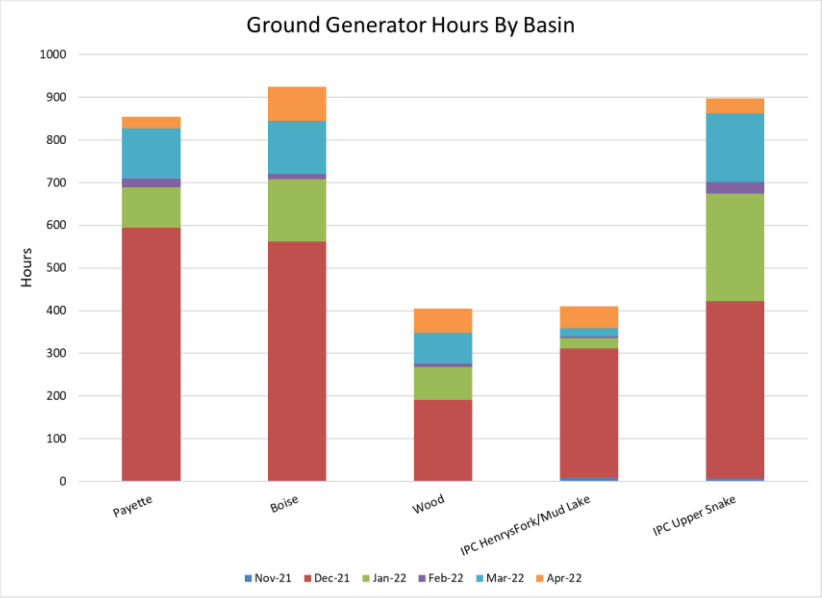

Figure 9: IPC Ground generator run time hours by basin by month

3.2 Aircraft Operations

Aircraft operations for the season saw 78 hours of operation by the two aircraft in the Western Project, while the Eastern Project aircraft saw 52 hours of operation, only having one aircraft in the Eastern Project limited the number of hours flown as many times seedable conditions occurred at the same in multiple locations in the project which forced to focus on one area over another. Figures 10 and 11 show the number of hours flown by month and by basin. Figures 12 and 13 show the number of flares used by month and basin.

