SUMMARY AND CONCLUSIONS OF AN INDEPENDENT ANALYSIS OF THE WEATHER MODIFICATION PROGRAM IN THE SAN LUIS VALLEY

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SUMMARY AND CONCLUSIONS

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AN INDEPENDENT ANALYSIS OF THE WEATHER MODIFICATION PROGRAM IN THE SAN LUIS VALLEY

Prepared for

The Colorado Advisory Committee on Weather Modification

and

The Colorado Director of Natural Resources

by

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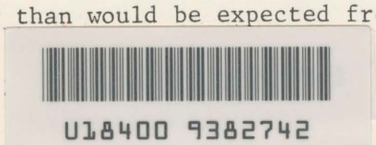
A comprehensive analysis of the cloud seeding activities in the San Luis Valley of southern Colorado is in progress. Several more months will be required for its completion. Certain tentative conclusions are now possible. These are presented in summary form and in some detail in the following sections. It is planned that a technical report will be prepared and submitted to a scientific journal for publication at the completion of the study.

Summary of Conclusions

(1) The cloud seeding program in the San Luis Valley has been very intense for a local area and its continuation for six consecutive years represents a long period of operation for a weather modification program. While the program has not been carried out in a manner ideal for research analysis, sufficient data is available for investigating some of the seeding effects.

(2) No conclusions can be made at this time as to the effectiveness of the program for hail suppression since hail or crop data are not available to the authors.

(3) The amounts of rainfall during the seeded period were greater than normal and greater than would be expected from comparisons with surrounding



areas. The frequency of months with precipitation above normal, or greater than expected from comparisons with surrounding areas, was also higher than would be expected. The above normal amounts and higher frequency of above normal rainfall extended to all parts of the Valley. These rainfall analyses, consequently, do not support the contention that overall precipitation has been reduced. There are indications that rainfall may have, in fact, been increased in some parts of the Valley. There are some indications that decreases in rainfall may have resulted from seeding on some days and that increases may have resulted from seeding on other days, but with the cases of rainfall increases more than off-setting the cases with decreases. The analyses of the effects of seeding on rainfall are being continued.

(4) The reports of decreased forage and crop production in some parts of the Valley are probably related to a lowering of the water table from which plants draw important quantities of water in the San Luis Valley. With lower water tables this sub-surface source of water is less accessible for plant growth. Since overall streamflow and Valley precipitation has been near or above normal for the past six year period, the lowering water table is probably related to the combination of (1) increased pumping rates that deplete the sub-surface waters, and (2) decreased water diversion into the Valley to resupply the sub-surface water.

(5) The conclusions regarding the reduction in underground water supplies are based on exploratory investigations. These should be pursued in considerably more detail. Short of controls on pumping or changes in water diversion patterns, winter time weather modification for augmenting mountain snowfall and subsequent streamflow may provide an additional source for supplemental water supplies. Seeding technology for augmenting precipitation from winter mountain clouds indicates that precipitation increases of 15-25% are probably feasible in the mountains of southern Colorado. An increase of this amount when combined with normal streamflow

may provide sufficient water for meeting river demands and also recharging the underground.

SUMMARY OF ANALYSIS

I. The San Luis Valley Weather Modification Program

The seeding program in the San Luis Valley has been one of the most intensive carried out in the U.S. and has been continuous for an interval of six summers. Aircraft have been used to place the silver iodide seeding material in or at the base of convective clouds for the purpose of suppressing hail. Table I shows (according to the operator reports to the State of Colorado) the amount of silver iodide released, the number of days when seeding took place, the average amount of silver iodide released on each day, and an estimate of the daily amount of silver iodide available for each square mile of the targeted area. Comparable data for 1967 and 1968 are not available at this time. Weather modification activities also occurred in the eastern part of the Valley in the years 1963-1965.

TABLE I

	1969	1970	1971	1972
Silver Iodide, Total Amt. (lbs)	34	305	447	168
Number of Seeded Days	42	42	47	42
Average Amount of Silver Iodide per Seeded Day (lbs)	0.81	7.26	9.51	4.00
Approx. Average Amount of AgI per sq. mile of Target (lbs)	(.00070)	.00629	.00823	0.00346

The extended period of intensive cloud seeding operations provides background material that justifies careful analyses.

II. Hail

No conclusions as to the effects of seeding on the occurrence or severity of hail in the San Luis Valley are warranted since no hail or crop data are available to the authors.

III. Precipitation

Precipitation records from the National Weather Service are available for determining the amount of precipitation that occurred during the seeded period and for making a reasonable assessment of the effect of seeding on the precipitation. Evaluation of the effects of seeding is restricted by the non-randomized nature of the seeding operations.

