Cloud Seeding Against the 1964 Drought in the Northeast

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ABSTRACT

A short account is given of seven cloud-seeding programs conducted in the summer and autumn of 1964 for drought relief in the Northeast, and evaluations of six of them by target-control regressions of normalized monthly data are presented. The results indicate increases varying from one to sixty per cent, averaging twenty-five per cent, nominally significant at the one per cent level. Circumstances such as non-randomization that compromise the evaluation are discussed. Note is also taken of an indicated fourteen per cent rainfall increase in 1964 in a hail-suppression target area where operations were recently suspended on account of a state law prohibiting cloud seeding on the grounds that it contributes to drought.

1. Introduction

The severe drought conditions that afflicted the northeastern United States in the summer and autumn of 1964 gave rise to a series of cloud-seeding programs intended for alleviation of the drought distress, seven of which were conducted by the Howell Associates. This article is a report of the conduct of these operations and the indications of precipitation increase associated with them, together with a discussion of this material.

In all of these operations, practical contribution to drought relief was the primary objective, and considerations of experimental design for the purpose of evaluation were entirely secondary. The sponsors of these programs were advised in advance that cloud seeding operations conducted by the Howell Associates under comparable conditions had resulted in indications of precipitation increase varying widely from plus 70 per cent to minus 10 or 15 per cent, and the increases of 15 to 25 per cent that appeared on the basis of these experiences to be a reasonable expectation would in all probability be too small to provide a trustworthy indication of whether or not a cloud-seeding program carried on for a few months during the drought had or had not produced any precipitation increase. The sponsors were advised furthermore, that although it had been established beyond a reasonable doubt that cloud seeding was associated with precipitation increases under certain weather conditions, the range and frequency of occurrence of these conditions was a matter of uncertainty and that no guarantee could be offered that cloud seeding in the situation under consideration would be effective. In each instance, the decision to proceed with the program was based on appreciation that the penalty of foregoing the reasonable expectation of even a small increase was unacceptable in comparison with the penalty of losing the relatively modest sum expended on cloud seeding if it were indeed useless, even though the outcome would probably not be known with an acceptable degree of confidence. The expectations established in advance were, accordingly, that variable amounts of increase would be indicated, probably averaging near 20 per cent, but without statistical significance.

2. Cloud seeding operations

Operational data for the seven programs are shown in Table 1. Fig. 1 shows the locations of the target areas and of the control areas used in making rainfall or run-off comparisons, except for the watershed of the St. Croix River in extreme eastern Maine. (Presentation of indicated results from the St. Croix program have been deferred pending outcome of an attempt by the St. Croix Paper Company to correct the series of streamflow measurements on that river for changes in storage in the principal lakes; historical rainfall records capable of characterizing the target area unfortunately do not exist.) During the first few days of the Hackensack program, the target was extended northward to include forest fires that were burning on both sides of Route 17 north of Sloatsburg in the Palisades Interstate Park.

Each program was under the immediate supervision of a field meteorologist stationed in the operating area. Cloud-seeding missions were conducted on the basis of weather forecasts and briefings furnished from Lexington, supplemented by local observations, in some instances by liaison with Weather Bureau radar stations with observing capabilities in and around the target area. Cloud-seeding missions were ordered whenever in the judgement of the field meteorologist there was even an outside chance of a weather situation that might be stimulated by seeding. Under this policy, there

TABLE 1. Tabulation of cloud-seeding programs.

Target	Began/ended	Number of seeding stations	Generator-hours of seeding
Mohawk-Mid-Hudson Parts of Washington, Rensselaer, Fulton, Schoharie, Saratoga, and Montgomery Counties, N. Y.	29 June/17 July (except 4 July)	26	1896
Hartford Northeastern Hartford County and northwestern Tolland County, Connecticut	26 July/26 Aug.	13	913
Dutchess-Ulster Dutchess County and southeastern Ulster County, N. Y.	5 Aug./3 Sept.	23	2542
Hackensack River Hackensack River watershed above Oradell, N. J.	26 Sept./31 Dec.	13	3532
Fitchburg-Leominster Northeastern Worcester County and northwestern Middlesex County, Mass.	10 Nov./13 Dec.	12	1484
Southern New Hampshire New Hampshire south of the Sandwich Mountains	19 Nov./7 Dec.	29	1650
St. Croix River Watershed of the St. Coix River above Woodland, Maine	29 Oct./7 Dec.	22	3572

were many occasions when seeding was done but favorable weather conditions did not develop.