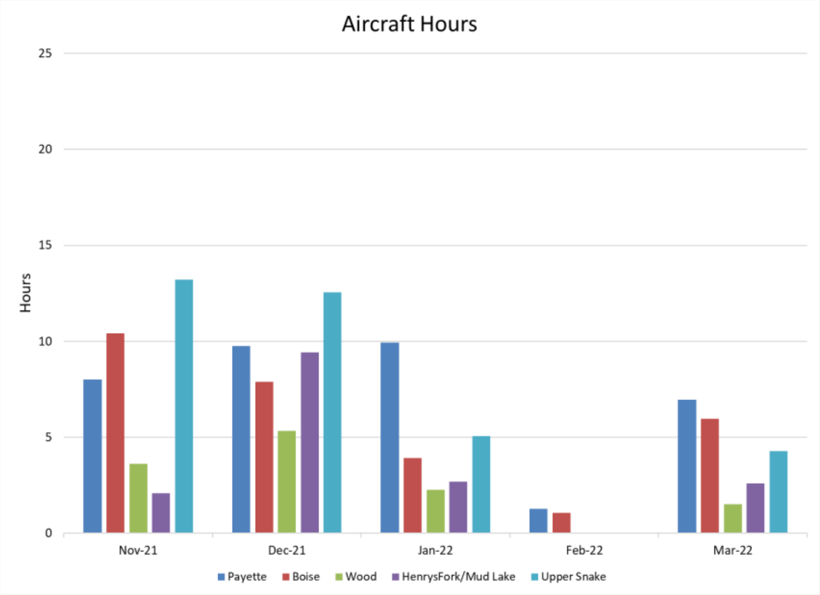

Figure 10: Aircraft hours by month by basin

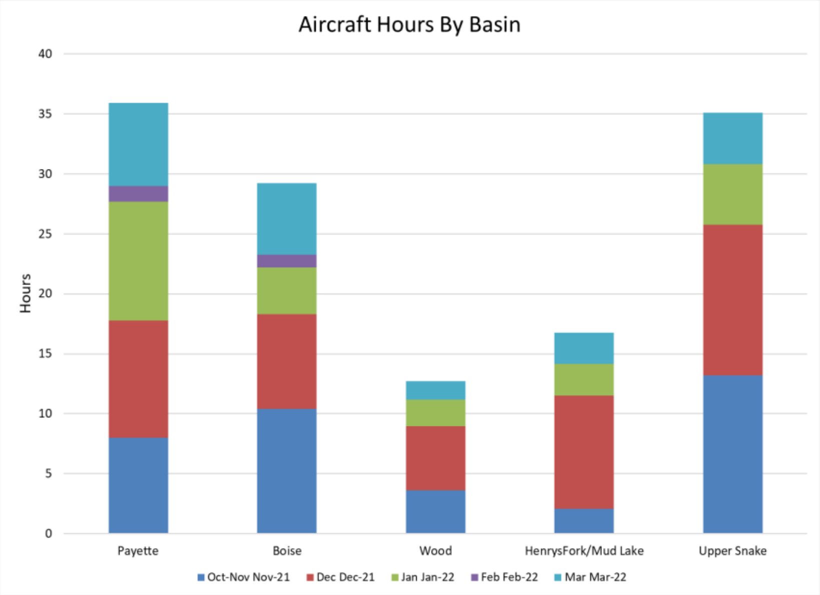

Figure 11: Aircraft hours by basin by month

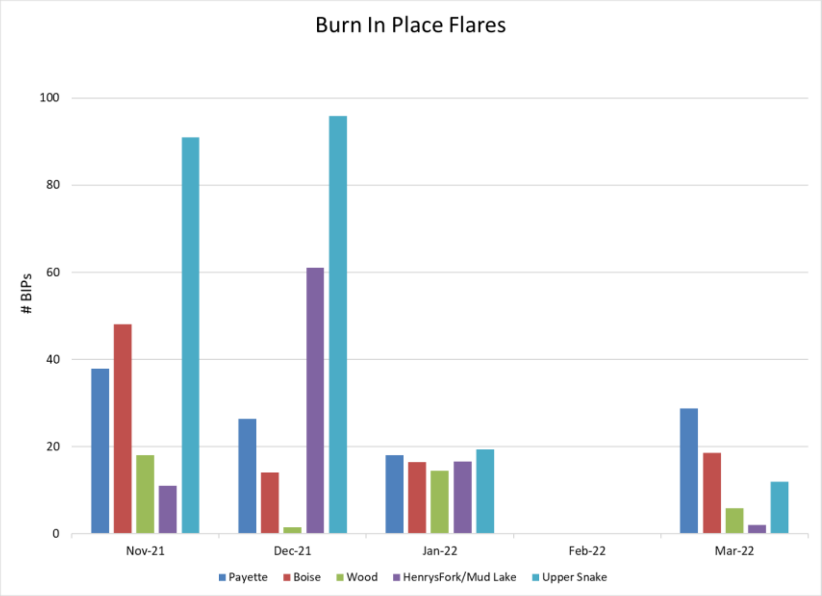

Figure 12: Burn in Place (BIPs) Flares used by month

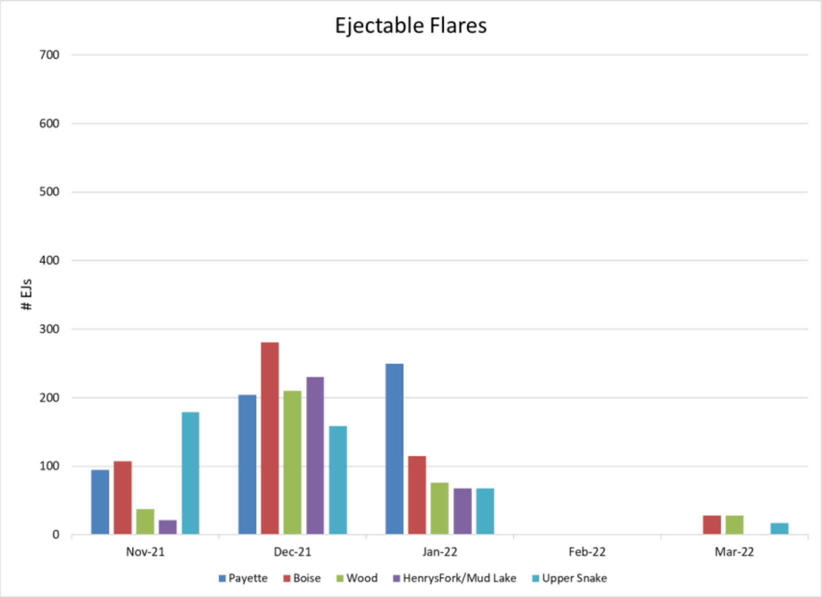

Figure 13: Ejectable (EJs) Flares used by month

3.3 Total Operations

Total operations for the year were a little below normal for ground generators and aircraft operations. This year conditions were quite variable, and it proved to be challenging to find consistent and favorable seeding conditions. Table 5 shows the total number of hours/flares used in basin during the WY202 cloud seeding season.

Table 5: Total hours/flares

	Payette		Boise		Wood		Henrys Fork		Upper Snake	
	2022	Average	2022	Average	2022	Average	2022	Average	2022	Average
GGENS	854	756	925	926	405	608	410	618	898	1044
A/C Hours	36	63	29	61	13	26	17	31	35	26
BIPs	111	345	97	306	40	118	91	144	218	127
Ejs	548	2104	531	1822	351	727	319	531	422	422

4.0 Target Control Analysis

4.1 Target Control Methodology and Data

The statistical technique used in this analysis is the "target" and "control" comparison (T/C). Dr. Arnett Dennis describes this technique in his book entitled “Weather Modification by Cloud Seeding (1980)”. This technique is based on the selection of a parameter that would be affected by seeding (e.g., liquid precipitation, snowpack, or streamflow). Data for the parameter(s) of interest is collected for a historical period (during which seeding did not occur in the basins of interest) for as many years as possible (20 years or more is best). The data is divided into “target” area data and “control” area data. Target sites are those expected to be affected by cloud seeding (e.g., the Payette River Basin, the Henrys