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# *Evaluations of Illinois Weather, Modification Projects of 1976-1980: A Summary*

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# INTRODUCTION

This report summarizes the key results of statistical and meteorological assessments of five summer weather modification projects in Illinois. During the 1976-1980 period, there were eight 1-summer weather modification projects in Illinois, each attempting to increase summer rainfall through cloud seeding with silver iodide. All the projects were operated in the same format involving meteorological forecasting and direction of the cloud seeding, aircraft for cloud base and mid-cloud seeding, and a weather radar for operations and data collection. These projects all involved cumulus cloud seeding for selected periods within the mid-June through early September period. Meteorological conditions related to the rain production of cumuliform showers and thunderstorms are generally uniform during this period (Changnon and Huff, 1980). These eight projects, their locations and periods of operations are identified in table 1, and the areas appear in figure 1.

The Illinois State Water Survey has had an extensive research and services program dealing with planned weather modification for 20 years (Changnon, 1979). One of the primary goals of this effort is to ascertain whether summer cloud seeding can produce agriculturally beneficial increases in rainfall under varying summer conditions.

One of the potential ways to gather information for addressing this complex scientific issue of weather modification is examination of operational (non-experimental) projects. If quality operational records and project data are collected, these projects represent an opportunity for learning whether the techniques employed may have altered the rainfall. As will be noted in table 1, many of the projects did not extend for long periods of time, all being two months or less. The actual number of days during which clouds were seeded is also not extensive.

A major NSF-supported research project conducted by the Water Survey concerns the development of techniques to evaluate operational projects, and one phase of that work is considering whether it is physically and statistically proper to combine the results of several operational projects of identical nature in the same climate zone. In the Illinois situation, this could mean the eight projects of 1976-1980 need not be analyzed as eight, separate events (each with too little data for meaningful conclusions), but rather their data combined and considered to represent a single, 8-summer project, giving a sizable data sample. The eight projects were all conducted in central and southern Illinois, an area of uniform rainfall climate in Illinois during summer (Changnon and Huff, 1980), and they all basically utilized the same seeding approaches and facilities. However, this report does not deal with the potential for this possible future research.

Over the past six years there have been preliminary, statistically focused analyses of five of these projects (Changnon and Towery, 1977; Changnon, Hsu, and Towery, 1978; Changnon and Hsu, 1980; and Hsu and Changnon, 1981). The five projects (those asterisked in table 1) are in a variety of locales. The aim of this report is to bring together the major findings of these statistically focused and reasonably limited assessments in a single document.

Table 1. Operational Weather Modification Projects in Illinois Attempting to Increase Summer Rainfall, 1976-1980.

| Year | Dates of Modification Operations | Counties of Operation | Areal Extent $mi^2$ | Number of Days Seeded | Volunteer Raingage Network |
|---|---|---|---|---|---|
| 1976* | 7/23 - 8/31 | Coles, Douglas Shelby, Cumberland, Moultrie | 2500 | 9 | yes |
| 1977 | 7/18 - 8/16 | Coles, Douglas Shelby, Cumberland, Moultrie | 2000 | 17 | yes |
| 1977* | 7/13 - 8/5 | McLean, Tazewell | 1200 | 9 | yes |
| 1977 | 7/29 - 8/17 | Vermilion | 500 | 6 | no |
| 1978* | 7/11 - 8/1 | McLean | 1200 | 8 | yes |
| 1978 | 8/4 - 9/4 | Saline, Gallatin | 650 | 10 | yes |
| 1979* | 6/23 - 7/26 and 8/10 - 8/15 | Saline, Gallatin, Franklin, White, Williamson, Hamilton | 1400 | 9 | yes |
| 1980* | 6/20 - 7/2 and 7/13 - 8/19 | Saline, Gallatin, Franklin, White, Williamson, Hamilton | 1300 | 18 | no |

*Projects evaluated.

