

**Idaho Collaborative Cloud Seeding Program
2019-20 Winter Season
End of Season Report**

Prepared by

Idaho Power

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
1.0 Introduction/History	3
2.0 2019-20 Winter Season Meteorological Conditions	6
3.0 Cloud Seeding Operations	10
4.0 Target Control Analysis	17
5.0 Results	22
6.0 Conclusion	21
7.0 Future Reports	21

<u>Figure</u>	<u>Page</u>
1 Number of IPC ground generators impacting the basins by years since 2008	4
2 Nino 3.4 SST anomalies (January 2000 through Feb 2020)	6
3 Mid-September 2019 Plume of ENSO Predictions	7
4 Seasonal Precipitation (Oct1, 2019 – April 30, 2020) for the PNW	9
5 Map of Central Mountains Cloud Seeding Project	10
6 Map of Northern Upper Snake Cloud Seeding Project	11
7 Map of Southern Upper Snake Cloud Seeding Project	11
8 Ground generator run time hours by month by basin	12
9 Ground generator run time hours by basin by month	12
10 Aircraft hours by month by basin	13
11 Aircraft hours by basin by month	14
12 Burn in Place (BIPs) Flares used by month	14
13 Ejectable (EJs) Flares used by month	15
14 Example target control analysis results (Payette River Basin)	18
15 Map of West Central Mountains Target Control Zones	19
16 Map of the two Upper Snake Basin Target Control zones	20
17 Future Target/Control zones	22

<u>Table</u>	<u>Page</u>
1 Years Cloud Seeding Conducted in Snake Basin	5
2 Water Year Monthly Divisions of Average Areal Precipitation	8
3 October 1, 2019 to April 30, 2020 Water Year Precipitation Percent Normal	8
4 Water Year 2020 Monthly Departure from Normal Mean Areal Temperature	8
5 Total number hours/flares used by basin WY 2019	15
6 WY 2020 Target Control results, plus basin averages	21

<u>Equations</u>	<u>Page</u>
1 Precipitation percent change	17

Evaluation of the Operational Upper Snake River Cloud Seeding Program in Idaho, 2019-2020 Winter Season

1.0 Introduction/History

The following report was prepared by Idaho Power with assistance from Let It Snow following the end of cloud seeding operations for the WY2020 cloud seeding season (1 November 2019 – 30 April 2020).

Cloud seeding has occurred in the Snake River Basin, in one format or another, since the late 1980s. Early operations were 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) began 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 began 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 Aquifer 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 Seeded and Natural Orographic Wintertime clouds-the Idaho Experiment (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.

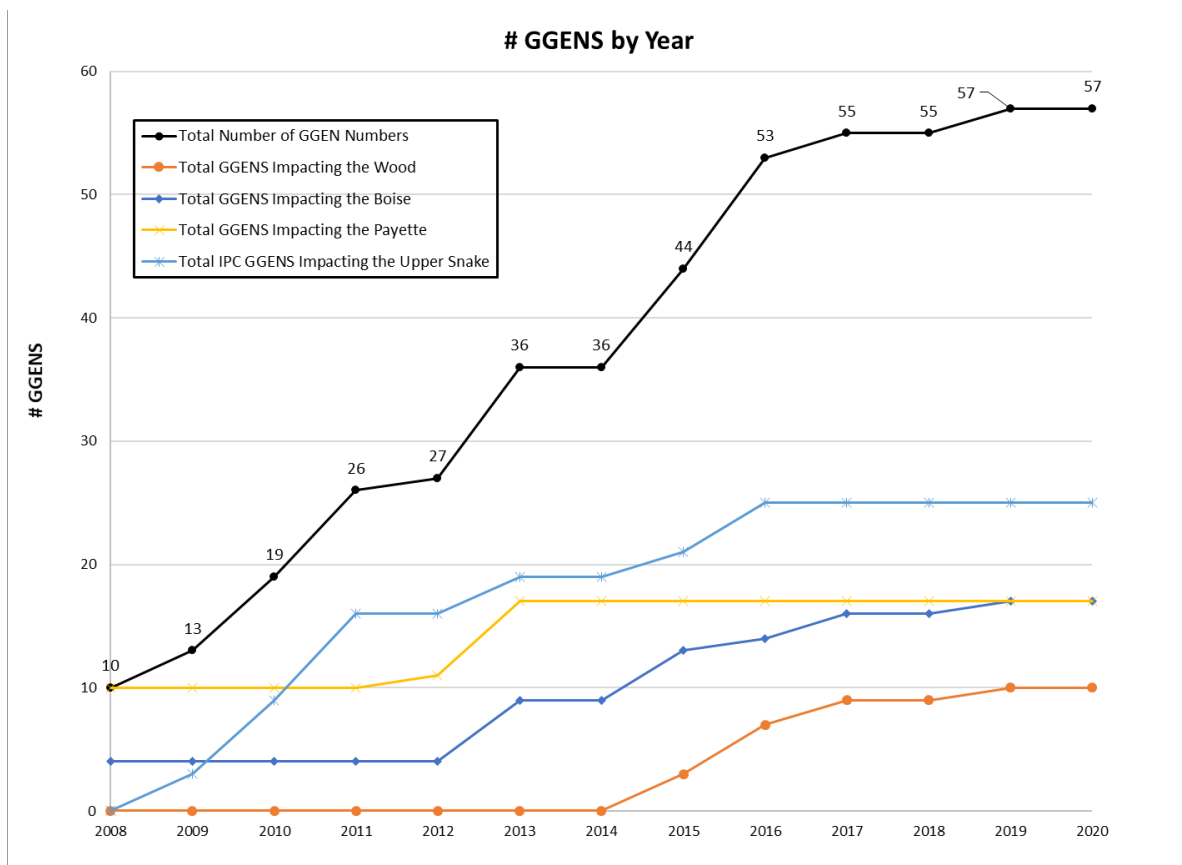


Figure 1: Number of IPC ground generators (GGENS) seeding basins by year since 2008.

Table 1: Years clouds seeding conducted in the Snake River Basin and the company's that conducted the operations (Since 1989).

Water Year	Payette	Boise	Wood	Northern Upper Snake	Southern/Eastern Upper Snake
1989	*	*	*	NAWC	NAWC
1990	*	*	*	*	NAWC
1991	*	*	*	*	*
1992	*	*	*	*	NAWC
1993	*	NAWC	*	NAWC	NAWC
1994	*	NAWC	*	*	*
1995	*	NAWC	*	*	NAWC
1996	*	NAWC	*	*	*
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/IPC	LIS/IPC
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

2.0 2019-20 Winter Season Meteorological Conditions

In the western United States, 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 2019, observations were indicating the tropical Pacific Ocean was in weak El Niño conditions (Figure 2).