Fork, etc…). The control sites are those outside of the areas expected to be affected by cloud seeding operations. Preferably control sites should be selected in an area meteorologically analogous to the target area. These data are evaluated for the same seasonal period as seeding is conducted.

The target and control data sets from the unseeded seasons are used to develop a statistical relationship that estimates the amount of precipitation (or other selected parameter) in the target area, based on precipitation observed in the control area. This relationship is usually expressed as an equation (normally from a linear regression). This equation is then applied to the seeded period to estimate what the target area precipitation would have been without seeding, based on the precipitation observed in the control area(s). This method allows for a comparison between the predicted target area “natural” precipitation and the “observed/actual” precipitation that was observed during the seeded period. This target and control technique works well where a good historical correlation can be found between target and control area precipitation. An equation indicating perfect correlation would have an r value of 1.0, but in natural systems this seldom if ever occurs. For precipitation and snowpack assessments, a correlation coefficient (r) of 0.90 is acceptable as it would indicate that over 80 percent of the variance (r2) in the historical data set would be explained by the regression equation used to predict the parameter (expected precipitation or snowpack) in the seeded years. Generally, the goal is to develop a relationship that has a correlation coefficient (r) of 0.95 accounting for 90 percent of the variance (r2) in the historical data. Data source for the data used is from the USDA/NRCS SNOTEL/Snow Course network.

