PRELIMINARY EVALUATION OF THE 1976 RAIN MODIFICATION PROJECT IN CENTRAL ILLINOIS

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INTRODUCTION

The first major weather modification project to occur in Illinois was pursued in East Central Illinois during late July-August of 1976. It related to an effort to increase summer rainfall. A group of farmers and others concerned with agricultural production in a 5-county area centered on Coles County decided to raise funds and hire a cloud seeder in an effort to increase the precipitation.

This report focuses largely on the joint effort of the College of Agriculture of the University of Illinois and the Illinois State Water Survey (ISWS) to assist this rain modification effort through 1) organizing facilities for evaluation of the precipitation data, and 2) interpreting the measurements in a preliminary evaluation of the outcome, done by the ISWS. Weather modification experience and knowledge among the staff of the Atmospheric Sciences Section of the Illinois State Water Survey were coupled with the agricultural research interests of the Agricultural Experiment Station of the University of Illinois and the responsibilities for communication to agricultural interests as part of the Agricultural Extension Program of the University of Illinois. These three groups joined hands in a hurriedly-assembled effort to collect precipitation data in and around the seeded area, and the Survey also agreed to do the evaluation of the precipitation statistics after the project ended.

Evaluation of non-randomized rain modification projects of short duration is extremely difficult and results specifying a change in rainfall cannot be expected. Nevertheless, the leaders of the Water Survey and the College of Agriculture deemed it both necessary and valuable to make the best possible evaluation of the very limited available data. The results will be useful in advising those in Illinois contemplating future use of weather modification.

This report presents first information on the background of the seeding project and the organization of the evaluation effort. In the second section, results relating to the statistical evaluation of rainfall data and radar echo data (indicative of storm and rain activity aloft) are presented.

We urge caution in the interpretation of these findings because they are based on a very limited set of measurements, from a weather modification evaluation standpoint. Although only coarse indications of any rain change can be derived, the need to present the best possible statistics has led to the preparation of this report. It is hoped that this report will help others in Illinois who wish to attempt weather modification efforts to dimensionalize the project and the allied need for evaluation. Prior history of operational weather modification (non-experimental in nature) has shown that without serious evaluation, these projects seldom continue and ultimately have no real measure of their effectiveness and the benefit or losses incurred from the seeding.

BACKGROUND

In mid-July 1976 a group of implement dealers, bank representatives, and farmers in the Mattoon, Illinois area began discussions about sponsoring a rainfall modification project with the goal of producing more rain to aid in the production of their grain crops. Weather conditions in East Central Illinois, as in most of Illinois, had been unusually dry from April up to that time. Consequently, there was considerable concern about reductions in corn and soybean yields that continued dry conditions would bring. The local leaders who conceived this idea quickly spread the word of this potential project and eventually more than 350 contributors including local citizens, agri-businesses, and banks in the area donated funds to support the seeding project. Unofficially, the total funding reached about $75,000, with much of that raised in a few days during mid-July. As the funds were raised, the leaders of the group formed a corporation entitled "Rain Incorporated".

They subsequently sought advice from the Atmospheric Sciences group of ISWS as to the legal responsibilities of the project under the Illinois Weather Modification Control Act. Rain Incorporated also sought general advice as to their likelihood of success or failure and as to names of reputable organizations in the nation who perform cloud seeding. Several names were supplied to them.

One of these firms, the Colorado International Corporation (CIC) of Boulder, Colorado, was contacted, and subsequently a contract for about $60,000 was signed between CIC and Rain Incorporated. However, before the rain modification project could begin, two legal obligations relating to the project had to be satisfied. First, a CIC meteorologist had to apply, according to Illinois law, for a weather modification license which defined his weather modification experience, education, and capabilities. This license was needed for him (or anyone) to direct a viable, state-of-the-art, weather modification project in Illinois. Secondly, according to Illinois law, the weather modification company (CIC) had to submit a permit-request and be granted said permit by the State. This permit was for conducting the actual seeding project and defined the period of the seeding, safety precautions to be used, the area in which clouds would be seeded, the instrumentation to be used (in this case, a turbocharged aircraft and a weather radar), other facilities to be used, and the staff. As part of this permit, a sizeable insurance policy had to be in effect along with a payment of $600 to the State of Illinois for the permit.

Applications for license and permit were presented to the Illinois Weather Modification Board on July 19. The Board subsequently recommended to the Director of the Department of Registration and Education, that the license and permit both be granted. These were signed by the Director on July 20, and the stage was set for the initiation of Illinois' first major weather modification project of the 20th Century.