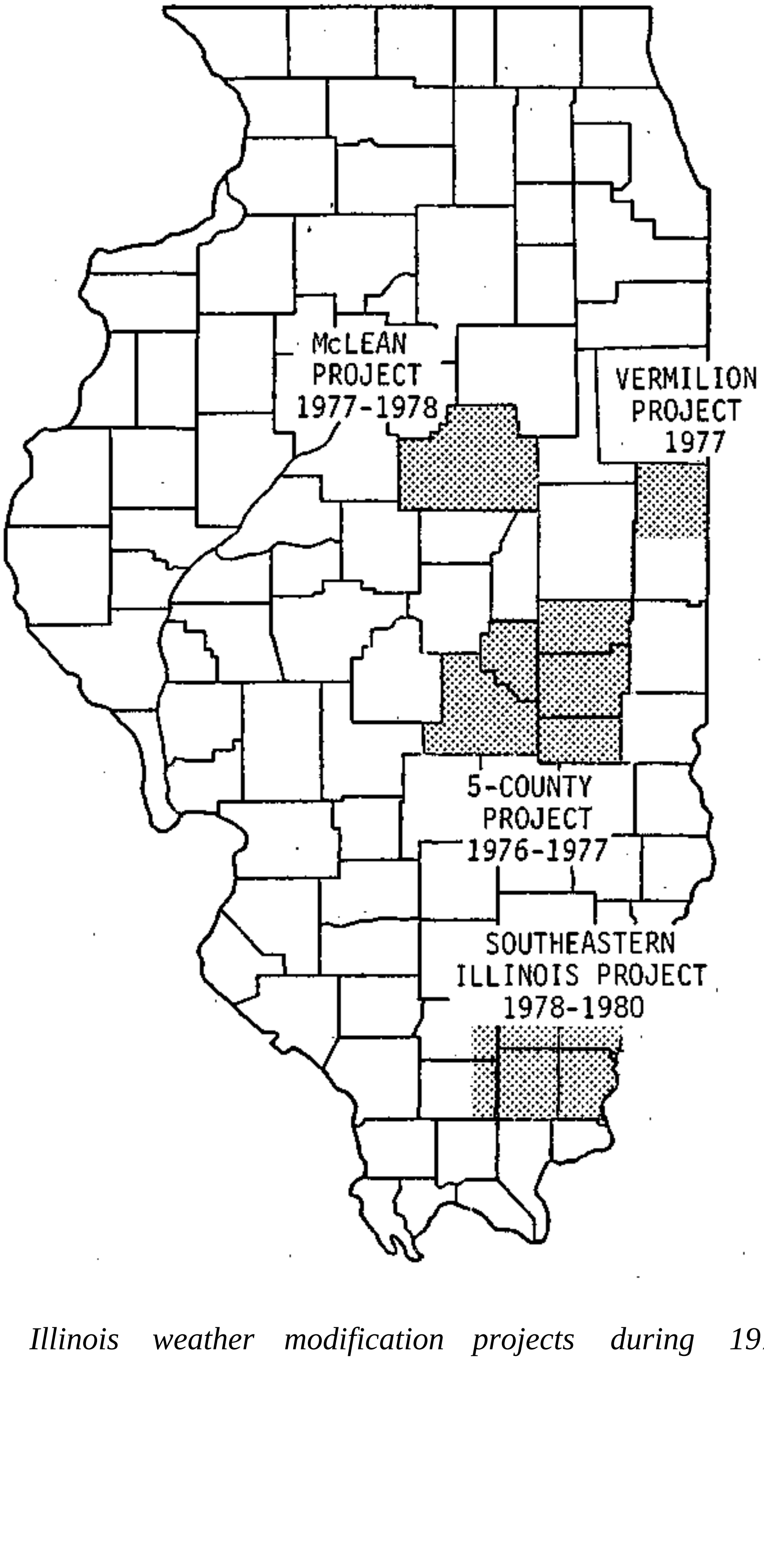


*Figure 1. Illinois weather modification projects during 1976-1980.*

## DATA AND ANALYSES EMPLOYED

The operational projects in Illinois, through the efforts of the cloud seeding firms operating under Illinois law, plus the efforts of the Illinois State Water Survey, the project sponsors, and the University of Illinois Agricultural Cooperative Extension Service, have provided three types of data useful in assessing the projects. In 4 of the 5 projects evaluated, specialized networks of non-recording raingages were installed with daily rainfall data collected by large numbers (80 to 100 per project) of volunteer observers during the project. Data were assembled by the county extension agents, and analyzed by the Water Survey.

Also, in all of the projects the cloud seeding firms were routinely tracing and/or photographing the radar scope, providing a source of echo data. As will be discussed later, the quality of the radar data was frequently poor, limiting the extent of the radar analysis performed to date. Furthermore, meaningful analysis of radar echo data requires considerable time and the skills of radar meteorologists, and expertise was not available at the Water Survey to perform in-depth echo analyses of all projects.

