Cloud-Seeding Feasibility and Preliminary Program Design for Southwest Montana

Project Summary

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Feasibility and Design Components

Climatology Analysis

How often are there opportunities for seeding clouds in this region?

What are the characteristics of clouds in this region?

Preliminary Design

What methods of cloud seeding might target the clouds in this region most effectively?

Test and Refine Design

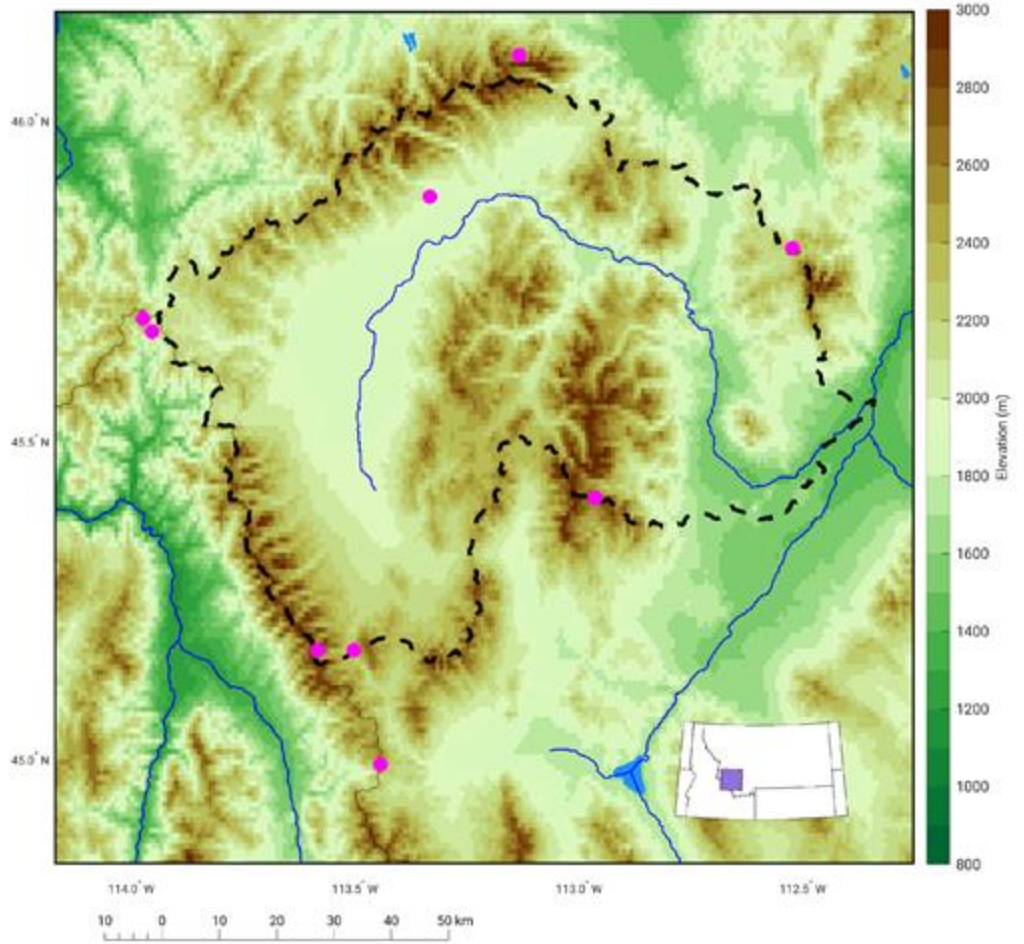
How effective are each design option at targeting and enhancing precipitation in this region?

Which combination of design options is recommended?

