THE EFFECTS OF EVAPO-SUBLIMATION ON THE PLANNING OF PRECIPITATION AND RUNOFF AUGMENTATION PROGRAMS

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INTRODUCTION

Precipitation augmentation programs continue to attract operational and research interest. The timing of precipitation augmentation efforts is largely opportunistic (Hess 1975, Betterton 1995). Recent research efforts have been aimed at optimizing the choice of precipitation events to augment (Betterton 1995). Evapo-sublimation losses to snowpack induced runoff are poorly documented and yet evidence is mounting that such losses can be both noteworthy and variable (Avery et al. 1992). We have recently undertaken efforts to document these losses through controlled experiments. An application of the value of these insights occurs when it is important to assess the cost-benefit ratio of proposed cloud seeding efforts.

METHODS

Part A – Field measurements of evapo-sublimation loss

Field measurements of evapo-sublimation losses from the seasonal snowcover were obtained from four sites on the high plateau country surrounding Flagstaff, Arizona. These studies used ablation lysimeters to measure evapo-sublimation and melt. Lysimeters were placed in a variety of natural and artificial environments during selected periods of four winter seasons between 1991 and 1994 (Figure 1). Evapo-sublimation losses from the lysimeters were compared to Flagstaff "Weather Service Office" (WSO) monthly precipitation reported averages.

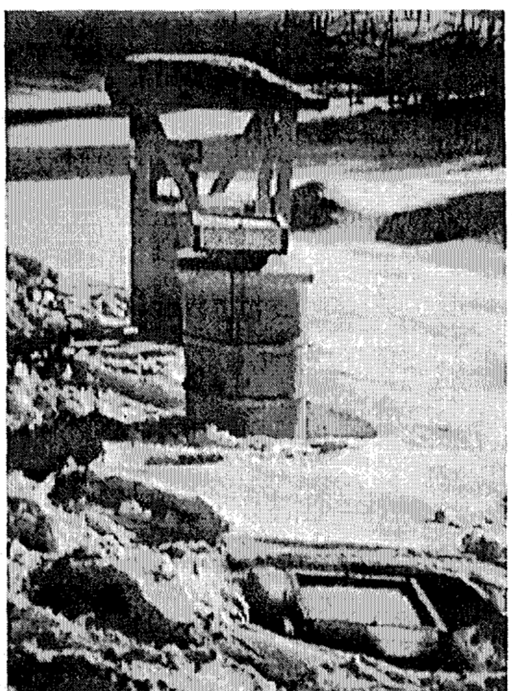

Figure 1. Typical evapo-sublimation site.

Part B – Natural analogs to early augmentation success

Yearly Flagstaff WSO winter precipitation and snowfall measurements since 1915 were compared to the current mean annual value of 254 cm (100 in). Monthly Flagstaff WSO winter precipitation and snowfall measurements since 1915 were parsed into percentages of the total winter accumulation arriving before the end of December (i.e. early arrival).

Two years were selected as analogs to precipitation augmentation programs with early season success. 1968 was selected as an above average snow accumulation year (150% of normal) with an unusually heavy early season delivery bias (60% of the total accumulation arriving before the end of December). 1971 was selected as a below average snow accumulation year (50% of the total accumulation arriving before the end of December).

Runoff for three major streams that drain the Flagstaff region was analyzed for peak discharge and total volume for the water years 1968 and 1971. Expected runoff as a function of above or below normal precipitation was compared to the observed runoff for these three drainages.

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RESULTS

Part A – Field measurements of evapo-sublimation loss

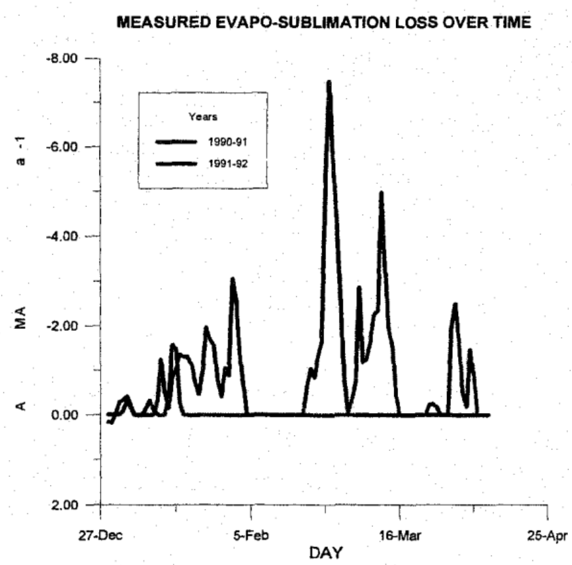

Figure 2. Two years of evapo-sublimation results.

Mean evapo-sublimation was measured at 1.56 mm of snow water equivalent (SWE) per day during all conditions reflecting non-precipitation days. Evapo-sublimation occurring during precipitation events could not be measured with the techniques used here and is assumed to be negligible.

Maximum evapo-sublimation was measured at 8.0 mm of SWE per day during windy and clear sky conditions (Figure 2). Cumulated mean evapo-sublimation over a snow accumulation season yields 284 mm (11.18 in) of SWE. Mean annual Flagstaff snowfall delivers 257 mm (10.12 in) of SWE (Table 1).

Table 1. Do-it-yourself evapo-sublimation budgets.