The contract for seeding activities specified initiation of cloud seeding on July 23, 1976. CIC brought their radar, aircraft, and other meteorological equipment needed in their forecasting effort to Mattoon; installed the equipment in a hanger at the Coles County Airport; and was ready for operations on July 23. The project contract signed between CIC and

Rain Incorporated was for essentially a 5½ week period of modification effort extending from July 23 through August 31, 1976.

The area where rainfall was to be increased covered parts of 5 counties including Coles, Moultrie, Shelby, Cumberland, and Douglas (Fig. 1). Subscribers to the project costs resided throughout these counties, and the seeded area defined by the contributors essentially formed a circle with a 50-mile diameter centered on a point just northwest of Mattoon at a point named Coles.

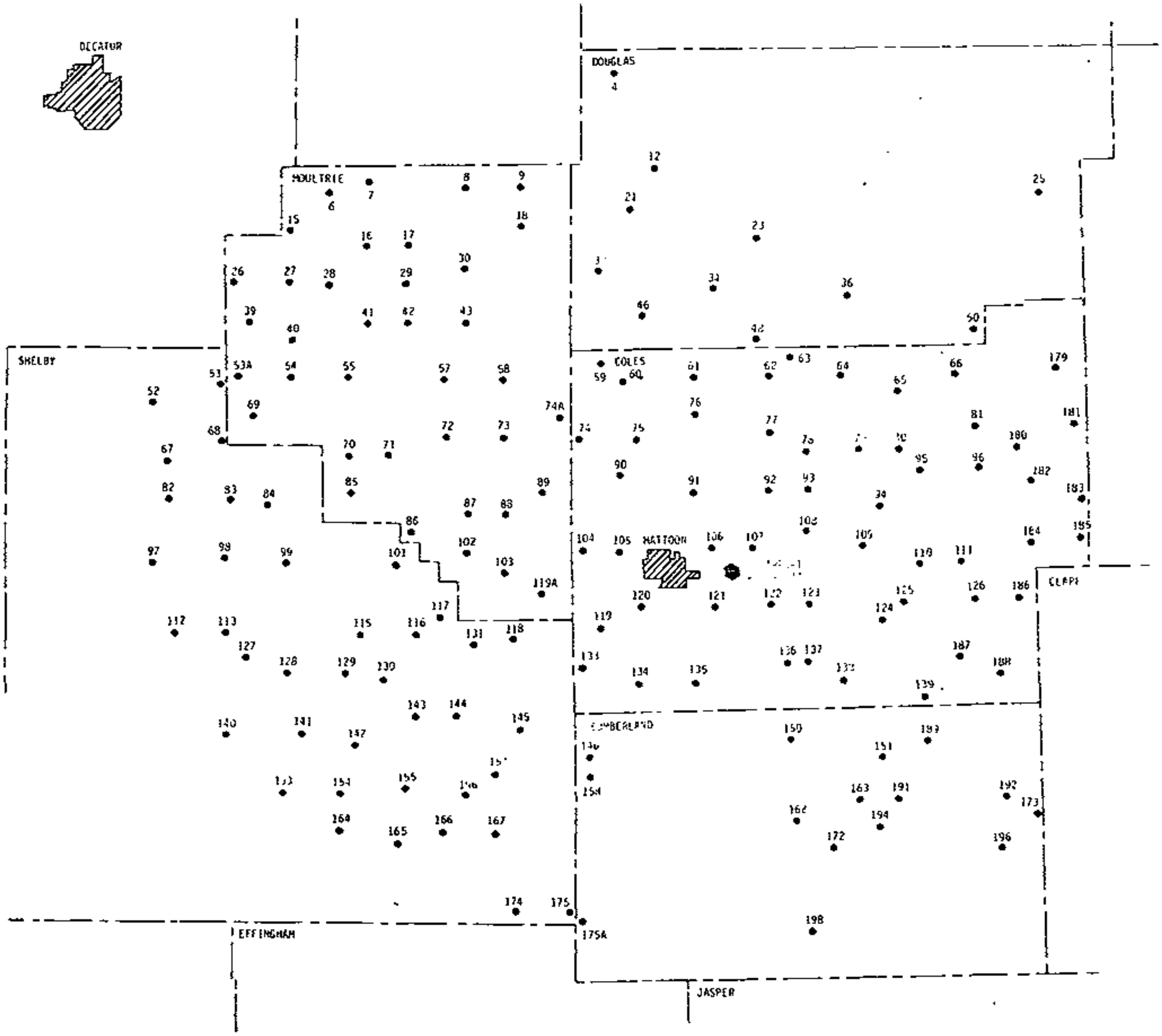

Figure 1. Raingage network established for rainfall measurements during August 4-31, 1976