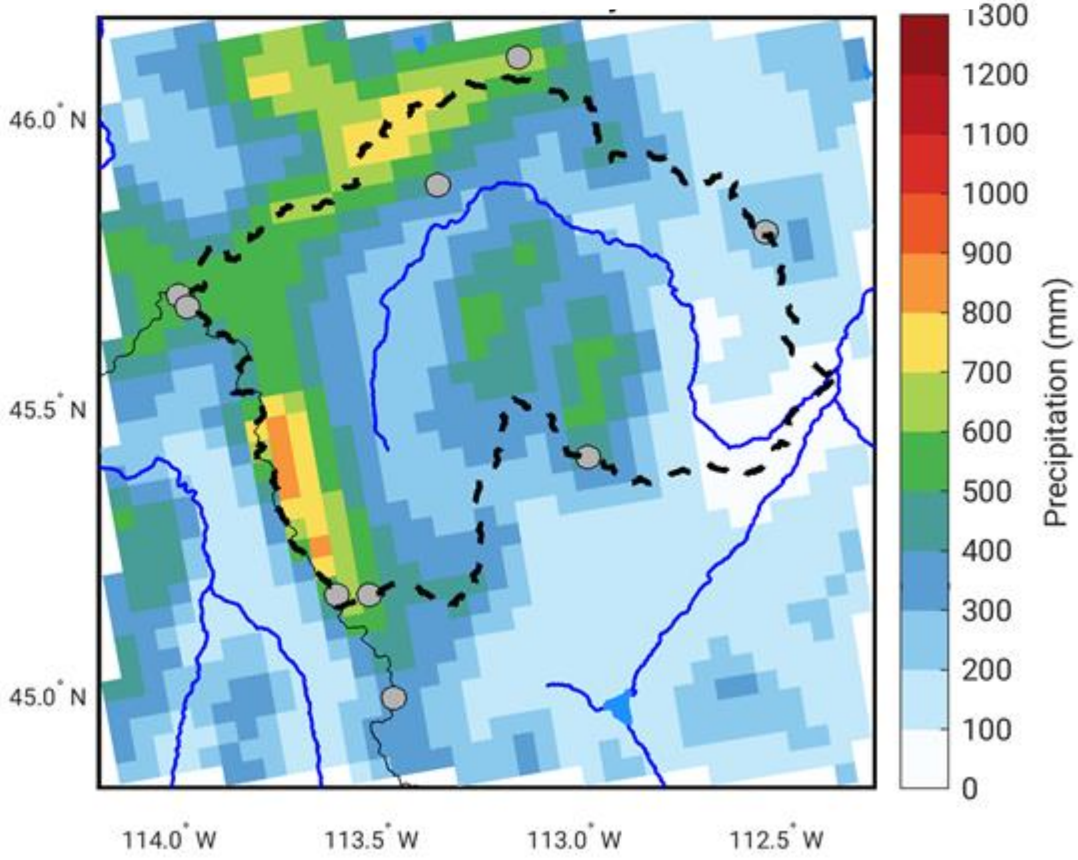
Cost-Benefit Analysis and Estimation

Region of Study: Big Hole Watershed

Map of Region of Study and SNOTEL gauge sites



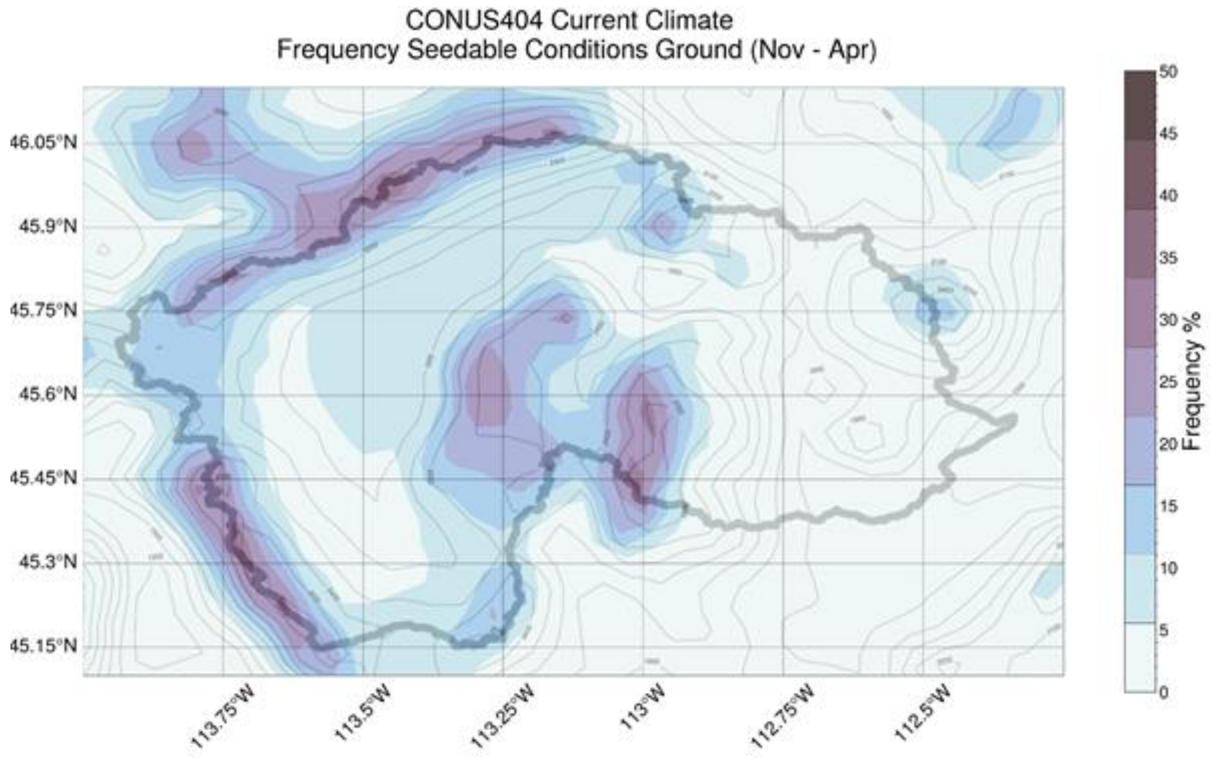
40-year Average
Wintertime Precipitation Accumulation