The third data available for all projects were the daily rainfall values available from the weather stations of the National Weather Service. These data were employed in all the analyses.

The reader should appreciate two factors relevant to evaluating these short, 1- or 2-month modification projects.

First, evaluations of short seeding projects, even with the best data, can not furnish conclusive proof of rain modification, and the degree of rainfall change indicated is very likely not to be statistically significant. The sample of seeded events is too small to make meaningful evaluations of sub-divisions of the data such as results for squall line storms, for cold front storms, etc. The natural variability of summer rainfall across short distances is a major problem, often blocking proof of cloud seeding effects. Further, the general lack of quality radar data for several projects limits the more physically oriented analyses so that the rainfall results are less conclusive than they could have been. For example, the radar scope photographs from the McLean County project in 1977 were so poor they could not be interpreted. The photographs in the 1978 McLean County project were of better quality but there were no suitable photographic data on 3 of the 10 seeding periods and on most of the other 7 periods, scope camera operations were so limited (turned on too late or off too soon) that the desired echo histories (birth to death of echoes, both those seeded and those not seeded) could not be followed for most echoes. This posed a considerable dilemma. However, a desire to still have some form of radar-echo evaluation led us to try a limited echo investigation of these 1978 data.

The second factor that the reader should realize (given the above problems) is that practically any evaluation of an operational seeding project such as these rests on some form of comparison of seeded cases with non-seeded cases. This is often called target (seed) versus control (non-seeded) comparisons. Basically the target (T) versus control (C) comparisons can be done in space and/or time. That is, the rain in the target area, say McLean County, during a seeded period could be compared with that either in prior years (a time, or historical, control), or that in adjacent unseeded areas (area control), or in both space and time.

Evaluation of seeding efforts can be improved if definitive operational seeding criteria are used and recorded. That is, "when weather and cloud conditions are of type Y, we will seed by approach X; and when conditions are type A, we will seed by approach B," etc. The day-to-day seeding criteria used in most Illinois projects were not sufficiently defined and often not recorded, and without this type of information, the evaluations could not be enhanced by such physical interpretations. At best, the statistical results can only be considered as indications of seeding-induced effects.

The basic approach used in the evaluations of these Illinois projects involved a target vs control area approach, plus a seeding period vs historical period evaluation in 2 of the 5 projects (1979 and 1980). Time and funding have limited further, more extensive investigatons.

The general approach to evaluation of the radar echoes involved measurements of echo area either a) before and after seeding, and/or b) of the seeded and non-seeded echoes, both those in and those around the target areas. The detailed rainfall data from the volunteer farmer networks were used in certain echo analyses to delineate the amount of rainfall from the seeded and non-seeded echoes.

The principal evaluation efforts involved the rainfall data of the National Weather Service. . In these instances, control areas equivalent in size to the target area were defined to the north, west, south, and east of the target area before the projects began. Raingage densities were generally uniform with one station per 200 square miles, on the average. Summer rain data at this density are generally adequate to define a meaningful monthly mean rainfall for county-sized areas.

Target area and control area mean rainfall values were compared with historical rainfall values for these same areas for the 1979 and 1980 projects in southern Illinois. In both of these projects, locally wet conditions developed during the summer operations leading to short term stoppages of seeding efforts during the 2-month projects. In these instances, the non-seed periods were deleted from the historical data periods to make them comparable.

## MAJOR FINDINGS FROM FIVE PROJECTS

### Five-County Project-1976

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 (figure 1) established a corporation (Rain Incorporated) which in turn raised funds and hired a cloud seeding firm.

This firm, the Colorado International Corporation (CIC) of Boulder, Colorado, was hired under a contract for about $60,000. However, before the rain modification project could begin, two legislative 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. Weather modification experience and education were needed for him (or anyone) to direct a viable, state-of-the-art, weather modification project in Illinois. Secondly, the weather modification company (CIC) had to submit a permit request and be granted the 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, and other conditions of record keeping.

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 was for a 5 1/2 week period of modification efforts extending from July 23 through August 31, 1976. The area where rainfall was to be increased covered five counties including Coles, Moultrie, Shelby, Cumberland, and Douglas.

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 hypothesis is often labeled as "dynamic modification."

The raingage network (figure 2) 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 radar data collected by CIC was non-quantified; that is, there was no routinely collected data to describe the rainfall production from 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.