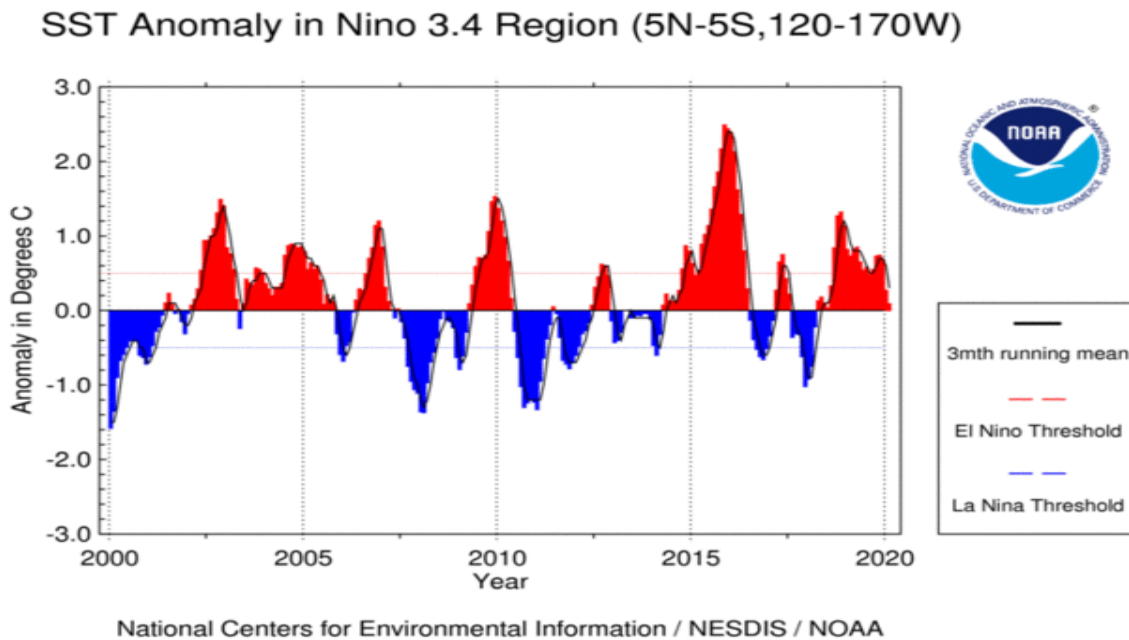


Figure 2: SST anomalies from the Niño 3.4 Region of the tropical Pacific (figure by NOAA).

September model predictions indicated the likelihood of remaining as a weak El Niño through the cloud seeding season and then beginning to transition to neutral conditions (Figure 3).

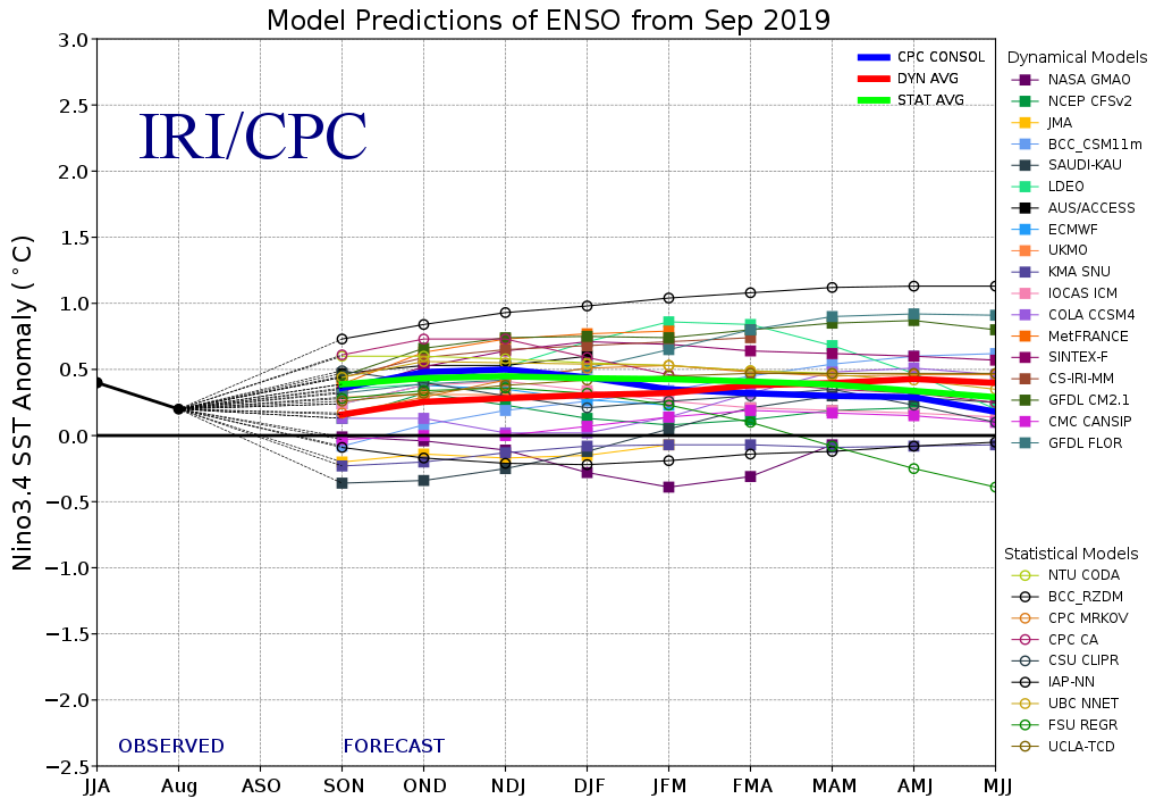


Figure 3: ENSO forecast plume from the International Research Institute for Climate and Society and the NOAA Climate Prediction Center showing the ENSO forecast during the fall of 2019.

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 below normal through the basin. These conditions came together to provide a cloud seeding season temperature that averaged 1.5 degrees below normal in the Upper Snake reaches and 1.1 degrees above normal in the Middle and Lower Snake reaches. Precipitation was regionalized also with the Upper Snake reaches averaging 93% of normal, while the Middle and Lower Snake reaches saw an average of 71% 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 2020 Monthly Divisions Average Mean Areal Precipitation October 1, 2019 through April 30, 2020
Snake River**

DIVISION NAME	Oct		Nov		Dec		Jan		Feb		Mar		Apr	
	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM	OBS (in)	% NORM
Henry's Fork River Basin	2.83	104	1.43	62	1.44	45	2.8	74	4.36	123	2.98	113	3.78	129
Upper Snake Tributaries	3.05	123	1.23	59	1.18	43	2.08	68	3.03	103	2.91	128	3.4	127
Upper Snake River Basin abv American Falls Dam	2.14	106	0.87	55	0.94	44	2.06	80	2.81	121	2.12	116	2.67	129
Middle Snake Tributaries	1.21	64	0.68	47	0.66	29	2.42	83	2.77	113	0.99	51	2.11	96
Malheur-Owyhee-Boise River Basins	0.85	56	0.42	38	0.41	21	1.93	83	2.38	122	0.91	62	1.51	82
Payette River Basin	1.56	57	1.12	57	0.37	10	3.11	65	4.83	120	2.2	72	4.02	118
Snake River Basin abv Hells Canyon Dam	1.3	74	0.62	46	0.61	30	2.05	80	2.62	119	1.4	82	1.96	100