All cloud seeding was done with the use of ground-based silver-iodide smoke generators. These were of the string-burning type, capable of producing 5×10^{11} ice-forming nuclei per second at an activation temperature of -10C, except that in the southern New Hampshire program a number of acetone-propane generators were used supplementally.

3. Evaluation

Each program was evaluated by comparing the precipitation (in the case of Hackensack, run-off) in the target area with that in a control area selected with regard to high correlation with the target area and freedom from seeding influence. Since these two considerations are not independent, there was a certain amount of trade-off between them.

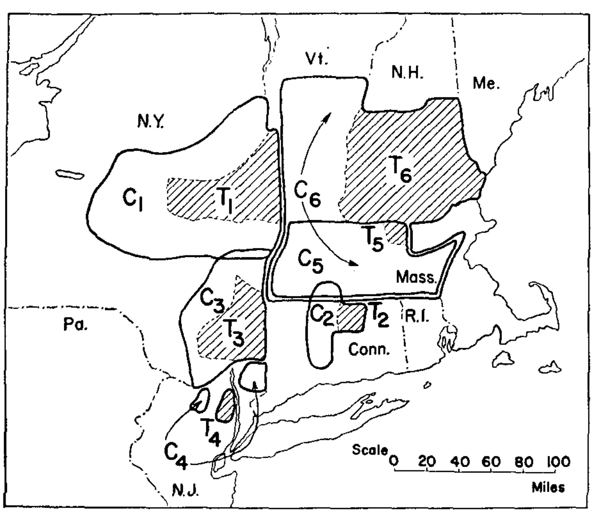

FIG. 1. Locations of target and control areas for 1964 programs of cloud seeding.

In the central Hudson area, the target occupies the low rolling country along the Hudson and Mohawk valleys. The control area was chosen to conform as much as possible to the same character of terrain, omitting the higher parts of the Adirondacks to the north and the Catskills to the south, and extending westward for some distance along the Mohawk valley. Table 2 shows the gaging stations used in each case to characterize the target and the control.

In the case of the Connecticut program, choice of the control stations was made by the meteorologist member of the Connecticut Weather Control Board, Dr. Thomas Malone, and coincided closely but not exactly with the control area previously used by the Howell Associates in evaluating a brief cloud seeding program carried out for approximately the same target area in 1962.

With respect to the Columbia-Ulster program, the control area was selected to conform as nearly as possible to the control area that has been used for evaluation of a cloud-seeding program conducted in the summer of 1962 for Dutchess and Columbia Counties; some accommodation was necessary because part of the control in 1962 was included in the 1964 target and vice versa. In general, the southern limit of the control was taken at the line of ridges that meets the Hudson River at Storm King Mountain, its westere boundary was set to exclude the higher portions of the Catskill Mountains, and the northern boundary ismorn or less arbitrarily established on the basis of distance from the target.

TABLE 2. Target and control precipitation gages.