The steps for developing the T/C are as follows:
- Collect period of record SNOTEL/Snow Course data from NRCS sites within the target area that represents the basin.
- Collect period of record SNOTEL/Snow Course data from NRCS sites within the control area that represents the basin.
- Separate the data into two sets, one representing the period prior to cloud seeding in the target area (historic) and the other representing the period since cloud seeding commenced.
- Using the data from the period prior to cloud seeding, develop a linear regression where the average (pooled) value from the control sites is regressed against the average (pooled) value from the target sites to produce a regression coefficient plus an intercept value.
- For each of the years since cloud seeding began, using precipitation for the control area calculate the target area precipitation using the developed regression coefficient and intercept value. This will be the expected precipitation in the target area if cloud seeding had not occurred.
- Calculate (equation 1) the difference between "expected" (unseeded) and observed (seeded) basin precipitation values and convert into a percentage to estimate the percent difference in basin precipitation attributable to cloud seeding. A positive % would indicate an increase in precipitation in the seeded basin.

Equation 1: Precipitation percent change

$$\%\ change = \left(\frac{ObservedPRECIP - ExpectedPRECIP}{ExpectedPRECIP}\right) * 100$$

Note 1: This technique can be applied to most parameters of interest in the T/C analysis (i.e., precipitation, snow water equivalent, snow depth, etc…), selection of which parameter to use is generally determined upon the available data set length/quality.

Note 2: The T/C analysis can be conducted upon a multitude of time spans, from monthly to seasonal. Length of analysis dependent upon the available data set length/quality and if acceptable statistical relationships can be developed

For an example of this process, figure 14 shows the target control results by year for the Payette River Basin. The Payette River Basin is the basin Idaho Power has been operationally clouding in the longest making it a good example of the process. Operational period shown is for water years 2003 through 2020.