The objective of the CIC program sponsored by Rain Incorporated was to increase rainfall using a seeding technique designed primarily to enlarge the area of rainfall rather than to intensify the existing rainfall. Among meteorologists the seeding technique is labeled as "dynamic seeding". Briefly, it consists of flying the airplane carrying seeding materials through cloud turrets growing on the flanks or edges of existing showers or storms. These turrets often become new cells of rain when the pyrotechnic seeding devices (small cylindrical capsules filled with 50 grams of silver iodide) are dropped into the cloud at heights above the freezing level. Theoretically, the silver iodide material, as it is discharged inside the cloud, provides the nuclei (small particles) or "seeds" for the formation of more and bigger raindrops. This then produces further cloud growth by increasing buoyancy due to the release of heat of condensation as the cloud drops form.

During the July 23-August 31 period, seeding was conducted on 9 days and there were 13 seeding flights (2 separate flight missions occurred on 4 days when rain occurred at different times of the day). Approximately 40 hours of flying were accumulated on the aircraft for the seeding.

There were certain operational problems during the seeding operations including an unfortunate 45-minute delay in takeoff as one rain situation approached the "target area" (the 2000-square-mile, 5-county circular area where it was desired to increase rain) and termination of one seeding mission when the aircraft was hit by lightning and forced to return to the airport. In general, the operational problems appeared to be few. There was good assistance from the Federal Aviation Agency (FAA) in allowing the seeding aircraft to fly to any storms and moving about as it wished under the directions from its own radar operater using radio communications between the meteorologist operating the radar and the project pilot.

ORGANIZATION OF THE EVALUATION EFFORT

Before and after the project developed, Stanley Changnon, Head of the Atmospheric Sciences Section of the Illinois State Water Survey, was engaged in several advisory discussions with the Board members of Rain Incorporated and with the leaders of CIC. The Rain Incorporated and CIC groups had arranged a meeting on July 29 at the Coles County Airport for a discussion of project progress. They invited Changnon and others who could in anyway observe or assist the project. The ISWS then contacted Dr. Glenn Salisbury, Director of the Illinois Agricultural Experiment Station, and Dr. Ben Jones, the Assistant Director. Discussions between these two groups and with Dr. Moyle Williams. Acting Director of the Agricultural Extension Service led to an agreement to have representatives attend this project meeting on July 29 and to assist the project in any meaningful way. An evaluation of the outcome, if possible, was deemed useful to everyone in Illinois.

At this meeting there was a presentation by the Chief Meteorologist of CIC, Mr. Ralph Papania, about their seeding operations on July 27 and 28. There had also been extensive public relations activities due to the uniqueness of this project in Illinois, not only a first for Illinois, but for much of the Midwest.

Those attending the meeting from the Water Survey and the University of Illinois included Stan Changnon of the Water Survey, Glenn Salisbury and Ben Jones of the Experiment Station, and Ed Barnes (Regional Extension Director) and the County Extension Advisors for the 5 counties in the seeded area. These included Dale Bateman (Tuscola), Lewis Christian (Charleston), Larry Paszkicwicz (Toledo), Ed Ballard (Shelbyville), and Bob Harris (Sullivan).

In a presentation, Mr. Changnon pointed out that the Survey's position about rainfall modification in Illinois was that "the outcome of efforts to increase rainfall in Illinois through weather modification were scientifically uncertain; hence there is a considerable need for experimentation and for careful evaluation of operational projects (seeding of all possible rain days) such as being conducted in the 5-county area." Changnon's recommendation for evaluation of the outcome of such a short duration project (5½ weeks), which was then already 6 days into its contract period, was discussed. Various questions were raised about how to do this and how the University of Illinois and the Water Survey might perform an evaluation effort. It was agreed that the Water Survey would take a leadership role in performing a limited evaluation of whatever field data that could be collected, and that the Extension Service would assist in various phases of the field measurement effort.

The evaluation effort planned at this meeting, and subsequently implemented, involved the following elements: 1) the distribution of some 200 non-recording fencepost type raingages on a even grid pattern throughout the 2000 square mile area (hence a gage for every 10 square miles); 2) a gage installation effort and an instructional effort for observers to get the network quickly operational; 3) a reporting system of rain values to an unbiased evaluation source (ISWS); and 4) an evaluation by the ISWS after all desired data including radar data from CIC were collected. This plan was accepted and implemented in almost unbelievably short time.