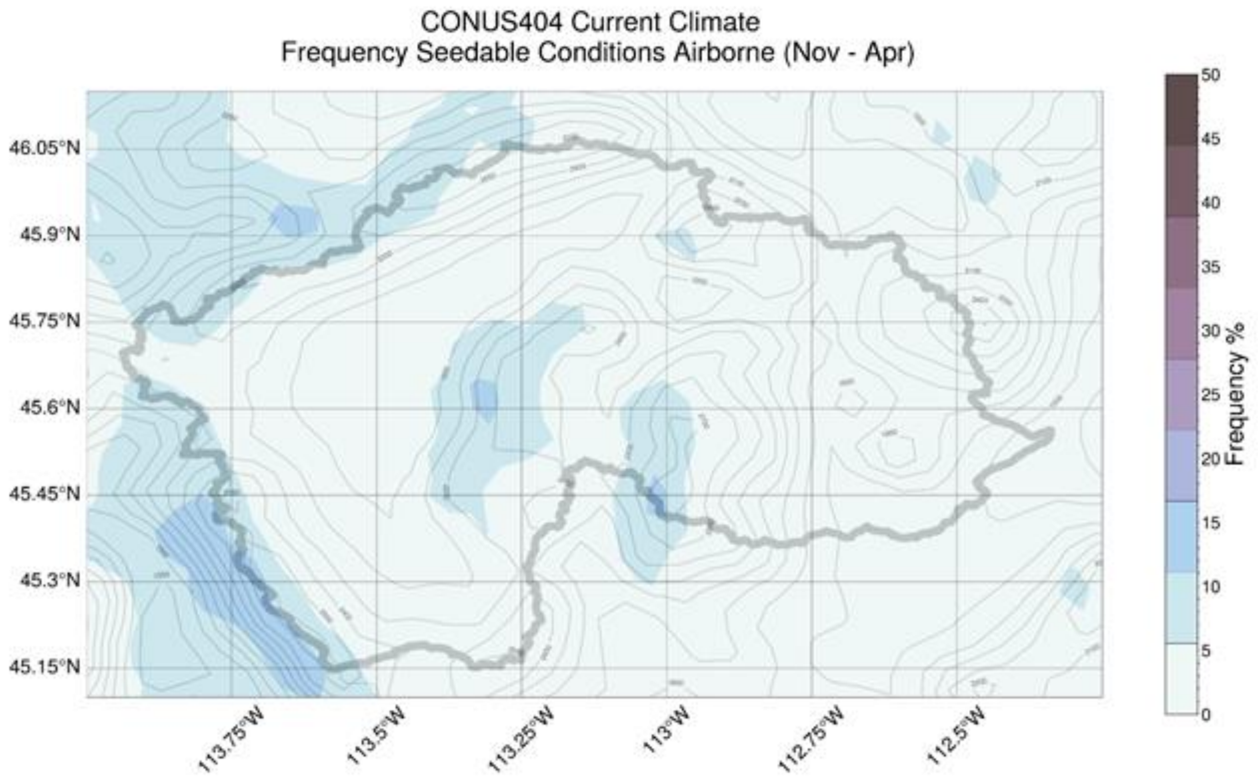
Most precipitation falls on the west and northern mountain ranges surrounding the basin