Tabulation of the data for the August 4-31 period showed that there were 6 identifiable periods of rain during which seeding had occurred. The rainfall amounts for each period 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 locations where the seeding material had been released by the aircraft in a cloud were plotted, and those for August 5 are also shown on figure 2. Typically, there were 3 to 6 different seeding locations on a given day. The plots 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, we constructed "echo envelopes"; these were outlines of all the storm cells that had been potentially affected 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 echo envelopes associated with each of the seeding events were

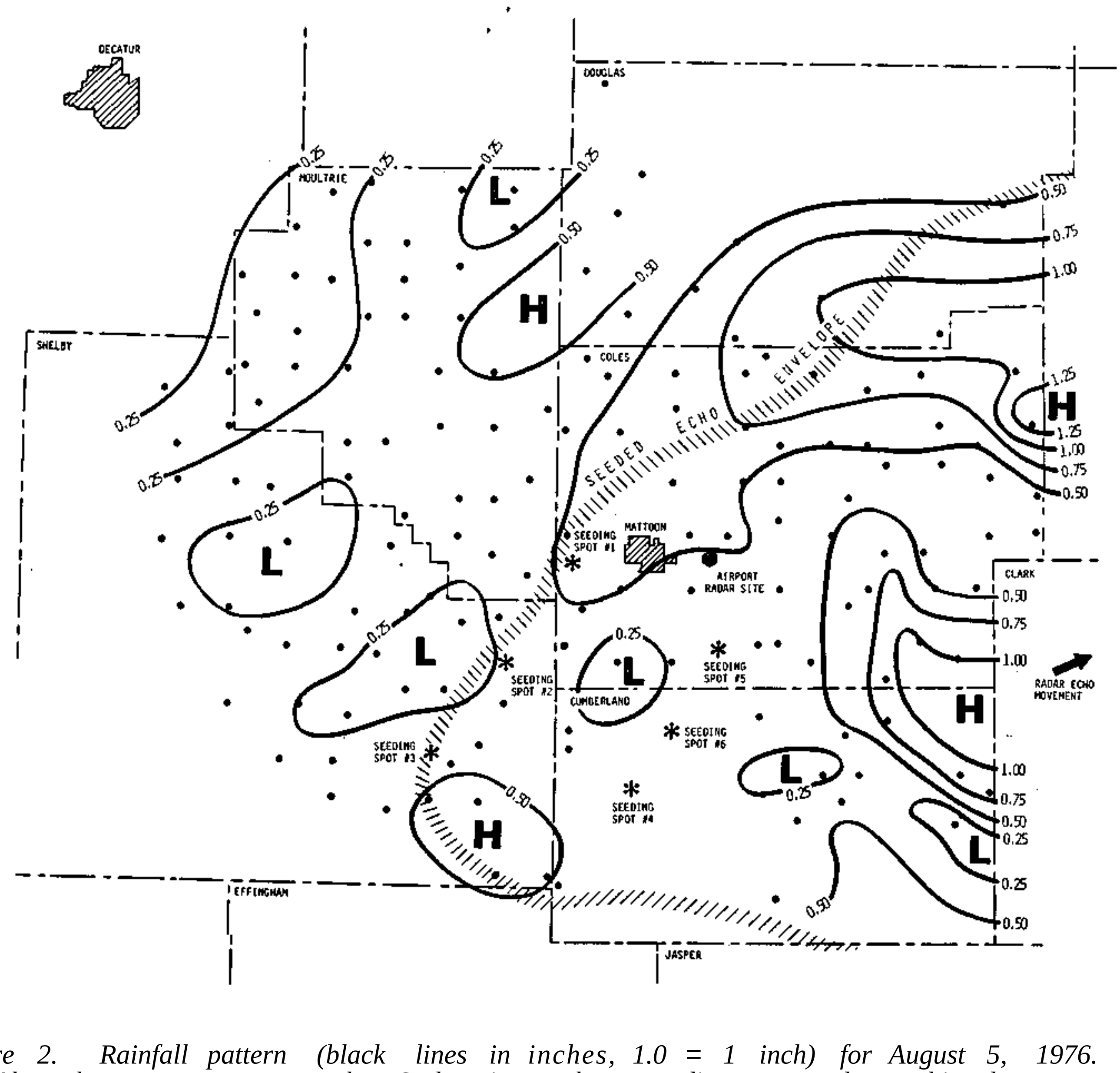


*Figure 2. Rainfall pattern (black lines in inches, 1.0 = 1 inch) for August 5, 1976. Also shown as stars are the 6 locations where seeding occurred on this day. The hatched line forms the "envelope," based on radar echoes that were seeded and their total area, where the rainfall was considered as potentially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

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" echoes.