**Table 3: October 1, 2019 to April 30, 2020 Water Year Precipitation Percent Normal
Snake River**

DIVISION NAME	OBSERVED (in)	NORMAL (in)	DEPARTURE (in)	PERCENT of NORMAL
Henry's Fork River Basin	19.6	21.1	-1.5	93
Upper Snake Tributaries	16.9	18.2	-1.3	93
Upper Snake River Basin abv American Falls Dam	13.6	14.5	-0.9	94
Middle Snake Tributaries	10.8	15.1	-4.3	72
Malheur-Owyhee-Boise River Basins	8.4	12.1	-3.7	69
Payette River Basin	17.2	23.7	-6.5	73
Snake River Basin abv Hells Canyon Dam	10.6	13.5	-3	78

**Table 4: Water Year 2020 Monthly Departures from Normal Mean Areal Temperatures (Deg F)
Snake River**

DIVISION NAME	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Seasonal
Henry's Fork River Basin	-1.2	-10.1	5.4	14.2	4	-4.1	0.9	-1.2
Upper Snake Tributaries	-2.6	-10.5	4.9	13.1	2	-4.1	-0.4	-2.6
Upper Snake River Basin abv American Falls Dam	-0.8	-9.7	4.9	11.1	3.2	-3.1	0.6	-0.8
Middle Snake Tributaries	0.8	-8.2	7	8.7	2.7	-0.6	0.1	0.8
Malheur-Owyhee-Boise River Basins	2	-7.2	6.2	5	3.9	0.3	0.3	2.0
Payette River Basin	0.6	-7.8	5.7	8.1	3.7	-1	-0.1	0.6
Snake River Basin abv Hells Canyon Dam	0.9	-8.2	5.5	7.4	3.6	-1	0.5	0.9

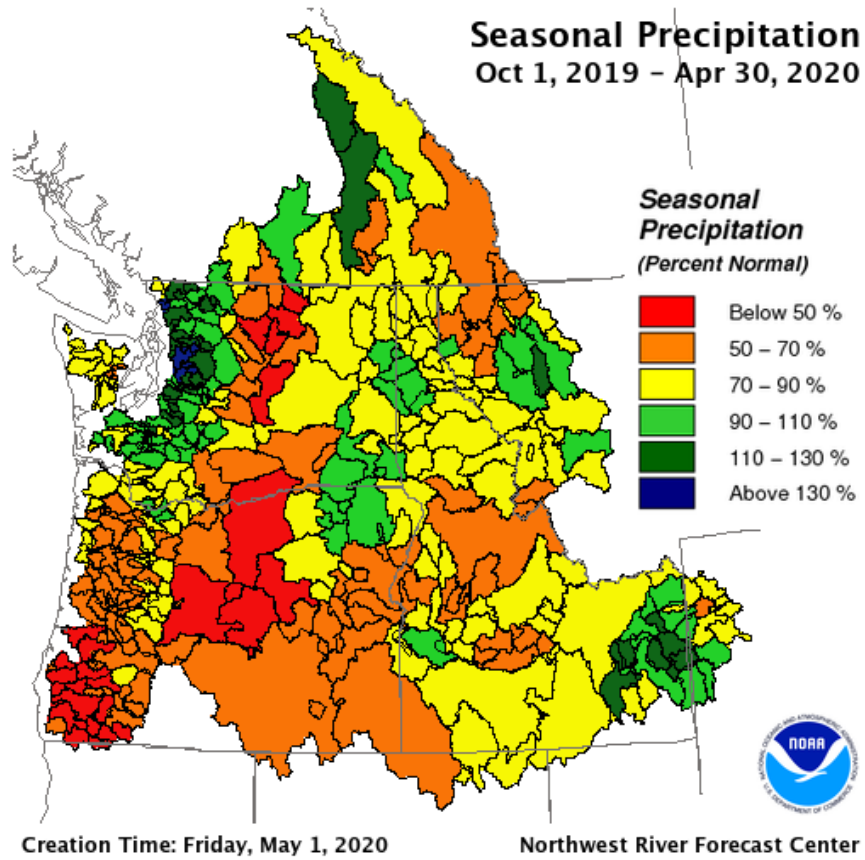


Figure 4: Seasonal Precipitation (Oct 1, 2019–April 30, 2020) for the Pacific Northwest (figure by the Northwest River Forecast Center) shows near normal precipitation through much of the Upper Snake River Basin and below normal seasonal precipitation in the remainder of the lower basin.

3.0 Cloud Seeding Operations

During the WY2019 cloud seeding season, 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 in the Central Mountains Cloud Seeding Project 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.