The ISWS developed a network design for these 200 raingages on July 30. On that same day, Rain Incorporated purchased the 200 raingages and supplied these to the five county extension advisors. Rain Incorporated also purchased 1000 postcards needed for reporting the rainfall amounts by the farmers and others in the area who measured the raintall These cards were delivered to the Water Survey on July 30 and were then addressed and printed that afternoon. The Survey also developed instruction sheets for installing the gages, for measuring the rainfall, and for the reporting system. The ISWS delivered the network base maps (showing desired gage sites), the reporting instructions, and reporting cards to the extension agents in the 5 counties on August 2. Then, the extension agents contacted farmers located as near as possible to the sites prescribed by the Water Survey's network design, and assembled these cooperating farmers to give them instructions, a raingage, and reporting cards. Some 140 farmers cooperated and about 140 gages were installed and data collection began August 4. The network operated in August is shown in Figure 1 along with the operational area.

In addition to the rainfall data to be supplied from tne raingage network through the cooperative efforts of the Water Survey and the College of Agriculture, plus the cards and raingages supplied by Rain Incorporated, another desired input for evaluation was the radar data collected by the commercial firm (CIC) during its field operations. Polaroid photographs of the radar scope were taken semi-routinely during all operational periods, about once every 15 to 20 minutes. Their radar (an AVQ-10) had no automatic means for routinely indicating the rainfall intensity or for photographing the radar scope. Thus, the only meaningful radar data available were the outlines of the minimum detectable echoes (storm areas) shown on the Polaroid photographs

In summary, the effort was substantial and included the decision to form an alliance for an evaluation effort, followed by the considerable efforts for obtaining raingages, reporting (and printing) postcards, planning the network, gathering the observers and instructing them, and assembling the data was substantial. That it was all done in a 5-day period was truly an outstanding achievement. Everyone involved in the decision and the activities is to be complimented.

RESULTS

Three major considerations must be stressed and understood about the evaluation of the available rain and radar data. First, findings herein must be considered preliminary and not final. In the interest of making some initial results available, certain data have been quickly examined without in-depth evaluation of related atmospheric conditions.

The second important consideration of this evaluation is that the rain data available are extremely restrictive for performing the exhaustive evaluation needed for weather modification.

A third important factor to be considered is the fact that a short sampling period, 5½ weeks in one summer, does not provide a sufficient rainfall data sample to develop any reliable statistical proof. Thus, the results herein must be viewed as rough indicators of an outcome without any proven statistical significance. That is, the data sample is too small to prove or disprove reliably any indicated rainfall change. Several more years of data of this type would be required, along with much more sophisticated atmospheric data collected simultaneously, to arrive at a definitive statement as to the degree of success or failure of the weather modification effort.

Given these limiting considerations, one may wonder why any evaluation was even attempted. However, as limited as the results may be, some general indication of the outcome was judged to be better than none and useful for planning future activities. *This report and its material are offered in that light.*

Data Limitations. The raingage network, as noted in the earlier part of the report, was not installed and operational until August 4. Thus, 24-hour (daily) rain totals were available only for the period of August 4-31, a very short period when one considers the normal space and time variations of summer rainfall in Illinois. It excluded the seeded rains in late July. The second unfortunate factor was that the available radar data collected by CIC was non-quantified; that is, there was no routinely collected data to describe rainfall production of the more intense (heavier rain) portions of the echoes. Given these less than optimum data, from a time and quality standpoint, the project period evaluated was August 4-31. it should be noted that three rain days were seeded during late July but due to the lack of raingage data then, these days were not included in this evaluation

Analytical Procedures. The cooperative rainfall observers in the seeded area reported rainfall as 24-hour (daily) totals usually measured either in the early morning or late afternoon. Tabulation of these data for the August 4-31 period showed that there were 6 identifiable periods of rain during which seeding had occurred. These dates were August 5,6, 11, 13-14 (night), 14, and 25. The rainfall amounts for each storm were plotted on base maps of the network and the patterns of rainfall were drawn. Such a pattern for August 5 is shown on Figure 2.

The next step in the analytical technique was to plot on these maps the locations where the seeding material had been dropped by the CIC aircraft in a cloud. Those for August 5 are shown on Figure 2. Typically, there were 3 to 6 different seeding locations on a given day. The plot of these seeding locations were combined with plots showing the outlines of the radar echoes during and after the seeding period. These echo outlines at different times were connected to show the sequence and evolution of showers and storms through the seeded area. From these" maps, then, we constructed "echo envelopes;" these were outlines of all the storm cells that had been potentially effected by the seeding from the point of beginning of seeding to the end of the echo's lifetime or until it disappeared from view on the radar scope. The envelope for August 5 is shown on Figure 2. Envelopes typically appear as oval shapes anywhere from 10 to 30 miles long and anywhere from 3 to 10 miles wide. These are much like the rain pattern of a thunderstorm on the ground. The echo envelopes associated with each of the seeding events were labeled as "seeded" echoes or areas, and all other envelopes or areas of rain on a given day were labeled as "non-seeded," or "control" cchoes, This was labeled as the "Large Seeded Echo" analysis.