Target	Control	
	Mohawk-Mid-Hudson	
Canajoharie	Albany WB Airport	Little Falls City Res.
Gloversville	Alcove Dam	Middleburg
Mechanicville	Canastota	Morrisville
Salem	Cooperstown	Mount Lebanon
Schenectady	Delta	New Berlin
Smiths Basin	Forestport	New London Lock 22
Spier Falls	Frankfort Lock	Salisbury
Tribes Hill	Hinkley	Sherburne
Whitehall	Hoffmeister	Utica FAA AP
	Hope	
	Hartford	
Hartford WB AP	Holyoke	Whigville Res.
Bloomfield	Westfield	Wolcott Res.
Hartford	Barkhamsted	Prospect
Hartford, Brainard	Bakersville	Mt. Carmel
Rockville	Collinsville 1S	
Manchester		
	Dutchess-Ulster	
Alcove Dam	Mohonk Lake	
Mount Lebanon	High Falls	
Tannersville	Rifton 1N	
Phoenicia	Millbrook	
Shokan Brown Station	Poughkeepsie	
Grahamsville	Poughkeepsie WB AP	
Ellenville	Glenham	
Warwick		
	Hackensack River	
New Mllford	Croton	
	Wanaque	
	Fitchburg	
Ashburnham	Adams	Northbridge 2
Fitchburg 2S	Amherst	Pelham
Gardner	Ashland	Peru
	Belchertown	Petersham 3N
	Chesterfield	Plainfield
	Chestnut Hill	Pittsfield WB AP
	Framingham	Quabbin Intake
	Hardwick	Shelburne Falls
	Heath	Southbridge 3SW
	Weston	S. Egremont
	Holyoke	Spot Pond
	Hoosac Tunnel	Stockbridge
	Milford	Turner's Falls
	New Salem	Ware
New Hampshire	*Southern New Hampshire Vermont*	*Massachusetts*
Bradford	Bellows Falls	Adams
Concord WB AP	Cavendish	Amherst
Dublin	Chelsea	Ashland
Fitzwilliam	Dorset 1 S	Belchertown
Franklin 1 NW	Mays Mill	Chesterfield
Gilmanton	Peru	Chestnut Hill
Hanover	Reading Hill	Hardwick
Keene	Readsboro 1 SSE	Heath
Lakeport	Rochester	Holyoke
Lebanon FAA AP	Rutland	Hoosac Tunnel
Massobesic Lake	Searsburg Mt.	New Salem
Manchester	Searsburg Sta.	Northbridge
Milford	Somerset	Pelham
Nashua 3 N	Vernon	Peru
Newport	Wardsboro	Petersham 3 N
S. Lyndeboro	Whitingham 2 W	Plainfield
S. Weare		Pittsfield WB AP
		Quabbin Intake
		Shelburne Falls
		Southbridge 3 SW
		Spot Pond
		Stockbridge
		Turners Falls
		Ware
		Weston

The Fitchburg target occupies a portion of the eastern part of the eastern Massachusetts highland, extending a short distance into the lowland of the Nashua River valley. The selection of a control in this instance was influenced by the southern New Hampshire program, which began operation soon after seeding for Fitchburg began. The control area selected for the southern New Hampshire operation was chosen to be practically identical with that chosen to evaluate a cloud seeding program in almost the same target in 1957. It takes in roughly the part of Vermont to the west of the target and all of Massachusetts except for the southeastern portion and the shore of Massachusetts Bay, excepting, of course, the Fitchburg target and a downwind area immediately to the east of it. The Massachusetts portion of the southern New Hampshire control area is used as a control area for the Fitchburg project.

The Hackensack target area is so small and encompasses so few raingages that it appeared the run-off, accurately measured through consumption by the Hackensack Water Company, would afford a better measure of the precipitation on the watershed than could be obtained by the use of precipitation observations directly. The control used, the run-offs from the Wanaque reservoir of the North Jersey District Water Supply Commission, and from the Croton system of the New York City Department of Water Supply, are the same as those used for evaluation of cloud seeding operations on the Hackensack target in 1954 and 1955.

In each of the five evaluations where precipitation measurements are used, the data were obtained from the official publications of the Weather Bureau. The length of the historical record used was generally chosen to maximize the quantity of information available for both targets and control characterizations, and all Weather Bureau regular and cooperative stations within the selected target and control areas were used that had substantially complete records for the period chosen. The time unit chosen is one month, and the historical record is constructed of area averages for those months during which cloud seeding took place, going back for the length of the homogeneous record selected. The average area precipitation data are rectified by a cube root transformation to remove the skewness of the distribution and a covariance analysis of the usual type was then performed on the normalized data. The data for partial months of seeding are first expanded to whole-month amounts, (multiplied by the ratio of the whole month to the fraction), then displaced toward the mean by a factor equal to the square root of the seeded fraction of the month; this corresponds to making the assumption that the variance is attributable entirely to the seeded fraction of the month, and that the unseeded fraction equalled the mean. In the case of the Hackensack evaluation, the historical data were transformed to normality by arranging them in rank order and assuming that the run-off amount corresponding to each rank standing had an equal probability of recurring. The resulting regressions are shown in the graphs, Figs. 2a through 2f, and the statistics are shown in Table 3. In the Connecticut and southern New Hampshire evaluations, data for previous seeded years are likewise shown.