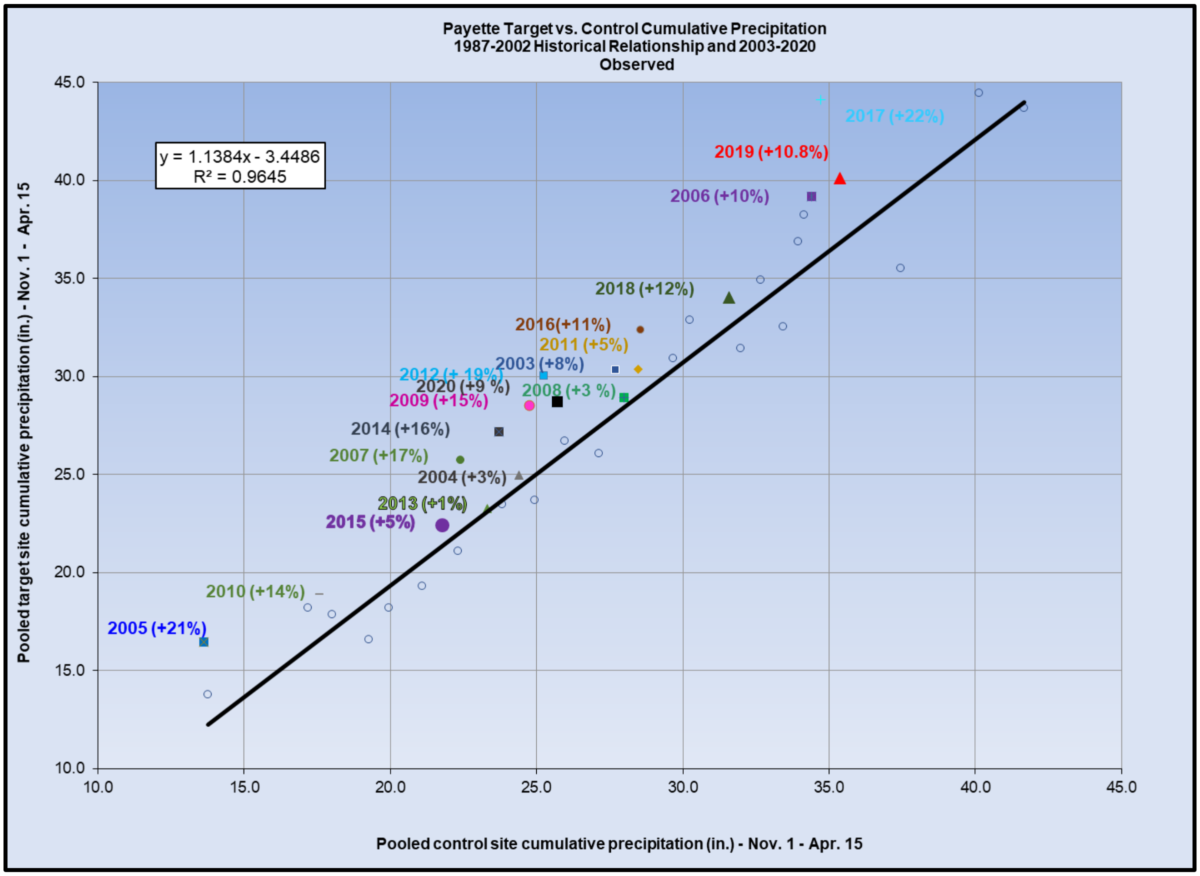

Figure 14: Example of Target Control Analysis results, the Payette River Basin results for the Water Years 2003-2020.

4.2 Locations for Target Control Analysis

The Snake River Basin is divided in sub basins based upon areas targeted for precipitation enhancement. This season those basins have been further divided to better represent where cloud seeding benefits are being seen, these new target control basins were shown in last years end of year report and are illustrated in Figure 15. The basins going forward will be:

Western Project:
WP1 - Middle and South Forks of the Payette River Basin
WP2 - Mores Creek, Middle and North Forks of the Boise River Basin
WP3 - Southern Boise River Basin
WP4 - Big Wood River and Camas Creek
WP5 - Little Wood River

Eastern Project:

EP1 - Mud Lake
EP2 - Henrys Fork and Fall River
EP3 - Teton River
EP4 - Upper Snake River North
EP5 - Gros Ventre River
EP6 - Upper Snake River South