The seeded and non-seeded (control) echo envelopes were also plotted on the rainfall base map for a given day (see Figure 2) to define the rainfall from the seeded and that from the non-seeded echoes. The rainfall values in these seeded and non-seeded (control) areas were then totaled, and averages, medians, and extremes calculated. Thus, for each day of the six days of rainfall and seeding in August, statistics on rainfall were available for the seeded 'target) portions of the 2000-square-mile region and for the non-seeded (control) portions of the region.

One variation in defining the seeded area using this envelope-rainfall analysis was chosen because of a potential delay time in the effect of seeding. Some results from other

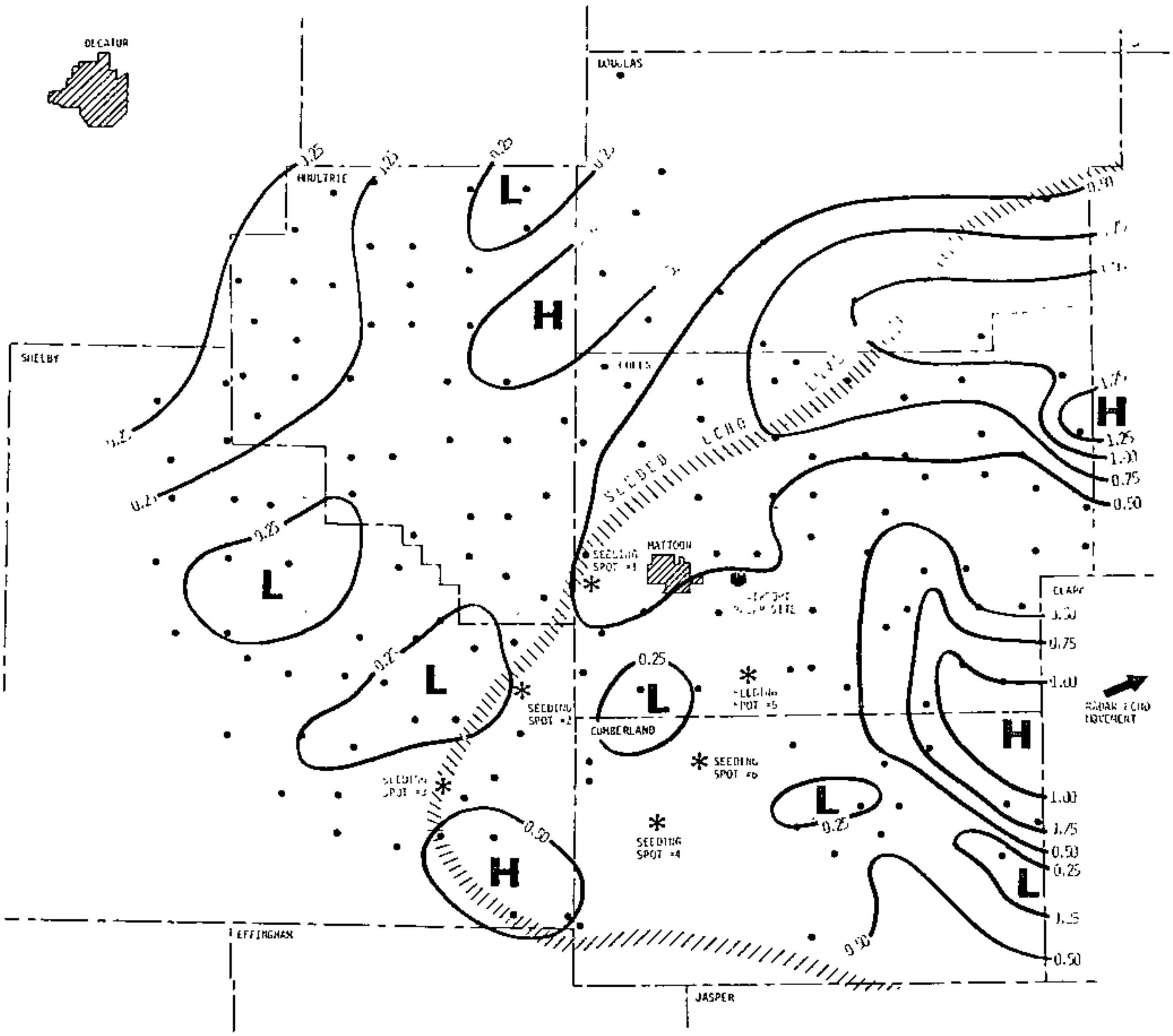

Figure 2. Rainfall pattern (black lines in inches, 1.0 = 1 inch) for August 5, 1976. Also shown as stars are the 6 locations where seeding occurred on this day. The hatched line forms the "envelope," based on radar echoes that were seeded and their total area, where the rainfall was considered as potentially seeded.