The elements of chance have undoubtedly played a large part in producing the wide spread between the lowest increase, in the area around Albany, and the largest increase, the Hackensack watershed. In the former instance, during the brief period of operations

TABLE 3. Evaluation data.

Program	Rainfall observed / estimated	Indicated increase inches / per cent	Odds for indicated increase occurring by chance	Regression equation ($Y^{1/3}=A+BX^{1/3}$) A	B	Correlation coefficient	Probable error of estimate
Mohawk-Mid-Hudson	1.56 / 1.54	0.02 / 1	1/2	0.172	0.854	0.754	0.134
Hartford	2.64 / 2.03	0.61 / 30	1/3	0.010	0.947	0.817	0.171
Dutchess-Ulster	1.91 / 1.31	0.60 / 45	1/7	−0.057	1.008	0.881	0.127
Hackensack River*	3.24 / 2.03	1.21 / 60	1/77	−0.003	0.865	0.870	0.478
Fitchburg-Leominster	4.54	0.44 / 11	1/3	0.057	0.961	0.874	0.125
Southern New Hamp.	4.10	0.66 / 19	1/4	0.069	0.932	0.872	0.108
Totals	17.99 / 14.45	3.54 / 25	1/55				

* See text for transformation.

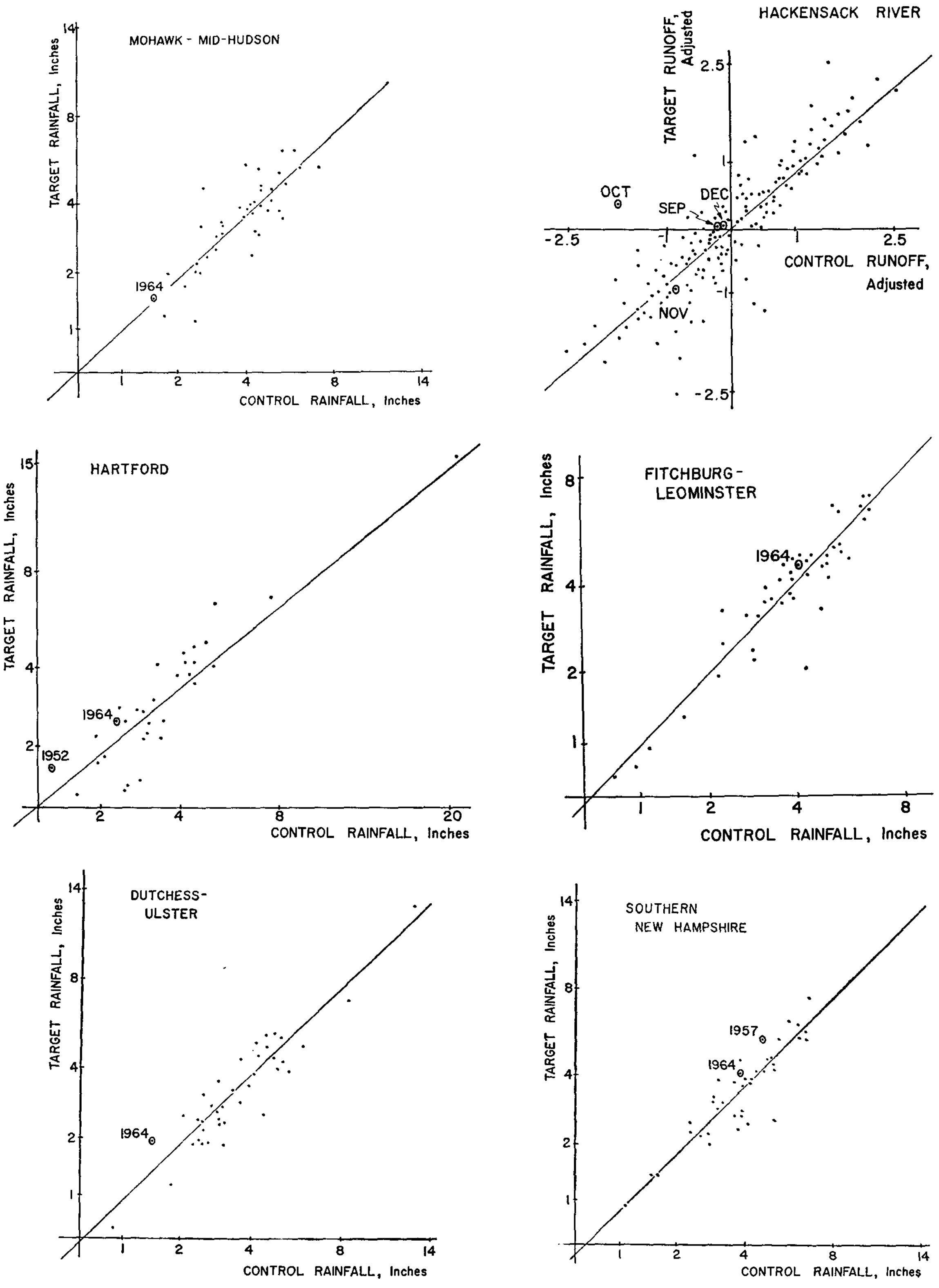

Fig. 2. Regression diagrams showing seeded and unseeded months.

there were several occasions when cold fronts reached New York State and gave good rainfall in the area of Ithaca during the late afternoon and early evening, tapering off to relative inactivity as they passed over the target during the night. Luck was on the other side in the Hackensack area in October, when rain-bearing clouds several times favored the target with their presence while avoiding the control areas. The extremes, therefore, are probably relatively unrepresentative of the true effectiveness of the cloud seeding.