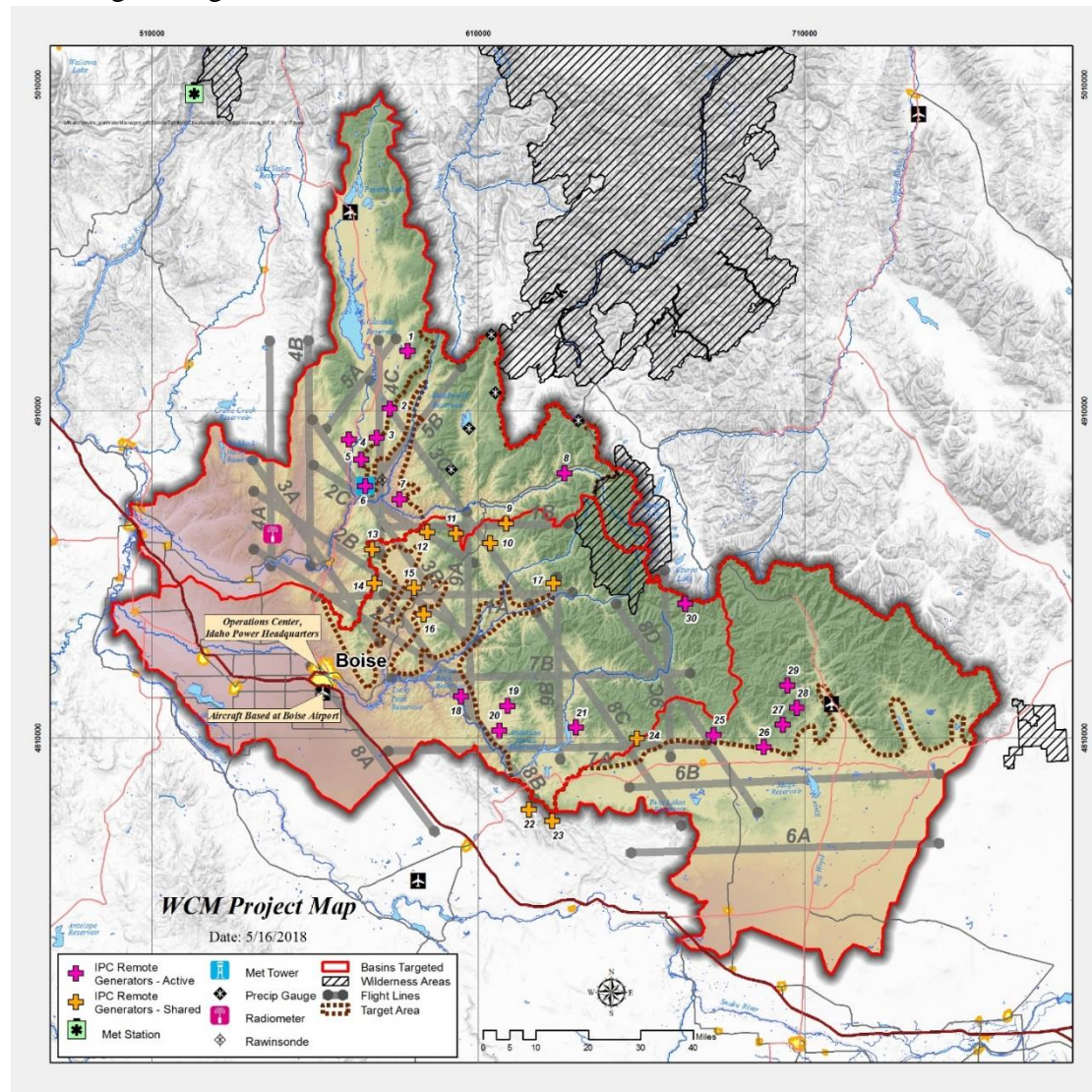


Figure 5: Central Mountains Cloud Seeding Project

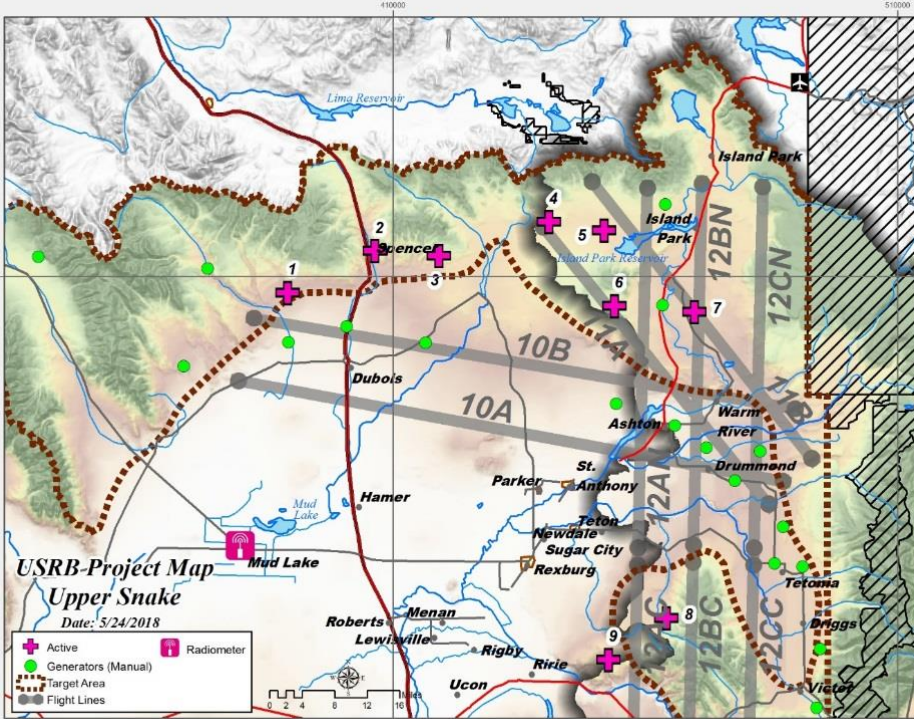


Figure 6: Northern Upper Snake Cloud Seeding Project

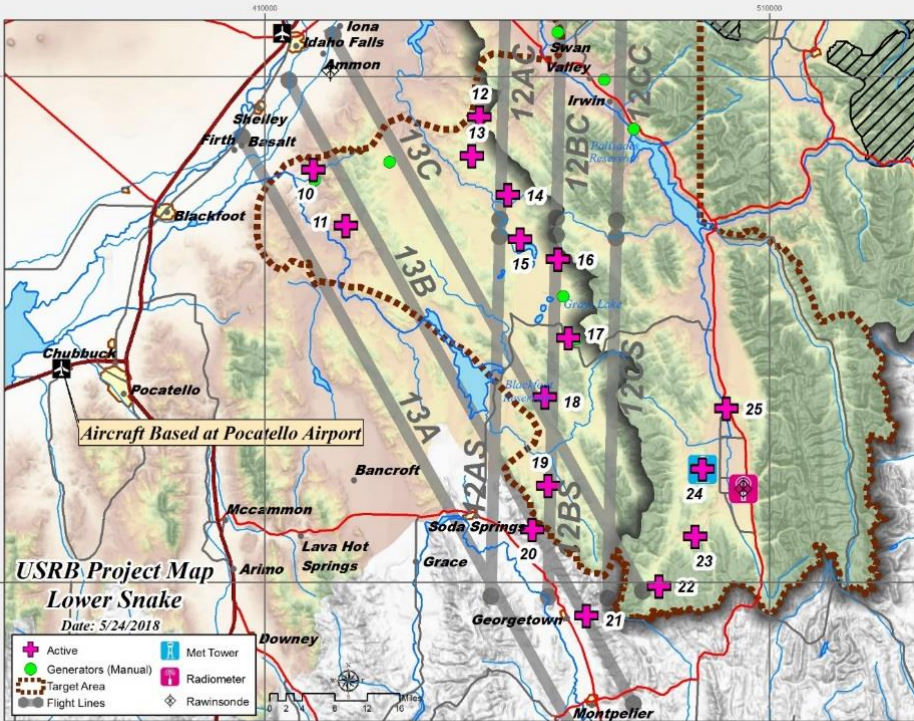


Figure 7: Southern Upper Snake Cloud Seeding Project

3.1 Ground Generator Operations

IPC operations varied across the basins from month to month as seeding opportunities varied greatly depending on the temperature and moisture of each weather system as it moved through the region. Ground generators were very active through the season with nearly 600 hours in November, peaking at just over 2300 hours in January and dropping off to 185 hours in April. 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.