modification efforts have shown that from the time seeding materials are released into a storm, it takes about 15 minutes for any rain alterations to occur at the surface, if they occur at all. Hence, the echo envelopes for the "seeded echoes" (areas), as based on the area from the point of seeding until the end of the storm, were altered in this analysis by allowing 15 minutes from the time of seeding until the "seeded cell" responded to the alteration. In most cases this, as based on the echo speed (often 20 miles per hour), showed that the "seeded echo area" began about 5 miles beyond (usually east) of the point where seeding occurred. Hence, the seeded area was slightly smaller in this variation of defining the seeded area which was labeled the "Limited Seeded Area."

The comparison of rainfall values under these two categories (Large and Limited) of seeded and no-seeded rainfall values was examined on the basis of two different calculations In one case, the values at all raingages in the seeded area and non-seeded area, including all zeros (gages with no rain), were used in the calculation of the average, the median, and extremes. In the other case, the averages, medians, and extremes were calculated using values from only those gages which had measurable amounts (those greater than .001 inch). Statistics on the dimensions of the echo envelopes were compared for those 3 days when the data were adequate for such comparisons. This formed the third phase of the evaluation.

Seasonal Average Rainfall Before presenting the results of the evaluation, it is interesting to examine the basic climatological conditions during the seeded period. First, rainfall in the area was 30 to 40% below normal during the April to mid-July period. There had been an unusually dry spring (April-May). June rainfall had varied considerably spatially, but was largely below normal.

In the project area, the normal rainfall for the 5½-week seeded period is 4.3 inches. Available data from the few National Weather Service stations in the area, which have been operated for many years, indicate the following totals for the July 23-August 31 period. Amounts were all below normal, ranging from about 1.0 inch up to 2.3 inches below normal: Mattoon — 1.95; Charleston — 2.85; Tuscola — 3.42; Windsor — 3.39; Greenup — 2.60; Moweaqua — 1.98; Effingham — 3.36.

Comparison of Rainfall in Seeded and Non-Seeded Areas Based on Large Echo Envelop Table 1 presents, for each of the 6 days, various rainfall values. This table shows the data for the "seeded" and the "control" (non-seeded) areas including the number of raingages located in each area. Due to differences in the placement and number of echoes (cells) seeded on any given day, the seeded and non-seeded areas (and number of gages) varied between days. The number of gages also varies depending on the number of reports received. The comparison of the daily averages show that the seeded-area average rainfall was greater than the control area averages on 4 of the 6 days (August 5, 13-14, 14, and 25), but was less than the control area values on August 6 and 11.

Table 1. Comparison of Seeded Area Rainfall and Control Area Rainfall
Based on Large Seeded Echo Envelope Delineation.

	Seededarea *				*Controlarea* *			
	Number	*Rainfall*			*Number*	*Rainfall*		
Date	***of gages***	*Average*	*Median*	*Maximum*	*of gages*	*Average*	*Median*	*Maximum*
5 August	36	0 53	0 50	1.40	37	0 30	0.20	1.00
6 August	39	0 25	0.16	1.38	33	0 37	0 10	3 10
1 1 August	27	0 02	T	0 10	110	0 06	0 02	0 45
1 3-14 August	90	0 12	0 08	0.80	44	0 09	0.02	0 58
14 August	36	0.38	0 31	1.31	100	0 25	0 24	0 73
27 August	71	0.23	0.10	1 20	37	0 03	0	0 30
	Means	0.255	0.19	1.03	Means	0.183	0.09	1 03

*Based on all raingages in aica including those with no rain.

Summarization of the 6 values shows that the mean rainfall per day in the seeded areas (as defined by the large echo envelopes) was 0.255 inches as compared to 0.183 inches in the control area. Remember, these are values based on all the gages in both areas including gages with no rain. The ratio of the seeded mean value to the control mean is 1.39, indicating 39% more rainfall in the seeded area, as based on this definition of seeded and control areas and on use of all raingage values. The difference in the mean values is also supported by the means of the median values of each group, showing a doubling of the rainfall in the seeded aréa. The averages of the maximum values of the seeded and no-seeded areas (Table 1) arc exactly the same, a suggestion that the maximum point rainfall amounts were not altered through the seeding process, although no conclusive proof can be drawn. A test for the statistical significance of the difference in the means of the average rainfall, 39%, was performed. Comparison of the t-test values, a means of evaluating statistical significance, showed that the t value on the difference was not significant, either for the 1 -rail or 2-tail t-tests for the 5% or 10% levels. The sample size is too small to make these differences statistically significant.