Before presenting the key 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 generally below normal. In the project area, the normal rainfall for the 5,1/2 week seeded period is 4.3 inches, but in 1976 amounts were all below normal, ranging from about 1.0 inch up to 2.3 inches below normal.

Comparison of Rainfall in Seeded and Non-Seeded Areas Based on Echo Envelopes. Table 2 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. Because of 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 shows 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.

Summarization of the 6 values shows that the mean rainfall per day in the seeded areas (as defined by the echo envelopes) was 0.255 inch as compared to 0.183 inch 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 area. The averages of the maximum values of the seeded and non-seeded areas (table 2) are 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-tail or 2-tail t-tests for the 5% or 10% levels. The. sample size was too small to make these differences statistically significant.

Comparison of Characteristics of Radar Echoes. The echoes measured on the six seeded days 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 ) 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 $T_2$ was 78 mi .

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

Table 2. Comparison of Seeded Area Rainfall and Control Area Rainfall Based on Seeded Echo Envelope Delineation in 1976.

| | Seeded area* | | | | Control area* | | | |
|---|---|---|---|---|---|---|---|---|
| | | Rainfall, inches | | | | Rainfall, inches | | |
| Date | Number of gages | Average | Median | Maximum | Number of gages | Average | Median | Maximum |
| 5 August | 36 | 0.53 | 0.50 | 1.40 | 37 | 0.30 | 0.26 | 1.00 |
| 6 August | 39 | 0.25 | 0.16 | 1.38 | 33 | 0.37 | 0.10 | 3.10 |
| 11 August | 27 | 0.02 | T | 0.10 | 111 | 0.06 | 0.02 | 0.45 |
| 13-14 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 area including those with no rain.

echoes and 16 control echoes completely measured. The average and median values of their envelopes and their areal extents at $T_o$, $T_1$, and $T_2$ appear in table 3.

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.

Summary. The percentage differences (increases or decreases) between the seeded rain and echo values and control values are summarized in table 4. None of the values are statistically significant differences. However, all but the $T_Q$ echo value (before seeding began) indicate an increase varying anywhere from 12 to 39%. 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 cloud seeder was attempting to seed the 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. .

The apparent enlargement of the echo and rain area in the seeded storms, as hypothesized by the seeding approach, coupled with the increases in all four rain categories, suggest 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.

## McLean County Projects of 1977 and 1978

This section discusses the highlights of an evaluation of the McLean County Project in 1977 and 1978 (Changnon et al., 1978). Although this project was very limited in time, it had the portent for a useful evaluation. Cloud seeding occurred over McLean County (1200 mi ) in two 1-month summer periods, one in 1977 and one in 1978 (table 1).

According to the project contract and permit filed with the State, all seedable rain events (save those weather periods forbidden by State law as too dangerous for modification) were to be seeded by project aircraft using one or both common seeding techniques (AgI released at cloud base or at mid-cloud levels). The hypothesis of modification was stated as both microphysical and dynamic, with the approach to be selected according to cloud conditions.

The written records of the operations in McLean County were adequate, under State Law, to define and describe the daily operations. The local sponsors were Rain Gain Incorporated (using local donations), and the cloud seeding firm was Atmospheric Incorporated (AI). There were radar operations involved, but as noted earlier, the data in 1977 were found to be useless, and those in 1978 were found to be of limited value. Other available data included daily rainfall values from a dense network of volunteers (107 gages in 1977, 90 in 1978) established by the County Extension Agent, and those from the National Weather Service raingage stations in and around McLean County (figure 3).