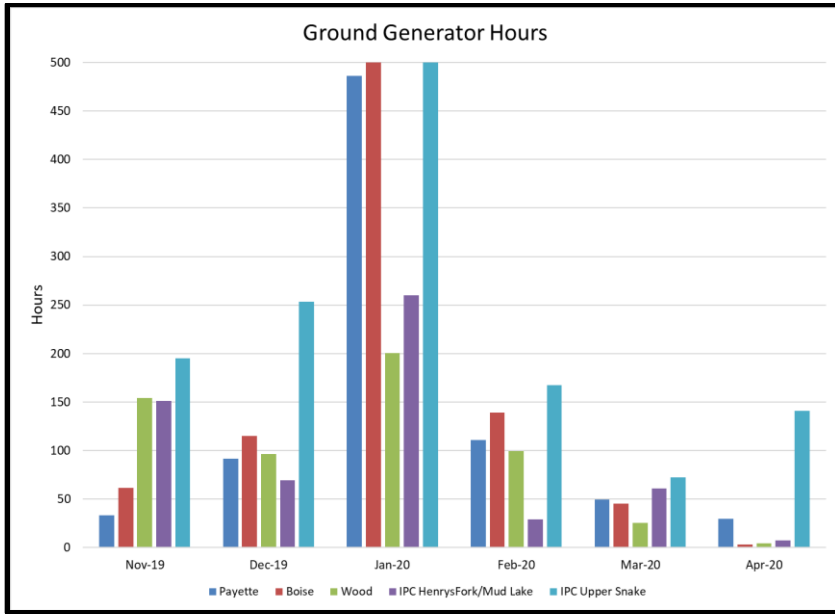


Figure 8: IPC Ground generator run time hours by month by basin

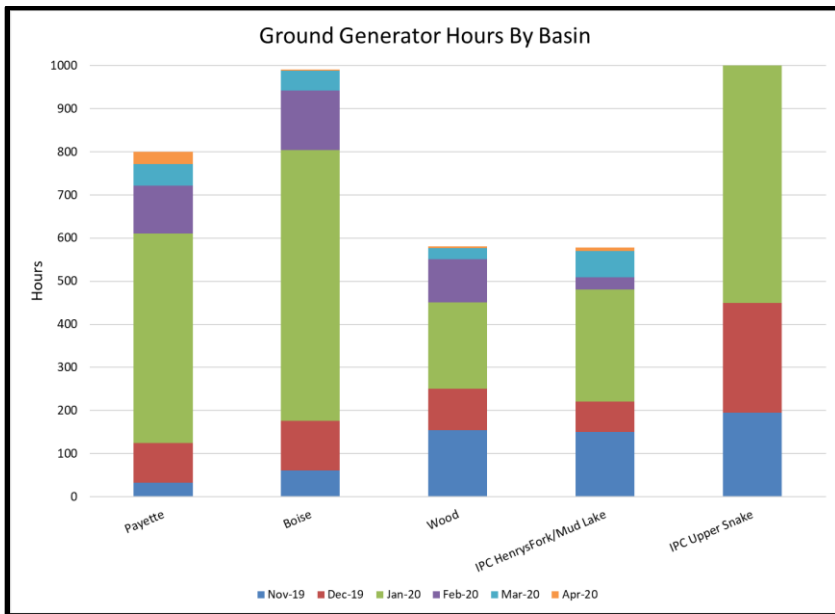


Figure 9: IPC Ground generator run time hours by basin by month

3.2 Aircraft Operations

Aircraft operations were also very active through the season with a nice start in November with nearly 54 hours of flight time, January was the busiest month with nearly 90 hours. Figure 10 shows aircraft flight hours by month, figure 11 shows a slightly different look at the aircraft hours with total hours by basin. Figures 12 and 13 show the total Burn in Place (BIPs) and Ejectable (EJs) flares used during the season. Due to only one aircraft being utilized in Eastern Idaho there were numerous seeding opportunities in the Upper Snake that were missed.