Cloud seeding frequency across the Big Hole

Ground-based Seeding Layer

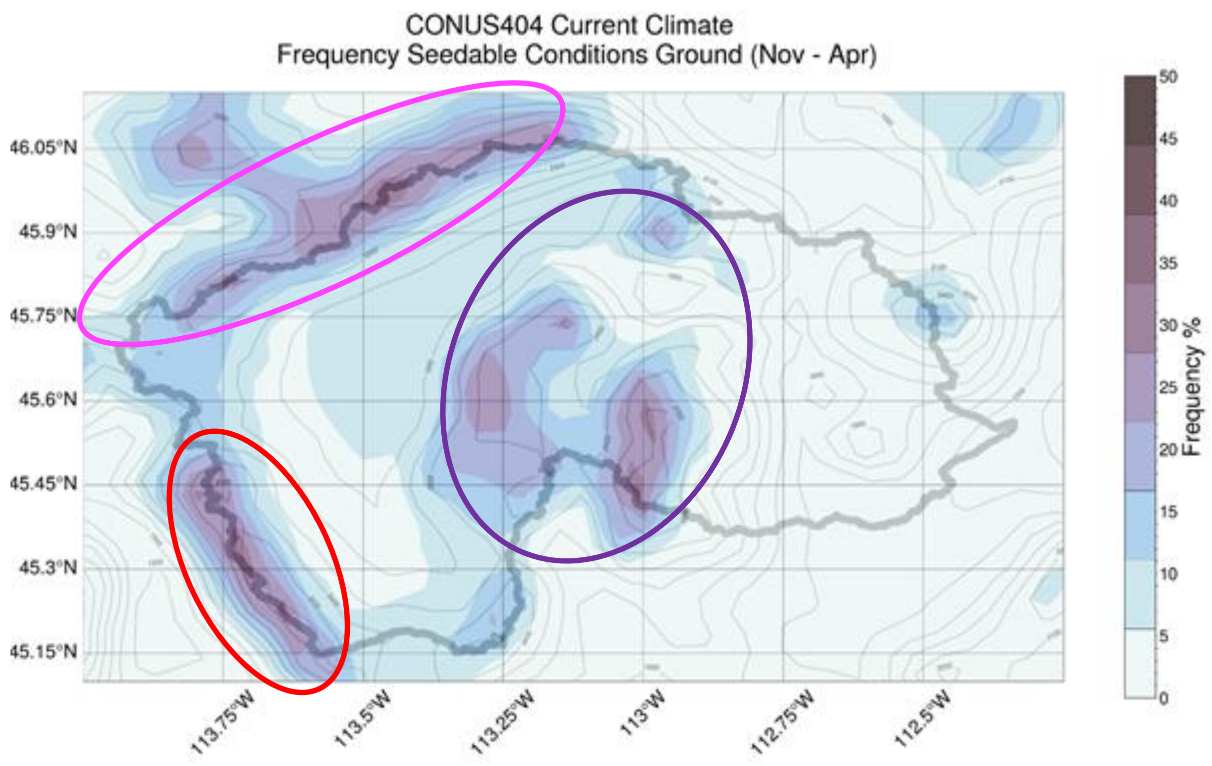


Airborne Seeding Layer

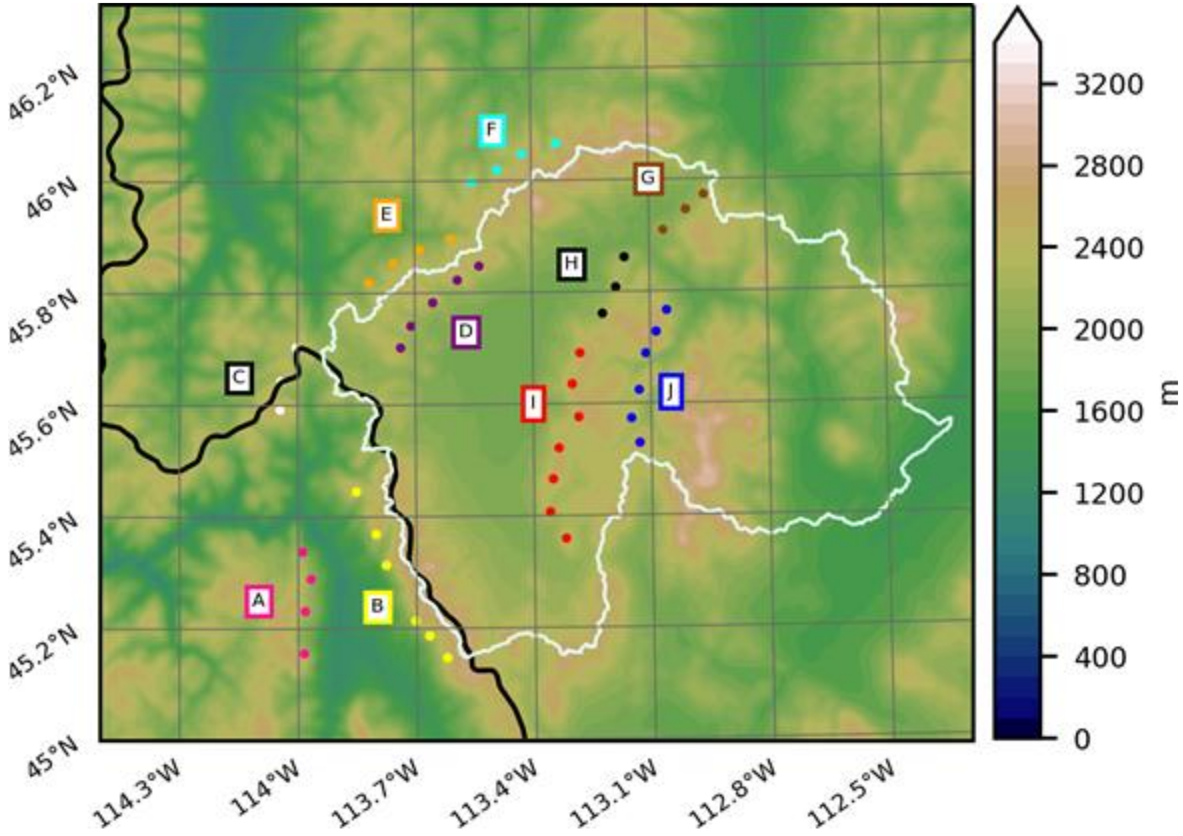


Ground-based seeding preliminary design options

Nov-Apr Average Frequency for Ground-based Seeding



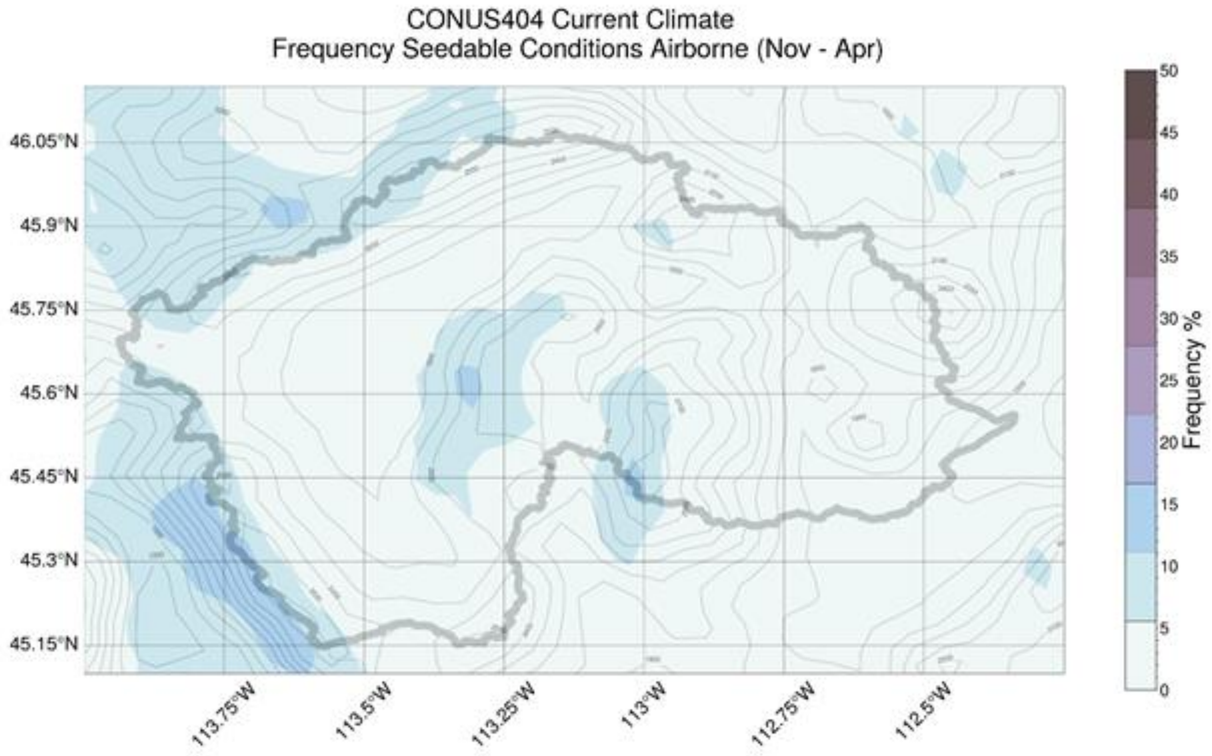
Hypothetical Ground-based Seeding Generator Sites