The total precipitation for all of the July and August seeded months has clearly been above normal. Based on a 20-year climatology, 1944-62 and 1966, using the records from Alamosa, Blanca, Center, Del Norte, Manassa, Monte Vista and Saguache, the average precipitation expected in the Valley for a period of six summer seasons is 15.49". Actual precipitation for the six seeded summers, 1967-1972, was 21.25". This is 5.76" or 37% above the average and is nearly 1" per season greater than the average for the historical years. Four (67%) of the six summers (1967, 1968, 1969, 1971) received above normal rainfall while two (1970, 1972) received below normal amounts. This is a higher frequency of wetter than normal seasons than would be expected. Wetter than normal seasons can be expected less than half the time, since some years have large excesses of rainfall and raise the average. The above normal amounts of rainfall occurred during both July and August. The excess for July was 3.18" or 43% and for August was 2.58" or 32%. The above normal pattern of precipitation for the summer season extended to all portions of the Valley. Table II shows the amount that summer (July-August) precipitation, 1967-1972, was above normal for the respective Valley stations.

TABLE II

Alamosa	+14.49"	+88%	Monte Vista	+5.75"	+39%
Blanca	+ 9.86"	+85%	Saguache	+5.53"	+31%
Center	+ 2.85"	+21%	San Luis	+7.04"	+44%
Del Norte	+ 8.86"	+50%			
Manassa	+ 3.91"	+27%			

The above figures only show that the summer seasons 1967-1972 were wetter than normal. They do not show that the wetter than normal summers were caused by the cloud seeding. An attempt is being made to determine the actual effect of seeding in the San Luis Valley on the rainfall. Computer prediction equations have been developed to calculate what the precipitation should have been in the Valley had no seeding taken place. These prediction equations are based on a comparison of the rainfall in the San Luis Valley with rainfall at other locations outside the Valley in southern Colorado and northern New Mexico. Precipitation records for years prior to cloud seeding activities have been used in developing the prediction equations. The observed rainfall data at the stations outside of the San Luis Valley during the seeded years were then used to predict what the rainfall in the Valley should have been had seeding not taken place. This predicted value has then been compared with the actual precipitation observed to see if Valley rainfall during the seeded months is different than would be expected. The prediction equations developed provide reasonably good estimates of what the rainfall should have been without seeding.

The computer predictions show that actual rainfall in the Valley should have been greater than normal during the seeded period. This is in agreement with the observations of above normal rainfall. The computer estimates that total Valley rainfall for the six summer seasons should have been 18.80" or 3.31" above the normal amount of 15.49". This clearly reflects the occurrence of above normal precipitation in other parts of the southern Colorado and northern New Mexico during these six seasons as well as in the San Luis Valley.

The actual precipitation in the Valley of 21.25", however, is even greater than the predicted amount of 18.80", by 2.45" or +13%. An excess of this amount from the computer prediction may represent an increase from the seeding but, on the other hand, could reasonably be expected to occur by chance (the 4% excess for August has a high natural probability, the 24% excess for July is not as likely to be a chance occurrence).

The actual precipitation was greater than the computer prediction for five of the six seeded years, 1967, 1968, 1969, 1971, 1972, and less than expected in one year, 1970.

Actual precipitation greater than the computer prediction occurred in all portions of the Valley except the extreme northern portion as represented by Saguache, where actual precipitation was slightly below the computer prediction.

IV. Valley Water Supplies

The many reports of the deteriorating conditions of dry land crops during the past several years are a major concern. Since the total Valley rainfall during July and August for the period of the past six summers has obviously been greater than normal, and somewhat greater than the computer prediction, other possible causes for this deterioration in crop production must be considered.

A. Precipitation in non-summer months

Dry land crop production is obviously related to precipitation throughout the year. Below normal precipitation during the other months of the year--particularly during spring and winter would result in reduced surface water available for plant production. An abnormal dry period during these other months, even though they would not be affected by the seeding, could be an adverse factor in dry land crop production. A review of the rainfall records for the 10 months preceding each of the seeded July-August seeded periods, 1967 through 1972, shows that Valley average precipitation during these years was essentially the same (+4%) as the long term

average. Approximately half (11 of 24) of the station months were above normal. And again, as would be reasonably expected, 1/3 of the years, 1967 and 1972 were below normal throughout the Valley, 1/3 (1969, 1970) were above normal, and 1/3 (1968, 1971) were in an intermediate category with some stations above and some below normal. Average natural precipitation in the San Luis Valley is very low. An adverse weather pattern that would reduce the amounts even further did not occur during the non-seeded months of the years that the seeding took place.

B. Sub-surface water

A preliminary survey of changes in Valley sub-surface water supplies of the shallow aquifer shows that the water table has lowered, resulting in a reduction of water supplies available to the root zone of plants. With a water table at around 2.5 feet below the surface, plants overall can be expected to utilize around or over the equivalent of 2 feet of water per year from this underground supply. The utilization of this underground water by plants drops off rapidly as the depth to the sub-surface water increases. Overall plant use of sub-surface water in the San Luis Valley is probably reduced to around 0.5 feet of water per year when the water table drops to about 7 feet below the surface. A review of selected well records shows that water levels in the unconfined acquifer in many parts of the Valley have clearly lowered during the summer months of the past several years. This lowering has been very marked in some areas and has been from depths at which sub-surface water would be readily available in the root zone to levels where the sub-surface supplies would be greatly reduced.