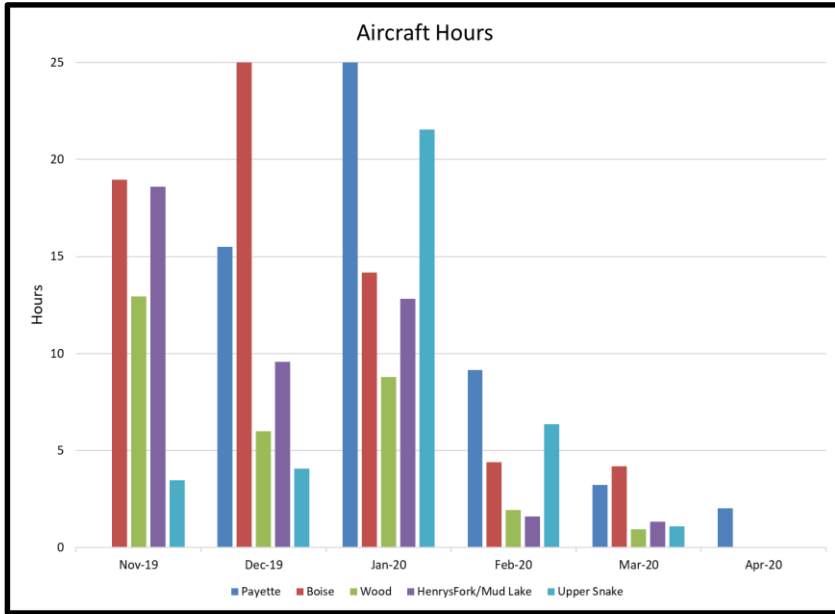


Figure 10: Aircraft hours by month by basin

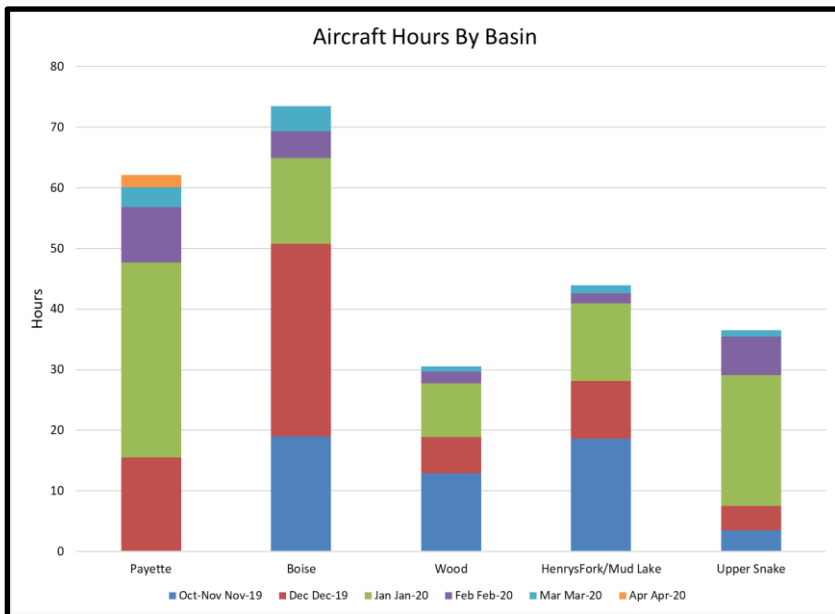


Figure 11: Aircraft hours by basin by month

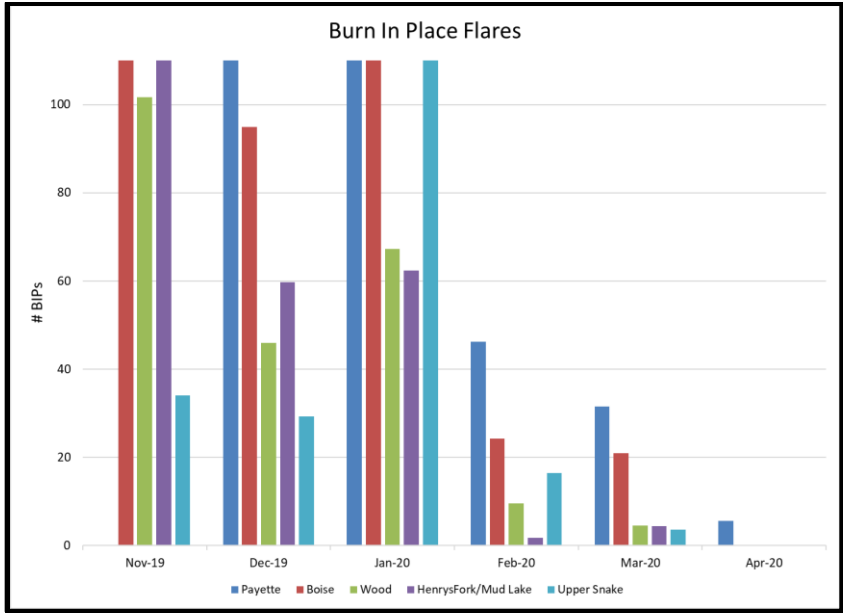


Figure 12: Burn in Place (BIPs) Flares used by month

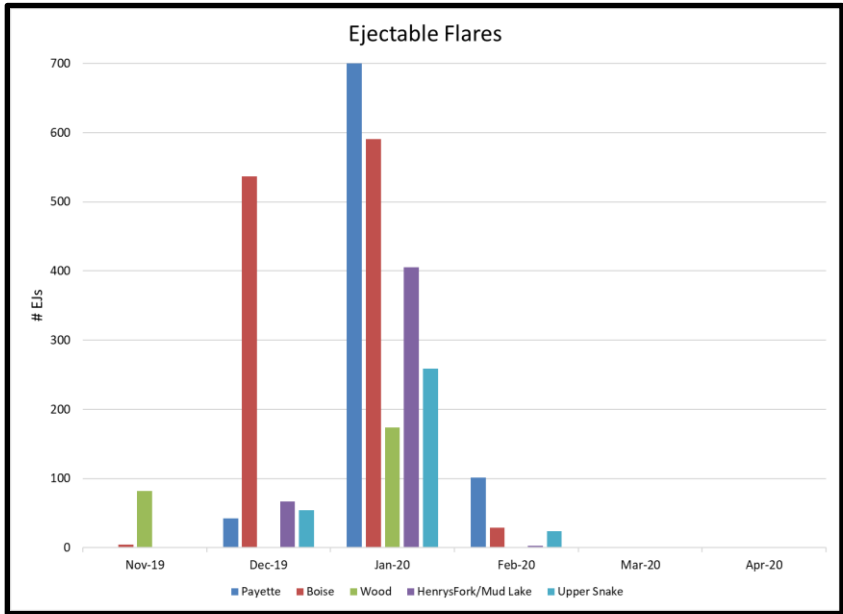


Figure 13: Ejectable (EJs) Flares used by month

3.3 Total Operations

Total operations for the year were near normal, based upon available storms systems to seed. Table 5 shows the total number of hours/flares used in basin during the WY2020 cloud seeding season.

Table 5: Total hours/flares

	Payette		Boise		Wood		Henrys Fork		Upper Snake	
	2020	Average	2020	Average	2020	Average	2020	Average	2020	Average
GGENS	800	592	991	595	580	401	578	705	1556	869
A/C Hours	62	52	73	49	31	12	44	29	36	21
BIPs	435	178	515	209	229	48	281	99	251	60
Ejs	932	2458	1161	2109	255	447	475	438	337	350

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 Northern Section of the Upper Snake River Basin, 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 (r^2) 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 (r^2) 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

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

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 16 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. Operational period shown is for water year’s 2003 through 2020.

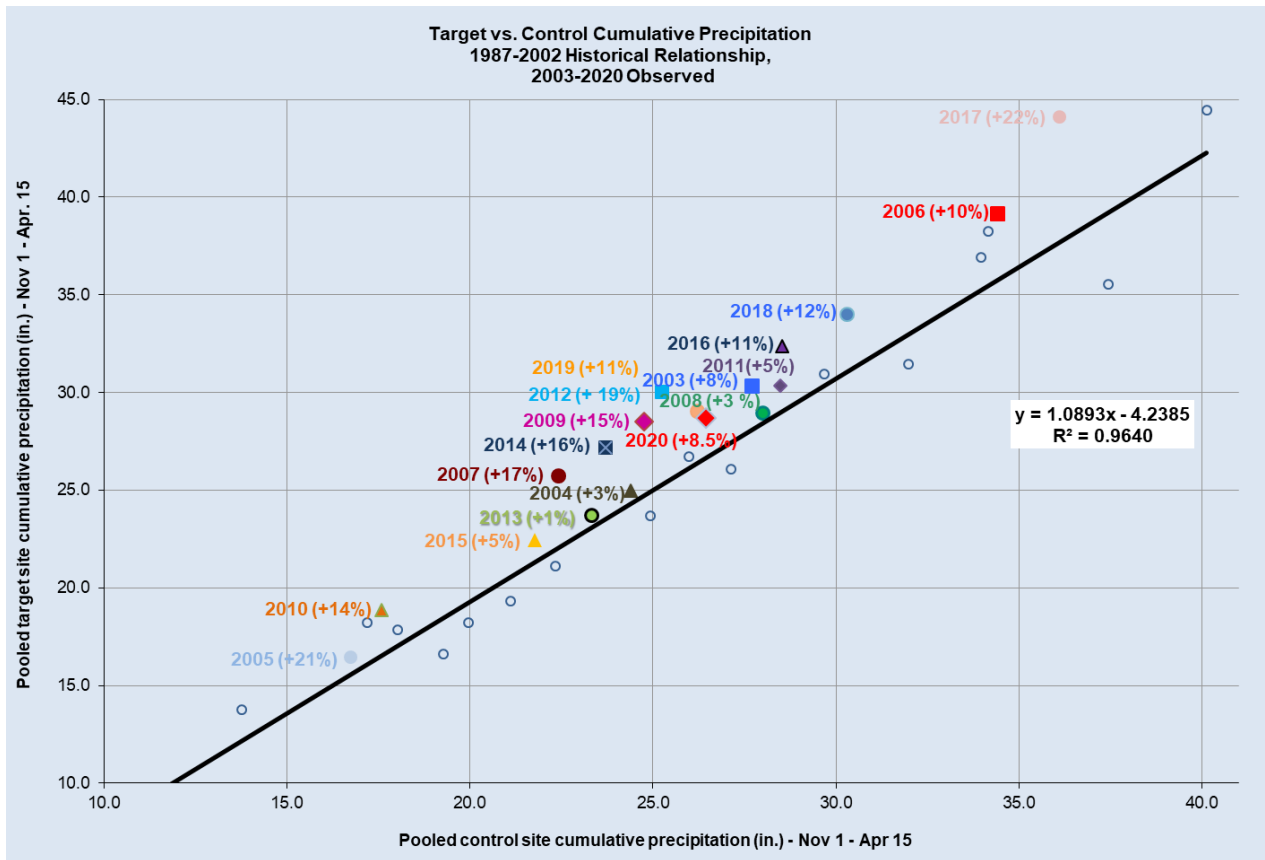


Figure 14: Example of Target Control Analysis results, the Payette River Basin results for the Water Years 2003-2020.