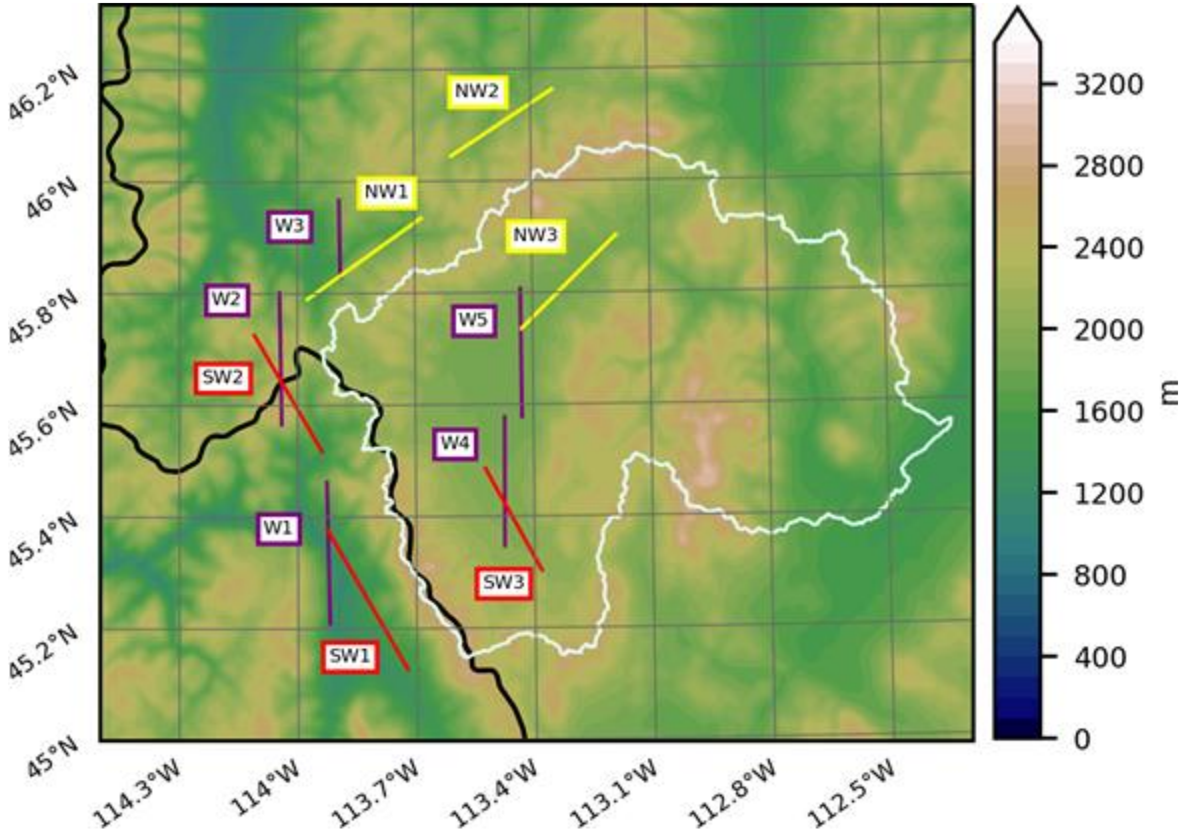
A & B Groups
C, D, E, F Groups
G, H, I, J Groups

Airborne seeding preliminary design options

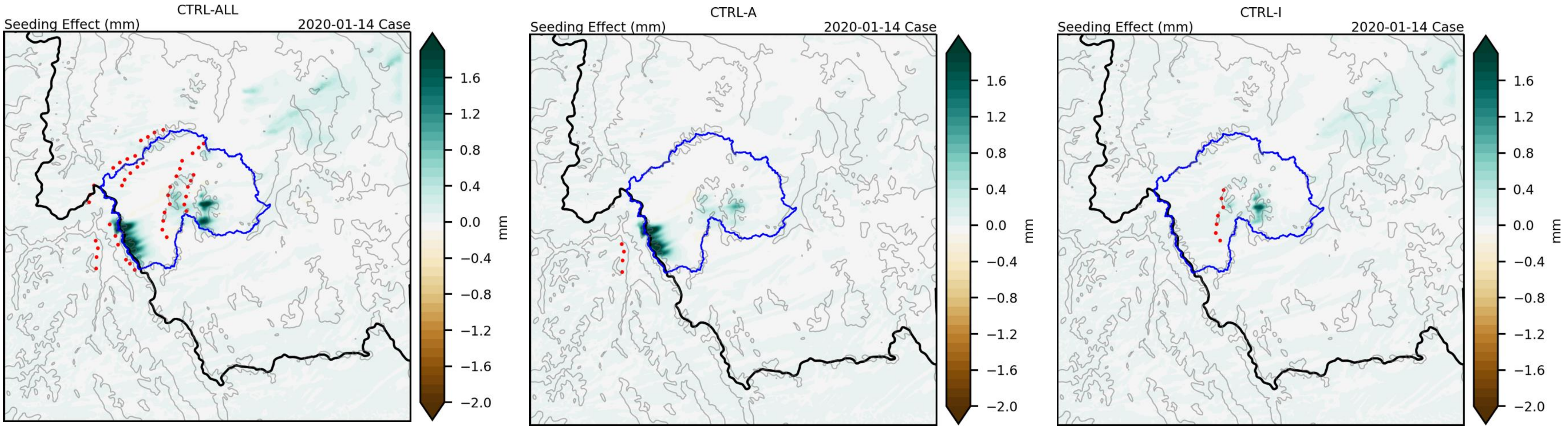
Nov-Apr Average Frequency for Airborne Seeding