For future analysis:
EAA1, EAA2, EAA3, EAA4, EAA5, EAA6

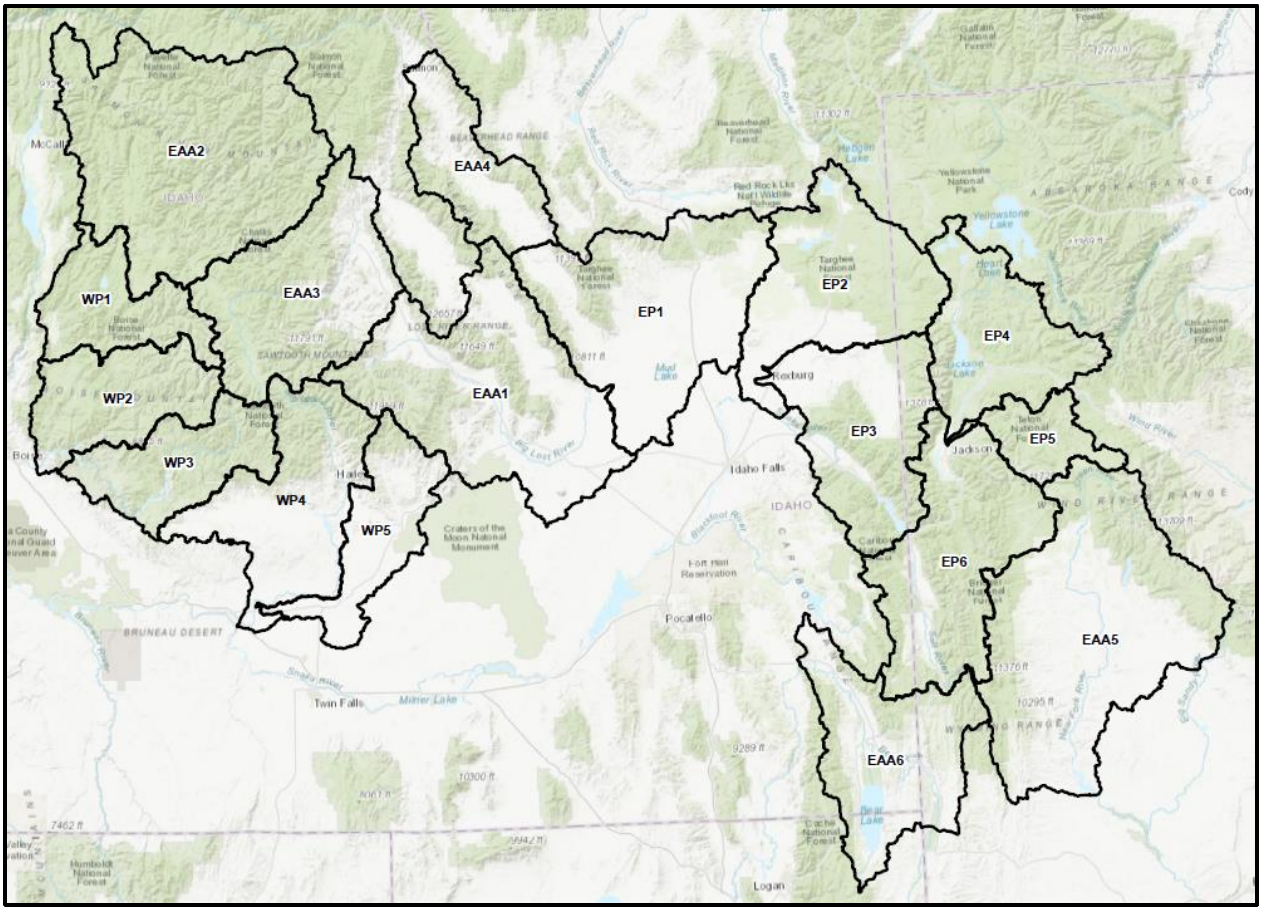

Figure 15: Map of Target/Control zones

5.0 Results

Water Year 2022 provided mixed seeding opportunities across the basin, but still seeing strong seeding benefit as shown through the target control analysis. Table 6 shows the calculated WY2022 enhancements in the Central Mountains as 6.4% and 5.4% in the Upper Snake respectively, with an average of 5.9% increase across the basin. Also shown are the average benefit for each basin based upon the years that seeding has occurred in those areas.

Table 6: Water Year 2022 target control results as well as the average basin benefit for the period of operations (period of operations shown in table 1).

	Payette	**Boise**		**Wood**		**Henrys Fork**		**Upper Snake**			
Year	**WP1**	**WP2**	**WP3**	**WP4**	**WP5**	**EP1**	**EP2**	**EP3**	**EP4**	**EP5**	**EP6**
2003	8%										
2004	3%										
2005	19%										
2006	12%										
2007	14%										
2008	4%					2%	3%	3%	3%	3%	3%
2009	16%					6%	8%	12%	10%	11%	9%
2010	16%					3%	4%	13%	13%	13%	9%
2011	7%					6%	7%	9%	8%	8%	8%
2012	18%					3%	4%	14%	14%	14%	9%
2013	1%	4%	3%	10%	9%	2%	3%	8%	7%	8%	5%
2014	15%	24%	22%	11%	10%	3%	5%	11%	10%	11%	8%
2015	5%	15%	14%	13%	12%	3%	4%	12%	10%	11%	7%
2016	14%	8%	7%	8%	8%	4%	6%	5%	5%	5%	6%
2017	21%	21%	19%	16%	15%	9%	11%	12%	10%	11%	11%
2018	15%	12%	11%	9%	8%	6%	9%	8%	7%	8%	8%
2019	15%	10%	9%	11%	10%	6%	8%	17%	14%	15%	11%
2020	6%	7%	7%	7%	6%	5%	8%	10%	9%	9%	8%
2021	8%	10%	9%	9%	7%	4%	5%	9%	8%	9%	7%
2022	6.6%	6.5%	5.7%	6.1%	7.1%	5.1%	4.0%	5.8%	5.9%	6.4%	5.4%
Average	11.2%	11.7%	10.8%	10.0%	9.3%	4.5%	5.9%	9.9%	8.9%	9.4%	7.6%

6.0 Conclusion

A challenging year for cloud seeding operations across the basin due to availability of good seeding conditions. Overall a good cloud seeding season across the Snake Basin indicated by the target control with an **average benefit** of **6.4% in the Western Project** and **5.4% increase in the Eastern Project for WY 2022**.