Table 3. 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 Extent ($mi^2$) | | |
|---|---|---|---|---|
| | | $T_0$ | $T_1$ | $T_2$ |
| Average | 146 | 40 | 53 | 86 |
| Median | 89 | 27 | 29 | 24 |

$T_0$ = First indication of echo

Mean Times: $T_1 = T_0 + 23$; $T_2 = T_0 + 58$

Control Echoes (16 total)

| | Total Envelope Coverage ($mi^2$) | Instantaneous Extent ($mi^2$) | | |
|---|---|---|---|---|
| | | $T_0$ | $T_1$ | $T_2$ |
| Average | 122 | 50 | 40 | 23 |
| Median | 88 | 31 | 17 | 13 |

$T_0$ = First indication of echo

Mean Times: $T_1 = T_0 + 25$; $T_2 = T_0 + 62$

Table 4. 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 |
|---|---|---|---|
| Seeded Echo Envelope | +39% | | +12% |
| 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% | |

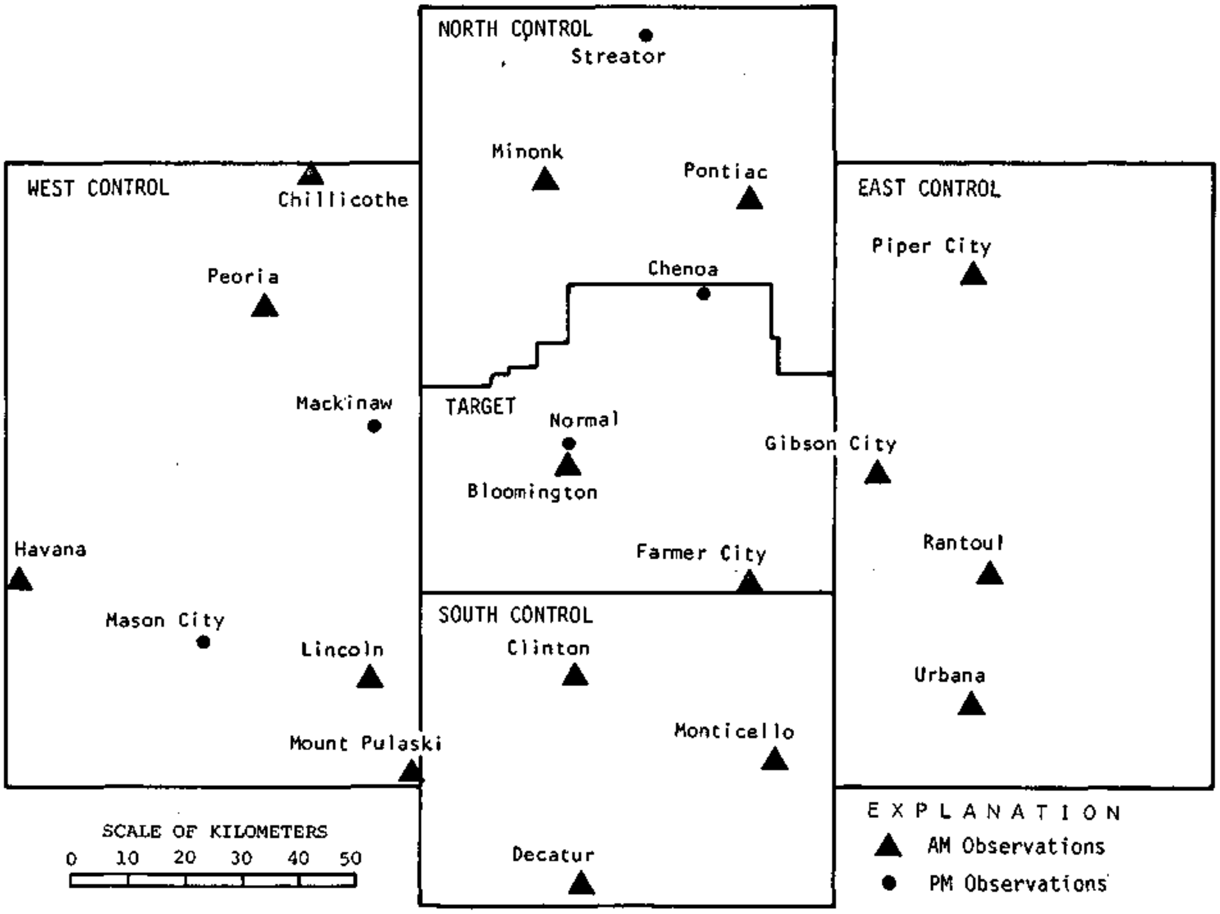


*Figure 3. Target and control areas and raingage stations used to evaluate McLean County Weather Modification Project, 1977-1978. The time of daily observations is denoted by symbol at each station.*

These data were used in target-control comparisons of one-month efforts. There are not too many NWS stations (4 in McLean County and a similar density in surrounding areas), but they offered a means to obtain comparable area mean rainfall.