A second analysis based on the same definition (Large Area) of the seeded and control areas (based on the total echo envelopes from the seeding points till dissipation) was performed using only the rainfall data from those gages (in each area) with measurable rainfall (all zeroes were omitted). This type of analysis allows for potential investigation and comparison of the areal extent of the no-rain areas, whether it be in the seeded or control regions. Table 2 presents these data showing the number of gages in each area (without or with rainfall), percent of the gages with rain, the area average rainfall, the area median, and the maximum point rainfall. Basically, the results are similar to those in Table 1 but with slightly less difference between the seeded and control values, particularly on August 1 3-14 and August 14. In general, the seeded area had more of its gages with measurable rain than the control area in all cases except August 5 when all gages in both areas had rainfall. These results do suggest a greater areal extent of rainfall in the seeded area.

Table 2. Comparison of Seeded Area Rainfall and Control Area Rainfall Based on Large Seeded Echo Envelope Delineation.

	*Seeded area **					*Control area**				
Date	*Number of gages*	***Percent gages with ram***	***Average***	***Median***	***Maximum***	***Number of gages***	***Percent gages with rain***	***Average***	***Median***	***Maximum***
5 August	36	100	0 53	0 50	1 40	37	100	0.30	0 26	1 00
6 August	39	92	0.27	0.19	1.38	33	73	0.51	0.17	3.10
11 August	27	74	0.04	0.04	0.10	111	71	0 09	0.06	0.45
13-14 August	90	72	0 16	0.12	0.80	44	61	0.15	0.06	0.58
14 August	36	100	0 38	0.31	1.31	100	98	0.25	0.24	0.73
25 August	71	80	0.29	0.20	1 20	37	46	0.06	0.03	0.30
	Means		0.255	0.40	0 94	Means		0.226	0.140	1.03

*Rainfall figures arc based only on gages with measurable rain.

The ratio of the means of seeded average and the control average rainfall was 1.12, a difference of 12%. The "t" values indicated that this difference between the mean of the heavier rain in the seeded area and the lesser mean in the control areas was insignificant. Of interest (Table 2) is the fact that the difference in the medians suggests a greater increase than in the averages.

Comparison of Seed and Control Rainfall Based on Limited Seeded Echo Envelopes. An analysis was desired which would allow for less immediate or direct seeding effects. The seeded area and the control area rainfall values were defined when the seeded area rainfall was outlined by echo envelopes which were classed as seeded approximately 5 miles beyond the seeding point in the storms, based on the direction of storm (echo) movement.

Results, as based on all the amounts (all gages) in the seed and control areas done in a manner similar to Table 1, are presented in Table 3. The results are quite similar to those in Tabie 1 showing more average rainfall in the seeded area on four days and less on two days. The mean values of the six days show a slightly greater difference than found in the larger envelope definition (Table 1). The seeded to control ratio is 1.496 indicating essentially a 50% greater rainfall in the seeded area. The t-test for differences does not show any significance at the 5% level, either for the 1-tail or 2-tail test.

Table 3. Comparison of Seeded Area Rainfall and Control Area Rainfall Based on Limited Effect Delineation of Seeded Echoes.*

	*Seededarea**				*Controlarea**			
Date	*Number of gages*	*Average*	*Median*	*Maximum*	*Number of gages*	*Average*	*Median*	*Maximum*
5 August	31	0.54	0.50	1.40	42	0.31	0.29	100
6 August	27	0.27	0.20	1.38	45	0.32	0.11	3.10
11 August	23	0.03	0.02	0.10	115	0.06	0.01	045
13-14 August	73	0.12	0 06	0.80	61	0.10	0.02	0.58
14 August	36	0.38	0.31	1.31	100	0.25	0.23	0 73
25 August	63	0.26	0.12	1.20	45	0.03	0	0.30
	Means	0.267	0.200	1.30	Means	0.178	0.110	1.03

*Based on all raingages in the area including those with no rain.