4.2 Locations for Target Control Analysis

The Snake River Basin divided in sub basins based upon areas targeted for precipitation enhancement. Those basins are the Payette, Boise, and Wood for the West Central Mountains and are shown in figure 17. The Henrys Fork (Lemhi, Clark, Fremont, Madison and Teton Counties) and Upper Snake (all remaining Idaho counties in the target area and target regions in Wyoming) and are shown in Figure 18.

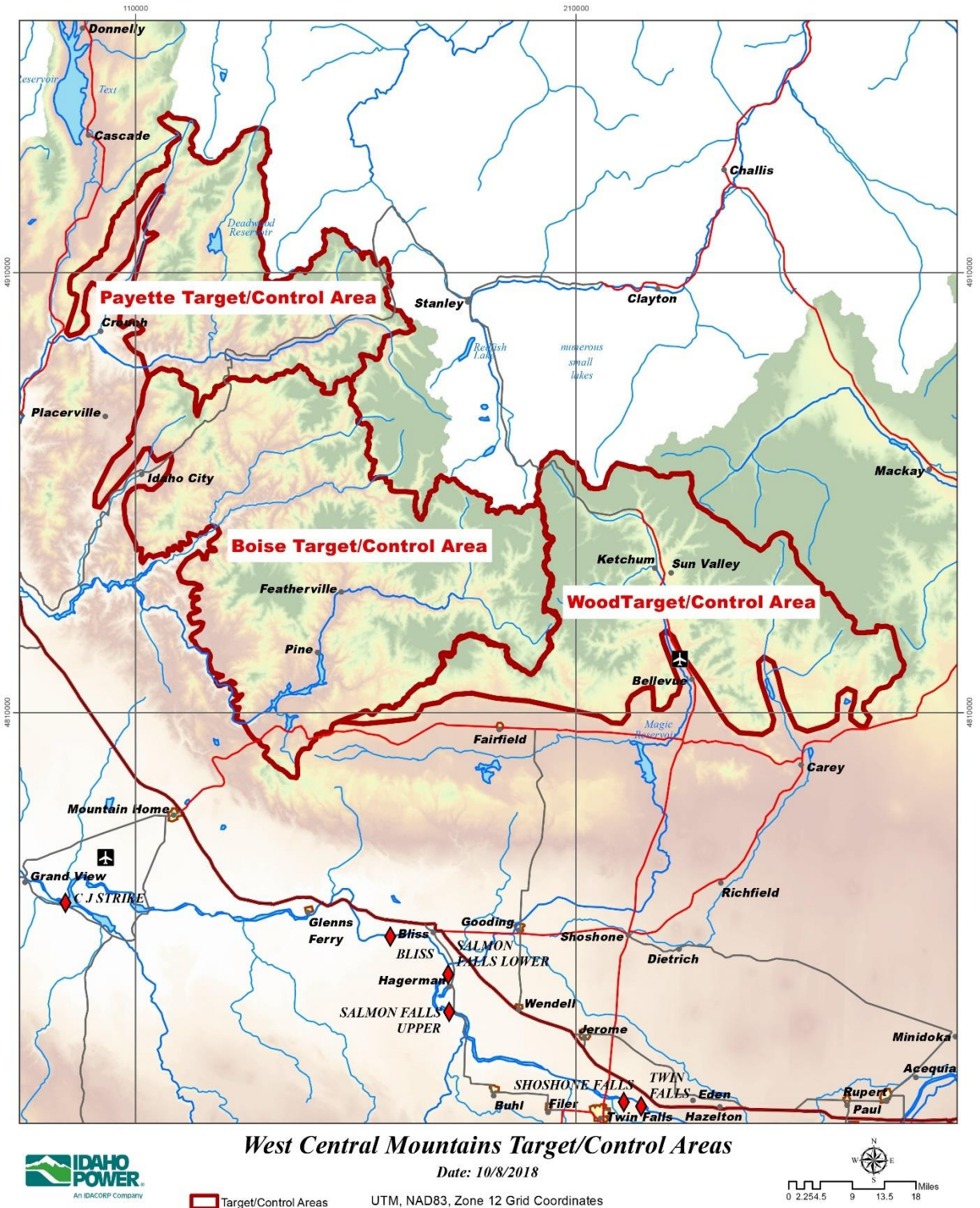


Figure 15: Map of the West Central Mountains Target/Control zones

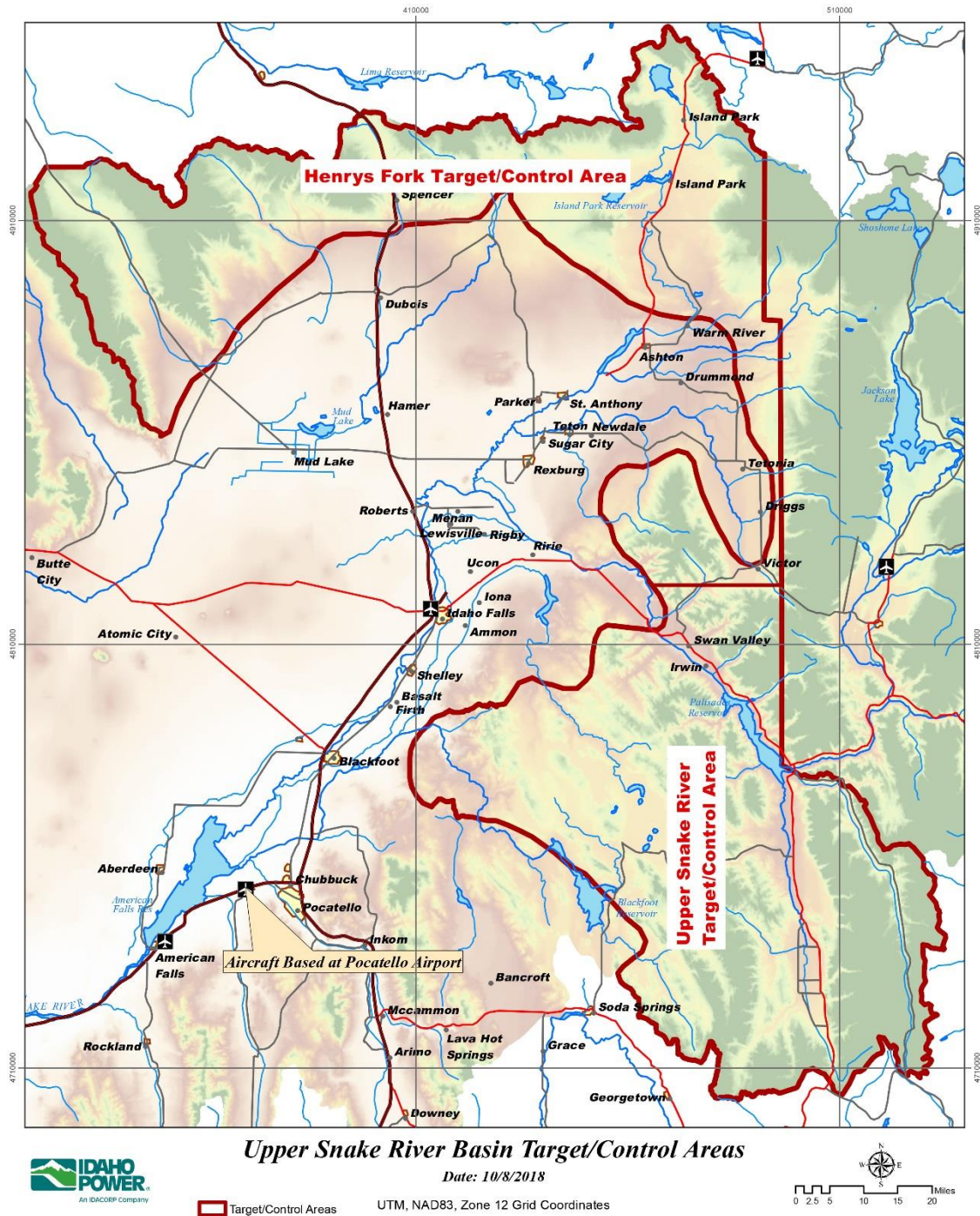


Figure 16: Map of the Upper Snake Basin Target/Control zones

5.0 Results

Water Year 2020 provided good seeding opportunities across the basin with a result of strong seeding enhancement as shown through the target control analysis. Table 6 shows the calculated WY2020 enhancements in the Central Mountains as 8.5%, 7.2% and 6.7.3% for the Payette, Boise and Wood Basins respectively, with an average across the Central Mountains of 7.5%. Comparing this season’s results with the average of previous seasons, the benefits in the Central Mountains are what we would be expected for a season that had fewer storms than normal that were seedable. As the projects in the Central Mountains continue to be built out with addition of more ground generators or refined placement of existing ground generators, we can expect