Hypothetical Airborne Seeding Flight Tracks

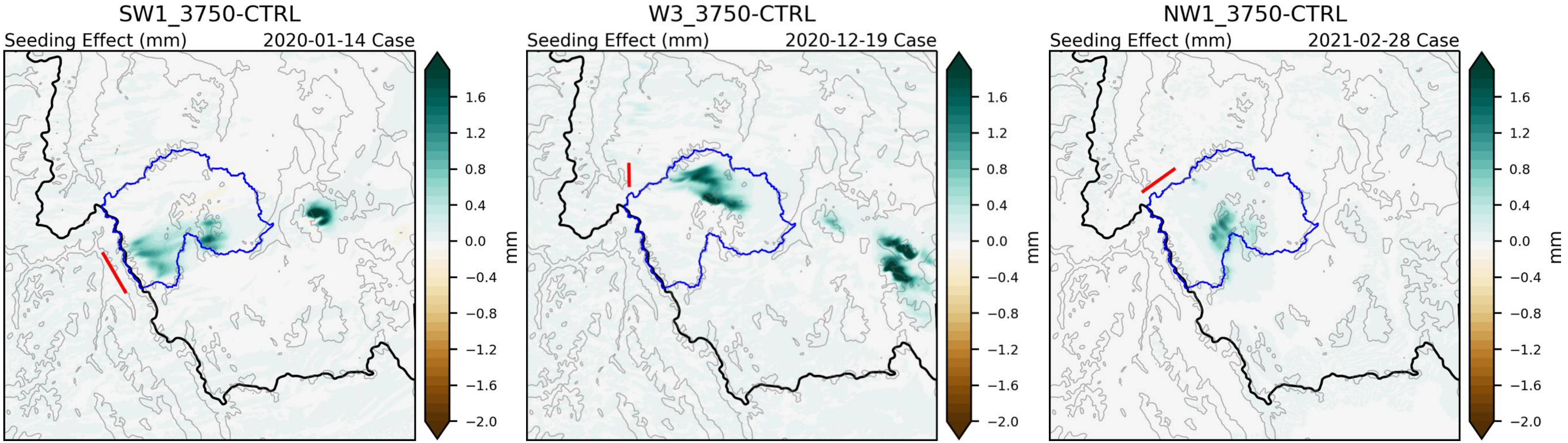


Preliminary Ground Seeding Design Testing



- Example outputs of WRF-WxMod® simulations showing the simulated precipitation change from potential cloud seeding in <u>one example case study</u>
  - WRF-WxMod was run for selected cases and each preliminary design
- Some ground seeding design options are more productive than others, but it depends on wind direction for each case as well

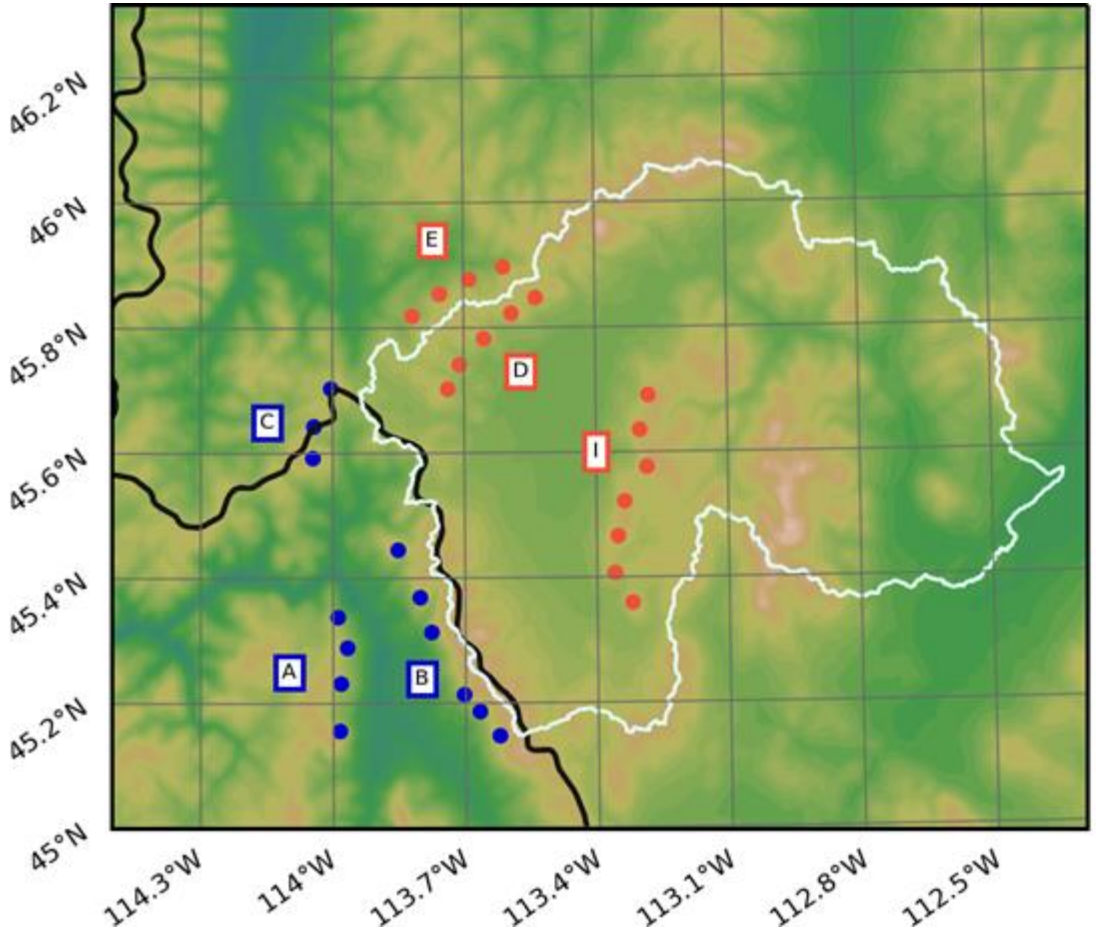
Preliminary Airborne Seeding Design Testing