There are, of course, substantial differences in depths to water and in the response of the water table to diversions, streamflow, pumping, etc. in various parts of the Valley. All of the wells being observed need to be examined in order to clearly define basin wide changes in the water table.

For this exploratory investigation, measurements from seven wells* have been used to index the general change in the depth to the shallow water table (the unconfined aquifer). The well hydrographs of the seven index wells have been plotted using the frequent observations available. The depth of the water table for 1 August (selected as near the middle of the summer crop season) has been determined from these well hydrographs. The water table has lowered at all seven wells between 1968 and 1972 (at one well the observation started in August 1969). The drop in the water table at the wells ranged from 0.2' to 3.6'. Individual changes in the depth to water at the respective wells were -1.6, -0.7, -3.6, -1.6, -0.2, -2.3, and -0.2 feet. (Corresponding figures for the period 1967-1972 are -2.2, +0.8, -2.4, -1.6, -0.6, -2.0 and -0.3.) This represents an average lowering of the water table of 1.46 feet (1.19 feet 1967-1972) and a median lowering of 1.60 feet (same for 1967-1972). A consistent lowering of the well depths during the past few years is apparent. The rate and timing of the lowering varies at the respective stations. If these wells are representative of the Valley, an increase in the depth of water at many of the sites could substantially reduce the water available to the root zone of many dryland grasses and crops.

It cannot reasonably be expected that the lowering of the water table is related to the weather modification program in July and August. First, as pointed out above, rainfall was clearly above normal during the seeded summers. And second, the small amounts of summer Valley rainfall are well below the evapotranspiration rates, and, except perhaps for heavy local showers, are quickly consumed in the surface layers.

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*Alamosa County, 39-9-3DDD
Rio Grande County, 39-8-6BBB
Rio Grande County, 40-8-18CBB
Conejos County, 34-9-35DDD
Alamosa County, 36-9-13AAA
Conejos County, 35-10-16CBB
Saguache County, 41-10-36DDD

Since precipitation in other months of the year is also low (a valley wide average of only about 5" for the ten other months) and since near normal amounts have occurred during the past five years, the water table lowering cannot be reasonably related to this additional precipitation factor.

A review of the streamflow into the Valley also shows that water supplies during the past few years have not been deficient. The average flow of the Rio Grande at Del Norte during these years has been 555,000 A.f. This is essentially the same as the average for the 24 year period from 1949 through 1972. The flow during three of the past six years has been above average, and for four of the past six years has been above the median.

The two factors that are probably related to a lowered water table are (1) the increase rates of pumping that withdraw water from the underground and (2) the decrease in diversions of river water into the Valley that could recharge the underground water supply. The number of wells pumping from the unconfined aquifer has steadily increased from around 200 in 1940 to near 2100 by 1969, and the average yearly volume of water pumped, about 40,000 A.f., for the fiveyear period ending in 1944 increased to an average annual amount of near 300,000 A.f. per year for the five year period ending in 1969. Data on numbers of wells and pumping rates are not available to the authors for the period beyond 1969. It is reasonable to assume that pumping rates have continued to increase. Streamflow diversions into the Valley that could serve to recharge the underground water have been slightly below (6%) during the past six years and have decreased each of the past four years and by substantial amounts in each of the past three years.

V. Augmenting Valley Water Supplies

Solutions to the Valley water problems also need to be considered. Short of controlling pumping rates or making changes in diversions of water into the Valley, weather modification of wintertime mountain clouds may have the potential for augmenting water supplies by an amount that may be sufficient

when combined with normal streamflow to meet river demands and to supply water for underground water recharge. The technology for seeding wintertime mountain clouds for augmenting snowfall is more advanced than that for seeding summer convective clouds. Physical models of orographic cloud processes are available. These models delineate meteorological conditions for which precipitation increases should occur. These models have been tested during randomized field seeding experiments in Colorado. The models and field experiments indicate increases in wintertime mountain snowfall of 15 to 25% are possible in the mountains of southern Colorado. An analysis of streamflow records following the experimental seeding in the Wolf Creek Pass area during the winters of 64-65, 66-67 and 68-69 shows that the seeding probably produced a total of 228,000 A.f. of additional water in the watersheds of the San Juan R above Pagosa Springs, the South Fork of the Rio Grande R above South Fork and on Alamosa Creek above Terrace Reservoir. Approximately half of this indicated increase was in the San Juan basin and about half in the Rio Grande drainage. Only portions of the respective drainage basins were seeded during these experiments.

Acknowledgments and References

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