Table 4. Comparison of Seeded Area Rainfall and Control Area Rainfall Based on Limited Effect Delineation of Seeded Echoes.*

	*See ded area **					*Control area**				
Date	*Number of gages*	*Percent gages with ram*	*Average*	*Median*	*Maximum*	*Number of gages*	*Percent gages with rain*	*Average*	*Median*	*Maximum*
5 August	31	100	0.54	0.50	140	42	100	0.31	0.29	1.00
6 August	27	89	0.31	0.24	1.38	45	80	0.40	0.10	3.10
11 August	23	74	004	0.04	0 10	115	64	0.09	0.06	0.45
] 3-14 August	73	73	0.17	0.12	080	61	64	0.15	0.10	0 58
14 August	36	100	0.38	0 31	1.31	100	98	0.25	0.23	0.73
25 August	63	86	0 30	0 22	1 20	45	44	0.06	0.04	0 30
	Means		0 268	0 220	1 30	Means		0 210	0.140	1.03

*Rainfall figures arc based only on gages with rain.

Table 4 presents the same statistics for the "Limited" echo envelope but based on comparison of the values from gages with measurable rain (≥ .01 inch). As with Table 2, the seed-control differences are less. Their differences are 20%, a value also not significant. The medians also continue the trend of showing a greater difference than the means, and as shown in Table 4, the areal extent of measurable rainfall in the seeded areas of the 6 days is always equal to or greater than that found in the control area, as based upon the percent of total gages in each area with rain.

Another valid comparison of values is between the seeded area means in Table 3 where *all* amounts are intituled (an average of 0.267 inches), and the control area average when all the zero values arc excluded (Table 4). This mean is 0.210 inch, suggesting a 27% increase in the seeded area.

Comparison of Characteristics of Radar Echoes. The echoes measured on the six seeded days in August (5,6, 11, 13-14, 14, and 25) were analyzed to derive their areal dimensions when first detected (T_0), at T_1 (usually 20 to 25 minutes later), at T_2 (some 60 minutes after first detection), and for the entire echo envelope. There were 36 potentially seeded echoes measured and the average area swept out by those echoes was 161 square miles (mi^2) and their median was 78 mi^2. The average value at T_0 was 40 mi^2; at T_1 was 52 mi^2, and at T_2 was 78 mi^2.

Unseeded (control) echoes and their envelopes could be defined well for only three days, August 5, 6, and 14. On these days there were 20 seeded echoes and 16 control echoes completely measured. The average and median values of their envelopes and their areal extents at T_0, T_1, and T_2 appear in Table 5.

Table 5. Comparison of Areas of Seeded Echoes and Control (no seed echoes) on August 5, 6, and 14.

Seeded Echoes (20 total)

	Total envelope coverage (mi^2)	*Instantaneous extern (mi^2)*		
		T_0	*T_1*	*T_2*
Average	146	40	53	86
Median	89	27	29	24

T_0 = First indication of echo

Mean Times = T_1 = T_0 4 23, T_2 = T_0 + 58

Control Ec hoes (16 total)

	Total envelope coverage (mi^2)	*Instantaneous extent (mi^2)*		
		T_0	*T_1*	*T_2*
Average	128	50	40	23
Median	88	31	17	13

T_0 = First indication of echo

Mean Times = T_1 = T_0 + 25, T_2 = T_0 + 62

Comparison of the seeded and control echo values (averages vs averages, medians vs medians) shows that the seeded values exceeded the control values in all cases except T_0 when the first indication of an echo appeared. The results, which are not statistically significant, suggest that the seeded echoes grew bigger after initiation than the control echoes.

The percentage differences (increases or decreases) between the seeded rain and echo values and control values are summarized in Table 6. *None of the values are statistically significant differences.* However, all but the T_0 echo value (before seeding began) indicate an increase varying anywhere from 12% to 50%. There is no doubt that the area in which storms were seeded received more rain than the areas that were not seeded. What cannot be said with any certainty is whether this increased rainfall was due 1) to the seeding, 2) to chance, or 3) to the fact that the seeder was attempting to seed more vigorous rain-producing clouds. The third possibility would lead to a condition in which the seeded area would naturally receive more rain than the non-seeded area.

Table 6. Differences in Seeded Area Mean Rainfall and Control Area Mean Rainfall, and Differences between Seeded Area Echoes and Control Area Echoes.

	All Gage Values	*Measurable Gage Values Only*
Larger-Area Seeded Echo Envelope	+39%	+12%
Limited-Area Seeded Echo Envelopes	+50%	+20%

Average Area of Echo Envelopes	+14%
Average Area of Echo at T_0	-20%
Average Area of Echo at T_1	+32%
Average Area of Echo at T_2	+37%

The apparent enlargement of echo and rain area in the seeded storms, as hypothesized by the seeding approach, coupled with the increases in all four rain categories, suggests that rainfall has been increased by the seeding. However, these results must be considered inconclusive due to the possible bias arising from the seeding of the more favorable storms, and the lack of good time resolution of the rainfall associated with the seeded and non-seeded echoes. It is recommended that some hourly raingages be installed for future evaluation of this or any other project.

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