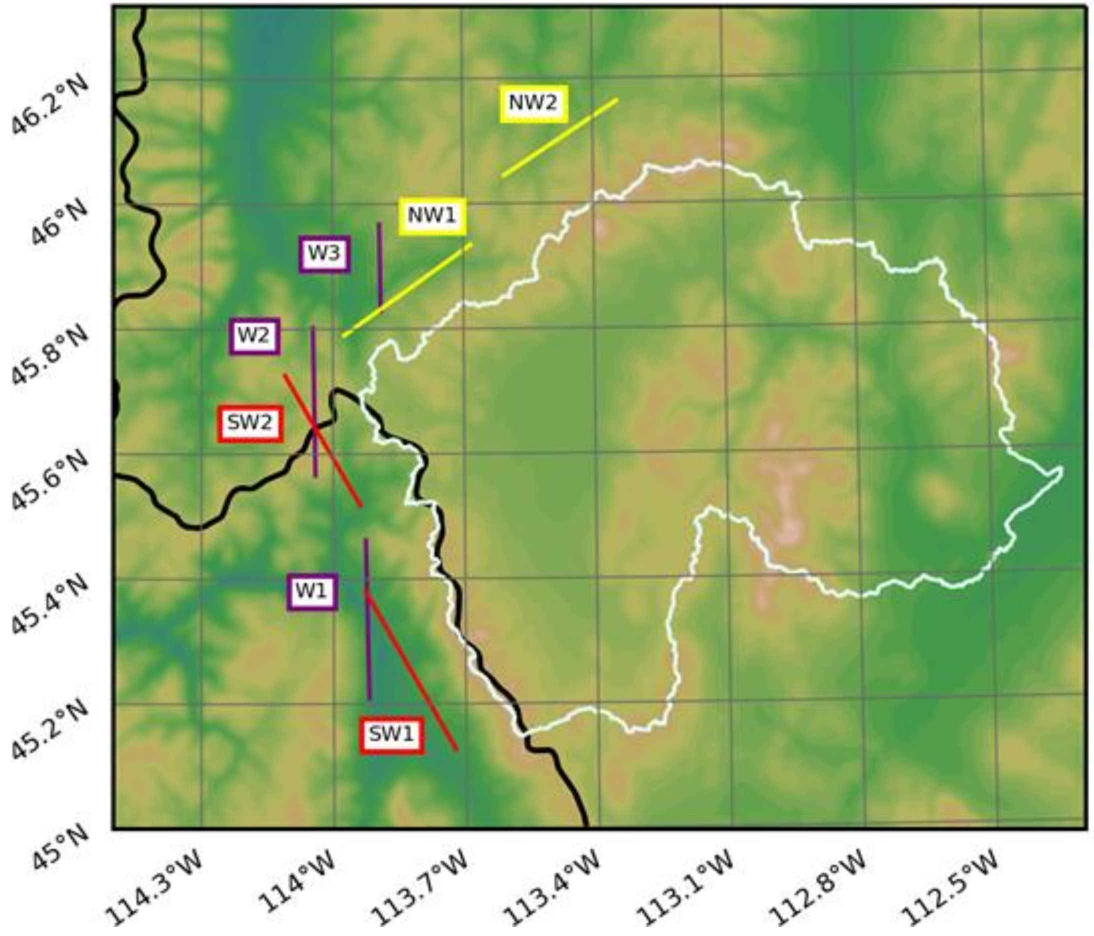
- Example outputs of WRF-WxMod® simulations showing the simulated precipitation change from potential cloud seeding in <u>three different case studies</u>
- Aircraft seeding can be more agile to adjust to the wind direction and most suitable seeding location for each storm system

Recommendations for Pilot Program Design

Ground Seeding
(Blue – Primary | Orange – Secondary)