Gains (based on mean Flagstaff precipitation):					Losses (based on mean measured evapo-sublimation):	
Month	Days	Cumulative Days	Precipitation (mm)	Cumulative Precipitation (mm)	Time Span	Cumulative Loss (mm)
November	30	30	31.00	31.00	Per Day	1.56
December	31	61	44.10	75.20	Per 30 days	46.80
January	31	92	49.50	124.70	Per 61 days	95.16
February	28	121	50.30	175.00	Per 92 days	143.52
March	31	152	42.80	223.50	Per 121 days	188.76
April	30	182	33.00	256.50	Per 150 days	237.12
					Per 182 days	283.92

Part B – Natural analogs to early augmentation success

Peak discharge for 1968 was 11% of normal and total volume was 82% of normal. Peak discharge was 7% of expected and total volume was 55% of expected based on the winter precipitation received during the 1968 water year (Figure 3).

Peak discharge for 1971 was 33% of normal and total volume was 32% of normal. Peak discharge was 66% of expected and total volume was 64% of expected based on the winter precipitation received during the 1971 water year (Figure 4).

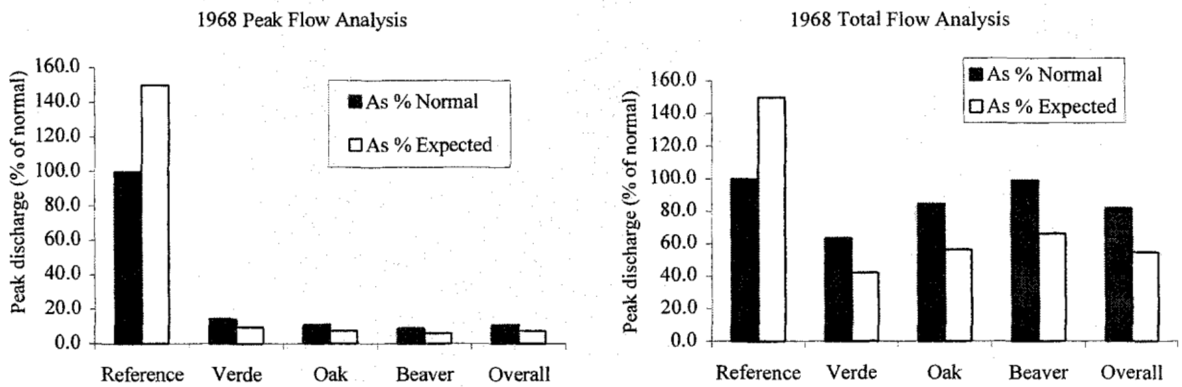

Figure 3. Peak and total flow analysis for 1968.

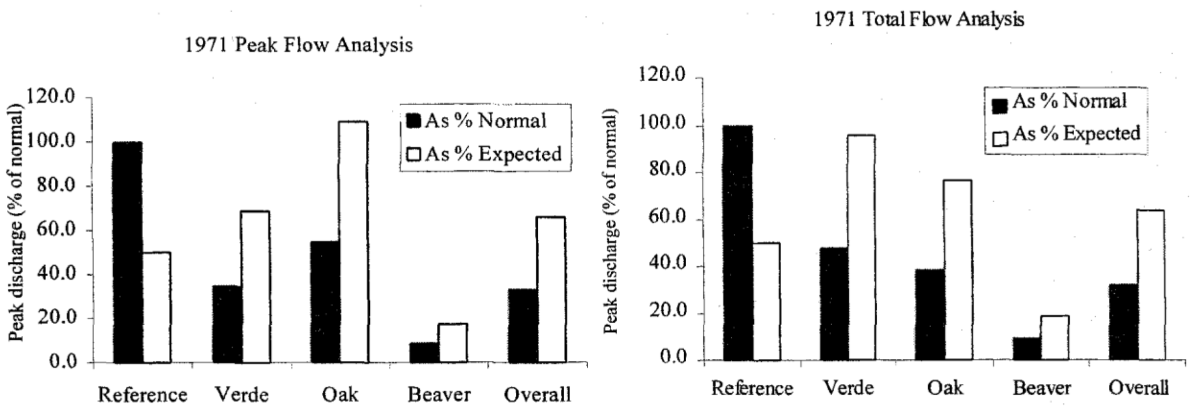

Figure 4. Peak and total flow analysis for 1971.

DISCUSSION

Evapo-sublimation from snowpacks at certain locations can account for a very significant depletion of the SWE. This analysis, based on data from two very different years, demonstrates that periodic runoff efficiency values are also altered.

The controlling factor seems to be the timing both of evapo-sublimation causing events and of snowfall events. While definitive precipitation-runoff relations are notoriously difficult to establish deterministically and are highly variable, the magnitude of the differences presented here are more than likely the result of significant snowpack losses leading to diminished runoff.

CONCLUSION

Maximum potential evapo-sublimation losses in the Flagstaff area can equal an entire average winter snow water accumulation. The timing of precipitation delivery and the variability of that timing between years will substantially alter the runoff efficiency.

Much effort has gone into demonstrating the feasibility of snow augmentation efforts, yet the success of these programs cannot be evaluated solely on the demonstration of increased precipitation delivery. Higher value should be assigned to later season snowfall delivery. It would appear that benefit-cost ratios are seasonally dependent with higher benefits accruing to late season augmentation successes.

REFERENCES

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