The other evaluation approach used was based on the limited radar data available from 1978. The areal extent of echoes that were seeded was compared before and after the seeding. Meaningful evaluations of seeded echoes and non-seeded echoes could not be pursued because life histories of so many echoes were not recorded. The statistics on seeded days and operational periods of the 1977 and 1978 projects are found in table 1.

Results for Monthly Rain Totals. Average total rainfall of all stations in the target and in each control area was calculated for 1977, 1978, and both years combined (figure 4). In 1977, the target area rainfall approximated the regional average (target plus control) rainfall. In 1978, the target had average rainfall much below that of the surrounding controls. When 1977 and 1978 were combined, the target had rainfall that rated a little below the average of the surrounding control areas.

Figure 4 also shows the ratio of the target value over the average value of the four control areas. These were 0.94 in 1977, 0.58 in 1978, and 0.79 in 1977+1978. These ratios are all less than 1, an indication that when the areal controls were used, the rainfall in the target area (McLean County) was below what one would expect.

A two-sample Wilcoxon rank sum statistical test was performed for the 1977+1978 rain data. The target had a rank sum of 9, based on a rank of 2 in 1978 (second lowest) and rank 7 in 1977. There were 10 possible ranks (5 areas and 2 years). The rank sum of 9 for the target area corresponds to a 1-sided significance level of 0.733. In other words, rainfall in the target area was not significantly greater than the control areas when areal monthly totals were used in the evaluation. In addition, for the binomial test with a parameter equal to half (which is the probability that precipitation in the target area is larger than the rainfall in the control), the significance level was 0.855, which again is not significant. The area rainfall averages showed less in the target, but these two tests indicated the 2-year differences were not significantly different.

The "normalized" average total rainfall of each area was calculated to compare the two years fairly (and to remove a possible yearly influence, or difference in the rain between 1977 and 1978). The normalization was based first on calculation of the 5-area mean and standard deviation of each year, then by subtracting the 5-area mean from the average of each area, and finally by dividing by the standard deviation. Results indicated the target area rain differences were not statistically significant departures.

Overall, when seasonal totals were used to evaluate the seeding effect, the target rainfall was not statistically significantly more or less than the control values.

Results for Daily Rainfall Analysis. Daily rainfall values were classified into seeded or non-seeded days according to the occurrence of