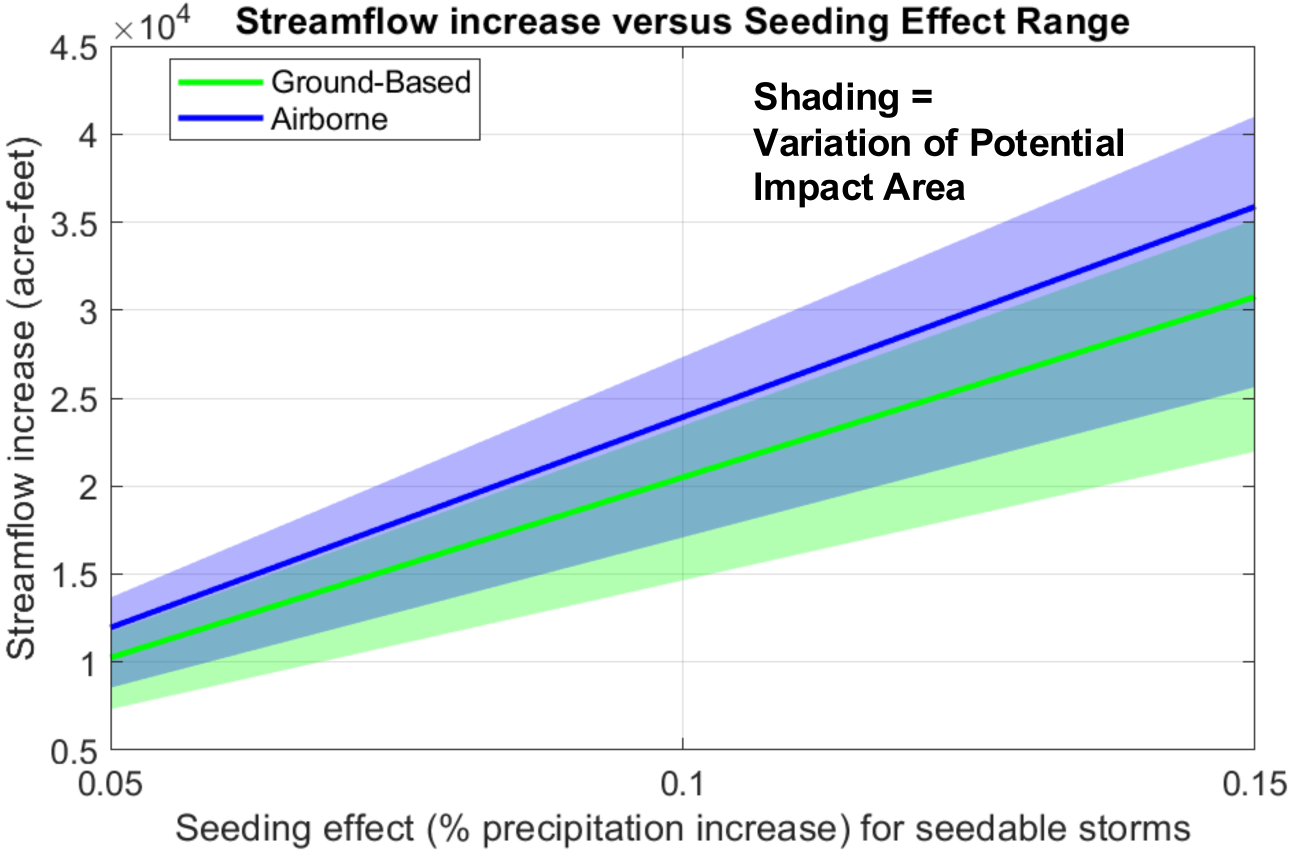


Airborne Seeding
(Purple – W | Red – SW | Yellow – NW)



Cost-Benefit Analysis Estimation

- Assumptions made for the following factors:
  - **Potential yield** of additional precipitation from seeding
    - Includes ground vs airborne climatological frequency of seeding
  - **Impact area** of the additional precipitation from seeding
  - **Snowpack melt to streamflow** efficiency



Variation of Potential Yield Percentage

Cost-Benefit Analysis Estimates

Seeding source	Assumed Cost of Operations ($)	Lower Estimated Cost/AF (80% impact area, 15% effect)		Higher Estimated Cost/AF (50% impact area, 5% effect)	
		Effect (AF)	$/AF	Effect (AF)	$/AF
Ground	$330,000	30,754	$10.73	10,251	$32.19
Airborne	$730,000	35,879	$20.35	11,959	$61.04
Combined	$1,030,000	66,633	$15.46	22,210	$46.38

- Additional streamflow from cloud seeding is estimated to cost between ~$10/AF and ~$60/AF
- Could produce between ~10,000 AF and ~70,000 AF of additional streamflow

Summary and Recommendations

- Ground seeding opportunities tend to be more frequent than airborne
  - The effectiveness of specific ground seeding sites is highly dependent on wind direction
  - Airborne seeding is more versatile
- The Beaverhead Mountains have the greatest opportunity for cloud seeding in the Big Hole region
- The estimated cost effectiveness of cloud seeding targeting the Big Hole is on the order of $10-$60/AF

A pilot program would be a next step to implementing seeding in the region:

- 3-5 year pilot program
- Ground and/or airborne seeding
- Include seeding operations and an evaluation by a 3rd party

There may be opportunities to partner with the State of Idaho (specifically, the Lemhi River Basin) on a joint cloud-seeding program for the region