the average annual enhancements to increase as well. The two basins in eastern Idaho, we saw nice results with 7.2% and 9.1% for the Henrys Fork and the Upper Snake respectively, with an average of 8.2% increase across the basin. As with the central mountains, we would expect continued enhancement with addition of more ground generators and an additional aircraft.

Table 6: Water Year 2020 target control results as well as the average basin benefit for the period of operations (period of operations shown in table 1).

Basin	Average (%)	WY2020
Payette	11.2	8.5
Boise	12.1	7.2
Wood	10.2	6.7
Henrys Fork	5.7	7.2
Upper Snake	8.2	9.1

6.0 Conclusion

Conditions throughout the season were favorable for cloud seeding. Overall a strong cloud seeding season across the Snake Basin indicated by the target control with an **average benefit of 7.5% in the Central Mountains and 8.2% increase in the Eastern Basins for WY 2020.**

7.0 Future Reports

In an effort to refine the target/control analysis to provide better information water managers and users on benefits across the project, future analysis will be conducted on a more granular scale as shown in figure 17. For the WY 2021 report, the regions identified as Eastern Project (EP) and Western Project (WP) will included, Extra Areas (EAA) will be included in later reports.

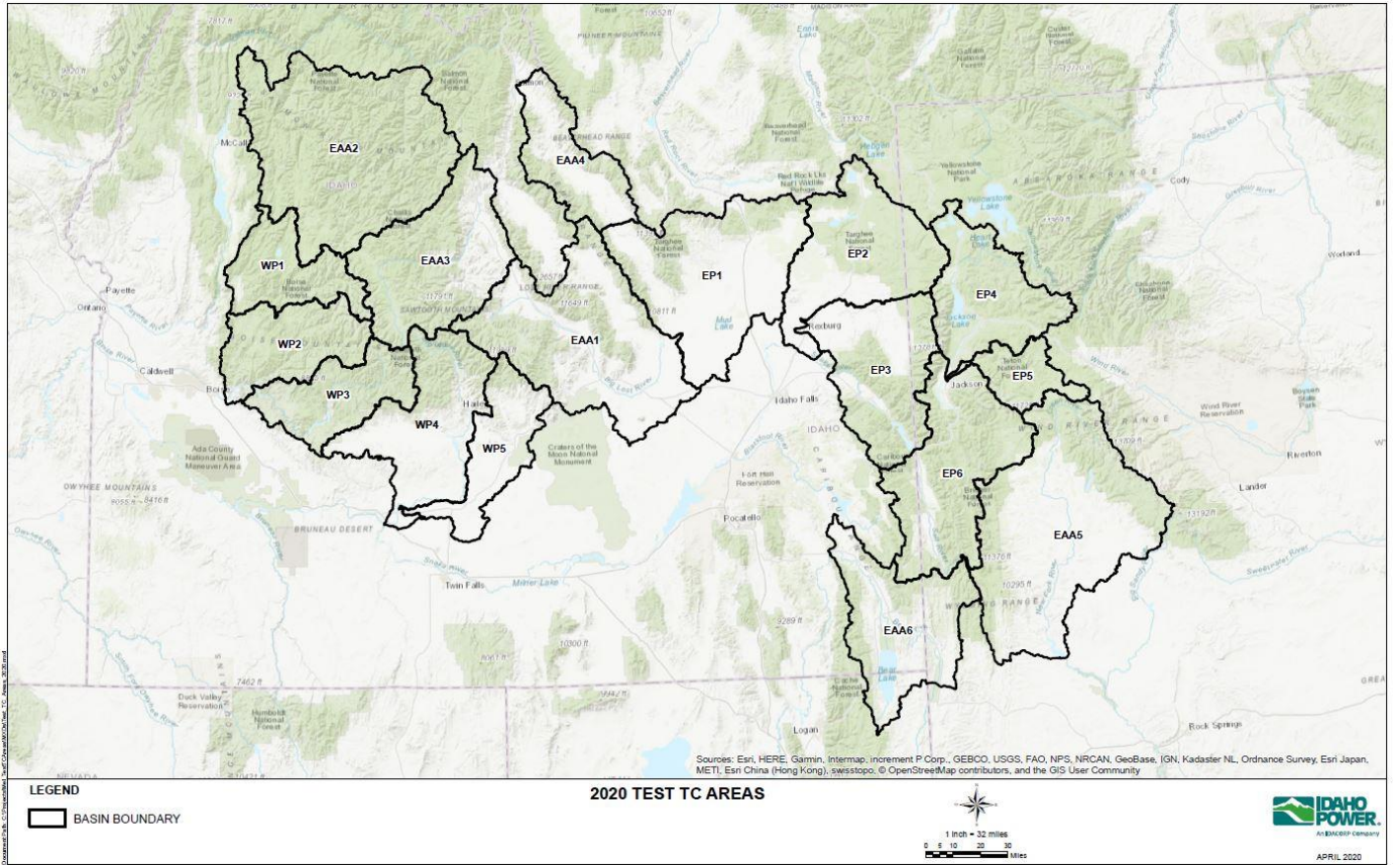


Figure 17: Future Target/Control zones