SEEDING EFFECTS ON CONVECTIVE CLOUDS IN THE COLORADO RIVER BASIN PILOT PROJECT

R. D. Elliott
North American Weather Consultants
1141 East 3900 South, Suite A-230
Salt Lake City, Utah 84124

Abstract. This paper addresses the matter of probable seeding effects during unstable air mass conditions in the target area of the Colorado River Basin Pilot Project (1970-1975). Various reports and articles have covered the neutral/stable condition which were the intended subject for testing, but not the unstable cases which had been inadvertently seeded as well. It is shown that when the upwind sounding gave indications that convection would be shallow enough to be embedded within the orographic cloud over the barrier, seeding effects appeared to be positive. However, for those cases in which there were indications that convection would be deep enough to emerge above the orographic cloud, there were indications of a negative effect. Reference is made to convection models in an attempt to explain how such a result is possible through the action of dynamic effects, which can diminish as well as enhance net precipitation.

The final analysis of the Colorado River Basin Pilot Project (CRBPP) (Elliott et al., 1976) and summary article (Elliott et al., 1978) indicated by means of post-hoc stratifications using three and six hourly time blocks that the original Climax (Grant and Mielke, 1967) hypotheses concerning seedability of orographic clouds as related to cloud top temperature appeared to be valid during stable and neutral orographic flow over the San Juan Mountains of this experimental area. A recent reanalysis (Shaffer, 1983) shows a strengthening of the support for such a seedability window when the height of the -5C level relative to the crest height is employed to eliminate cases in which ground generator plumes are unlikely to reach an effective nucleation level.

The original analysis eliminated seeded cases in which the anemometer network had indicated flow around rather than over the barrier, as well as non-seeded cases susceptible to contamination from pooling of nucleant during a prior seeded day. The additional removal of cases where the ground generator plumes would be unlikely to attain the -5°C level, even though flow up and over the barrier was assured, has eliminated additional noise from the seeding signal.

The CRBPP was a Bureau of Reclamation five year randomized orographic seeding test where experimental units were selected by a forecaster in Durango Colorado, and were seeded or not according to random selection. The target area included the higher elevations of the San Juan mountains (see Figure 1), and the seeding was carried out by a network of ground based silver iodide smoke generators; one condition for seeding was that there be no deep convection present. Unfortunately, some convective periods did occur within many of the experimental 24 hour blocks. Such periods of convective activity were sorted out in a post-hoc analysis that broke the 24 hour experimental units down into 3 hour blocks. The convective 3 hour blocks showed variable effects with respect to seeding. Under certain circumstances, a negative seeding response seemed to have occurred. This was revealed when seed-no seed precipitation ratios were arranged with respect to the time of the 700 mb trough passage ("tropas"). Table 1 displays ratios for three different precipitation groups extending from the southwestern slope up over the crest to the north-eastern (downwind) slope. Rather low seed/no seed precipitation ratios appear near the 700 mb tropas and for six hours thereafter. Elsewhere ratios are greater than unity more often than not. This is the same region, relative to tropas, where convection tends to be deepest, and where the orographic cloud over the barrier is thinning out most rapidly. This suggests that the negative seeding window occurs where the tops of convection over the barrier rise above the top of the main orographic cloud top.

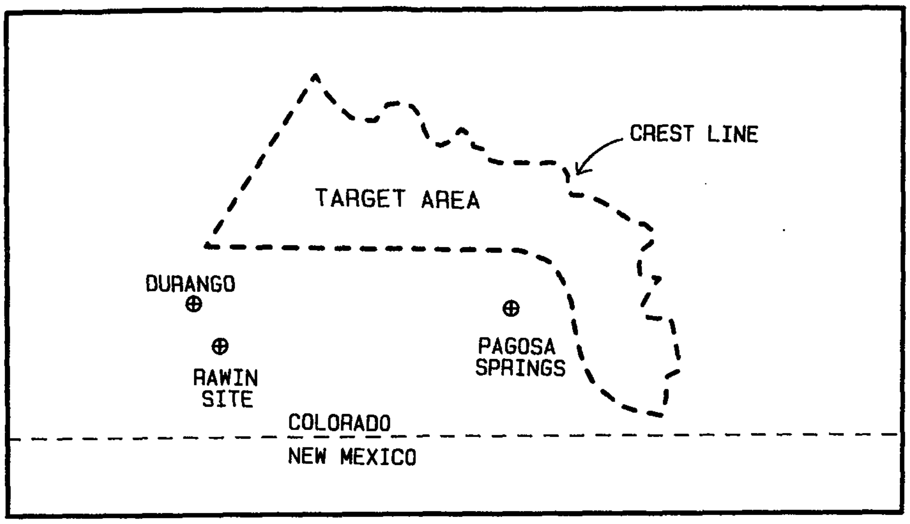

Fig. 1 COLORADO RIVER BASIN PILOT PROJECT AREA

Table 1 **Ratios of seeded to not seeded precipitation in three-hour blocks for unstable cases.**

	Hours before (-) or after (+) Tropas (trough passage)						
Precipitation Group	+9	+6	+3	0	-3	-6	-9
Wrn upwind flank	1.09	.79	.33	1.08	1.33	1.32	1.75
Wolf Creek Pass	1.15	.81	.62	.78	.85	2.26	1.37
Downwind flank	.73	.76	.65	.65	1.38	1.79	1.60

To test this hypothesis, the entire sample, without reference to position with respect to tropas, was divided into two groups. In one the top of the positive area shown on the upwind sounding (found associated with convection tops over the barrier) was higher than the cloud top calculated to exist over the barrier by lifting the top of the main deck, using the Durango upwind sounding. This will be referred to as the "emergent" case. In the second the reverse was true. This will be referred to as the "embedded case". However, it is not the same as the "embedded band" precipitation echo type employed in the Sierra Cooperative Pilot Project. The cases employed were subject to the various exclusions used by Shaffer, but in addition the base of convection, as determined from the sounding, had to lie below the crest level so as to insure entrainment of the ground generator plumes into convection.