Cloud seeding was also carried out in another portion of the 1964 drought area, in the central Potomac valley and neighboring localities, but the purpose of this program was not rainfall stimulation but suppression of hail. Nevertheless, the question of the influence of the cloud seeding on the rainfall in this case is of some consequence, in as much as questions were raised regarding the possible effect of the seeding in intensifying the drought there. In a study of this question begun in 1963, a control area consisting of two zones, one to the northeast and the other to the southwest of the target, was selected after study of the rainfall records over a wide area. The region immediately northwest of the target was excluded from the control because it was found the rainfall patterns of the target area are closely associated with the ridge-and-valley physiography; both the control zones are situated in the same physiographic province, but the correlation of rainfalls drops off rapidly as one goes northwestward into the Appalachian plateau province. The target and control areas are shown on the map, Fig. 3, along with the raingage locations used in the comparison. The

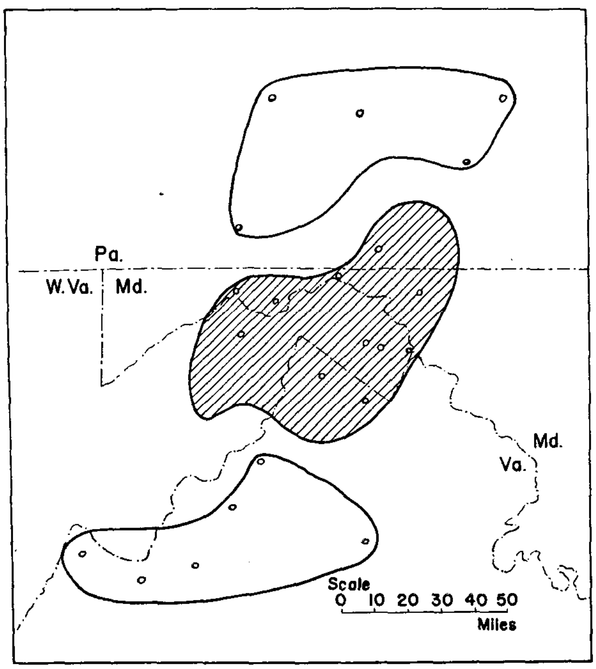

FIG. 3. Location of mid-Potomac hail-suppression target, control areas, and raingage sites.