Results of this division (Table 2) show that the Wolf Creek group of precipitation stations experienced a low ratio of seeded to not seeded precipitation in the emergent case. The rankings of the precipitation values for the seeded and not-seeded samples were compared using the Mann-Whitney U test. This indicated that the probability of a null effect was .008 for Wolf Creek pass. The other groups do not appear to be adversely affected. In the embedded case all groups show a positive ratio, with a probability of .073 in the downwind flank group. It should be mentioned that the crest group used in Shaffer's article included stations covering a larger area than used in this analysis.

2. DISCUSSION

In the embedded case, constituting 72% of the unstable sample, positive effects of seeding seem to be indicated. In the emergent case the crest zone shows an adverse effect with a seed/no seed precipitation ratio of 0.55. The region of adverse effect appears at about the same place in the synoptic sequence that has been chosen by Cooper and Marwitz (1980) in their analysis of aerial observations over the San Juan Mountains as a region favorable

Table 2 **Group precipitation (mm/3 hr) statistics for embedded and emergent convection.**

State of Instability	Item	Precipitation Group			No. of cases
		Wm. Upwind Flank	Wolf Creek Pass	Downwind Flank	
	S precip	1.36	2.47	1.43	63
Embedded	NS precip	.95	2.05	.98	53
	Ratio	1.43	1.20	1.46*	
				Total	116
	S precip	1.70	1.53	1.60	22
Emergent	NS precip	1.71	2.80	1.54	24
	Ratio	.99	.55**	1.04	
				Total	46

* Probability = .073 for two tail Mann-Witney U test.
** Probability = .008 for two tail Mann-Witney U test.

for seeding from ground generators. The generalized criteria developed by Vardiman and Moore (1978) suggest that with a greater depth of convective instability, such as would occur in this region, the odds for a favorable response to seeding diminishes. This supports the author's analysis.

From the viewpoint of a purely microphysical effect of seeding, it is difficult to identify a reason why seeding effects in the mergent cases would be radically different from seeding effects in the embedded cases. One possible reason would be that in the emergent cases there are more high tops than in the embedded cases, thus leading to excessive nucleation and therefore to overseeding. As a test of this idea, all the cases with a positive thermodynamic area exceeding 200 mb in depth were examined and a table (Table 3) similar to Table 2 constructed. In the Wolf Creek Pass group the same adverse effect appears in the emergent case and again, the embedded cases do not show this effect. Therefore, a purely microphysical explanation is ruled out.

There is an argument for relative seeding losses in the emergent case due to dynamic effects. In presenting this argument we first refer to Weinstein's (1972) analysis of numerous soundings by means of a one-dimensional convection model, in which he showed that the effect of a dynamically produced (by seeding) rise in convection top could be associated with precipitation loss, as well as a gain. In the former case, the loss resulted from the reduction in time for growth of the particles due to the stronger updraft, even though the top was raised and total condensation increased. His analysis showed that the model did predict this outcome on a substantial fraction of the soundings he analyzed. A logical extension of this thesis is that the adverse effect on precipitation would be more pronounced in emergent convection due to the entrainment of relatively dry air at higher levels. Also, a factor not considered by Weinstein is the possibility of some evaporation of ice particles ejected from convection tops in their passage through dry air to the lower orographic cloud deck.

In the embedded case, although seeding growth time would be reduced due to dynamic effects, precipitation could be increased simply because of the added growth of the ice particles as they fell through a greater depth of cloud.

On the basis of this argument, an adverse dynamic seeding effect in the CRBPP in connection with the seeding of convection having a potential for emergence is quite likely. It might be argued that seeding with ground based generators would not provide an adequate concentration of nuclei to produce such a dynamic effect. However, this argument fails to consider that the nuclei concentrations were adequate to glaciate the available liquid water, which was small in comparison to that found in summer convection, but which is just as large in proportion to the size of the convection systems involved.

This conceptual model for adverse dynamic effects of seeding cannot safely be extended to very large convective systems, or to banded mesoscale systems, both of which generate their own embedding cloud mass. Nor can it be extended to convection under a limiting stable layer where tops cannot rise into the drier upper region. Since it appears

Table 3 **Group precipitation (mm/3 hr) statistics for embedded and emergent convection for cases with positive area deeper than 200 mb.**

State of Instability	Item	Wm. Upwind Flank	Wolf Creek Pass	Downwind Flank	No. of cases
	S precip	2.29	2.86	2.13	11
Embedded	NS precip	1.72	3.13	1.80	11
	Ratio	1.33	.91	1.18	
				Total	22
	S precip	2.01	1.33	1.73	14
Emergent	NS precip	1.99	2.98	1.73	20
	Ratio	1.01	.45	1.00	
				Total	34

* Probability = .003 for two tail Mann-Whitney U test.

at the crest only, the effect is keyed to a time period of about 100 minutes from the average nucleant source in an average wind flow.

The relatively low frequency of occurrence of conditions favoring such an adverse seeding effect under convective conditions in the winter orographic setting can cause this effect to be easily lost in analyzing a sample that includes all convective cases. In the much larger fraction of cases (embedded) that appear to have a positive reponse to seeding, the response quite likely is also dynamic in character. Therefore, future seeding experiments should be designed to detect dynamic responses to seeding, including enhancement of vertical circulation as well as direct effects on precipitation, even though the intent of the seeding is to produce only a microphysical effect.

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