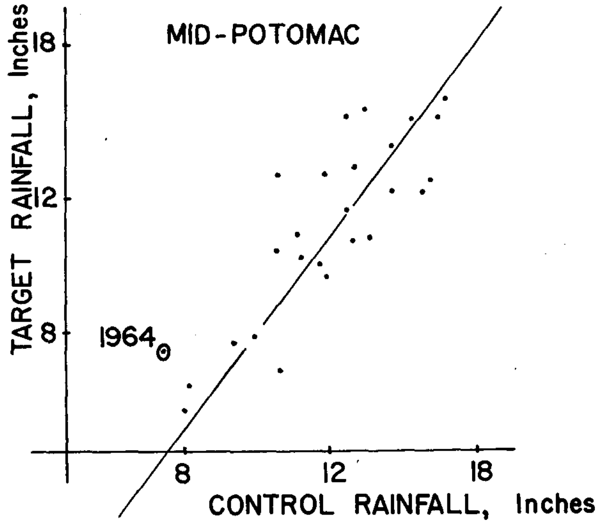

FIG. 4. Regression of target on control rainfall for hail-suppression program.

total rainfall for the summer trimester June-July-August was used in this study, comparing the rainfall of unseeded years from 1932 through 1956 with that of the seeded years 1957 through 1963. The regression diagram, Fig. 4, shows the results of this comparison; for the period as a whole a rainfall increase of 3 per cent is indicated, but for 1964 the indicated increase was 14 per cent. Ironically, suspension of the program in 1965 after eight years of operation has been forced by legislation outlawing cloud seeding in the State of Maryland put forward on the grounds that seeding had been at least partly responsible for the droughts of the past three summers.

4. Discussion

As mentioned previously, the conditions under which these programs were carried out established the maximum stimulation of rainfall on every possible occasion as the primary mission, and the randomizing of cloud-seeding occasions that is desirable from the point of view of statistical testing of the hypothesis that cloud seeding has a positive effect, was therefore out of the question. The indications of the evaluations presented will have been falsified if there were to have been a change in the target-control relationship between the historical period and the seeded period, or if the selected control area were, through accident or design, to reflect a negative bias during the historical period or a positive bias during the seeded period. The Connecticut control area, as previously mentioned, was selected by an uninvolved meteorologist; the Dutchess-Ulster and Southern New Hampshire control areas follow as closely as practicable control areas selected by the cloud seeder for evaluation of previous programs with no foreknowledge of the 1964 program. It is not obvious what variations of these choices might have been arrived at by a different meteorologist, and the effect of different choices must remain a matter of conjecture until someone tries an independent re-evaluation.

For the present, it can be stated, at least tentatively, that the indications of precipitation increase have amply fulfilled the expectations established in advance of the operations. Beyond adding modestly to the sum of cloud seeding experiences available for scientific study, these programs are perhaps most noteworthy as signs of a hopeful trend for the future and as a demonstration of the willingness of people and organizations afflicted by drought to support programs that yield at least modest and uncertain indications of success, when these indications are reasonably well substantiated. Finally, these operations are one more indication that a brief program, undertaken under severe drought conditions, cannot be counted upon to achieve an "average" success nor a statistically significant measure of increase.

Acknowledgments. The names of Farm Bureau members, of Farm Bureau officials, members and officials of various agricultural organizations, public officials having concern for agriculture and water supplies, who have contributed to the undertaking of these programs are too numerous for individual mention. Special thanks are due to the Farm Bureaus of the several New York counties involved, to the Connecticut Potato Producers Association, the Shade Tobacco Growers Association, and to the Hackensack Water Company and the Palisades Interstate Park Commission. Cooperation of the North Jersey Water Commission and the New York City Department of Water Supply in furnishing data from their areas is appreciated.