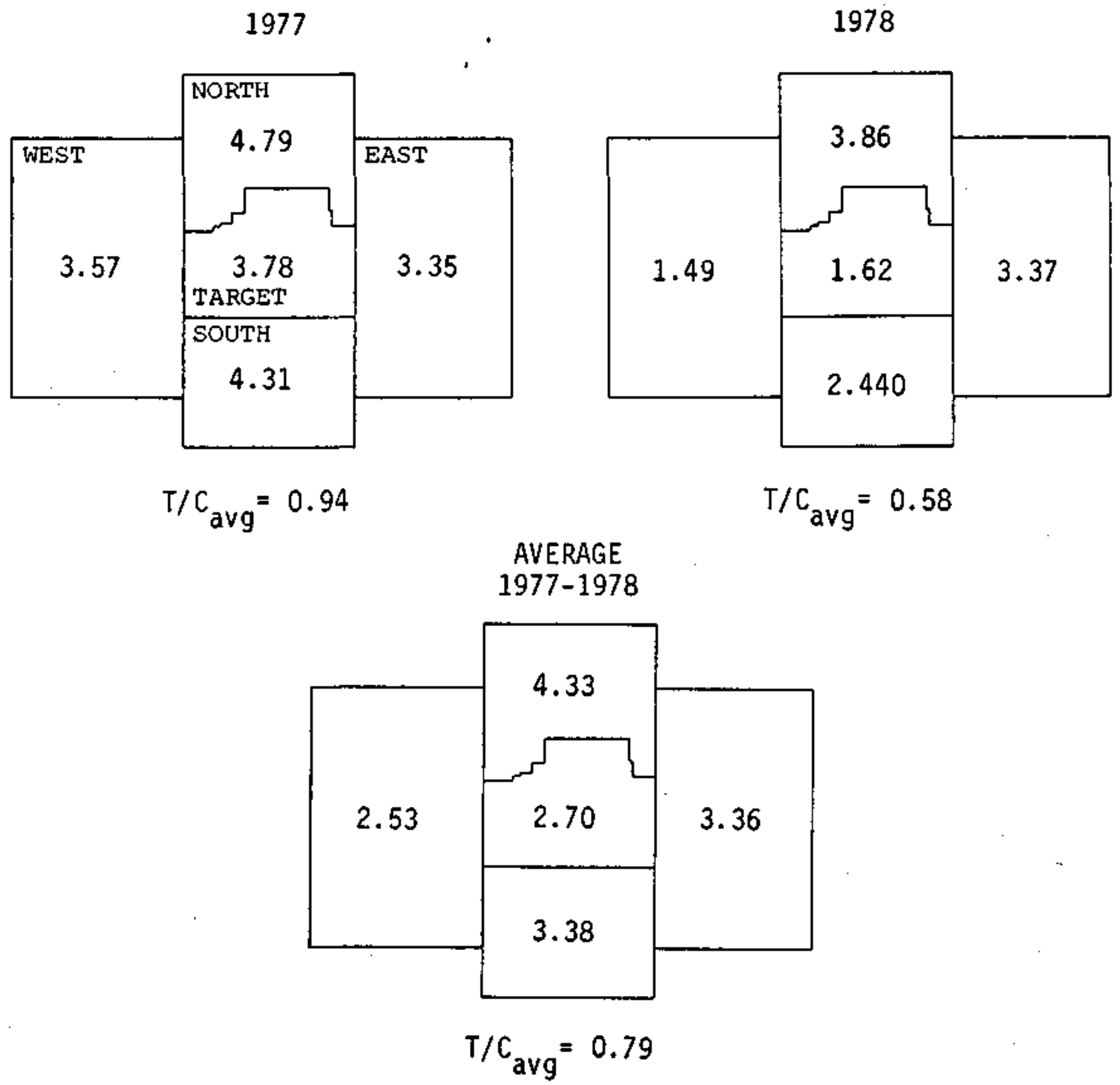


*Figure 4. Average total rainfall (inches) of all stations in each area.*

seeding. That is, if seeding occurred at 1600 on 15 July, the associated rain at 1600 was the amount reported at 0700 on 16 July, the following day. Table 5 presents daily means and standard deviations of each area using the data from 0700 daily observations for 1977, 1978, and 1977+1978. There were 16 seeded rain days and 25 non-seeded rain days in the 2-year sample.

Also shown in table 5 are ratios of target over average control for the seeded days and non-seeded days. For seeded days, the ratios are 0.99, 0.48, and 0.79, for years 1977, 1978, and ,1977+1978, respectively. For non-seeded days, the ratios are 0.88, 0.65, and 0.83, for 1977, 1978, and 1977+1978, respectively. All ratios are less than 1, which is consistent with the seasonal rainfall findings (target values were less than control).

When the ratios of target over average control in the seeded days are divided by the ratios in the non-seeded days (table 5), one gets "double ratios" of 1.13, 0.74, and 1.06, for 1977, 1978, and 1977+1978, respectively. These findings indicate that there was a 13% rain increase in 1977 on seeded days, a 26% rain decrease in 1978 on seeded days, and a 6% increase of rainfall on the seeded days when 1977 and 1978 were combined.

The double ratios of target over each individual control area were calculated (table 6) to further analyze the target and control area differences. For example, the double ratio of target over west (upwind) control is 2.15 in 1977, 1.86 in 1978, and 2.05 in 1977+1978. From these results, we see that when the west control is used to evaluate the target, there is relatively much more rainfall on the seeded days than on the non-seeded days. Furthermore, except when east control was used, all double ratios in 1977 are larger than 1.00, which could indicate a positive (increase) seeding effect. In 1978, double ratios of the west and south were larger than 1.0, whereas those of the east and north were less than 1.0. When 1977 and 1978 were combined, the results were mixed. Results suggest a positive seeding effect in the target with respect to the west and south control areas, but a negative seeding effect based on comparisons with the north control and east control areas. When the east control is used, the results show a great decrease in the target. This might be due to downwind (east) influences. On the other hand, when the west, or upwind, control was used, it shows a very significant increase. This could indicate a positive seeding effect, but on the other hand, it may also be due to the below average precipitation in the west control when no seeding was carried out.

Summary. As part of their required project activities in 1977 and 1978, the cloud seeding firm (Atmospherics Incorporated) furnished project ending reports to the State of Illinois and to the local project sponsors, Rain-Gain, Inc. The firm's evaluations of their modification results are of interest.

Their evaluation of the 1977 seeding project led AI to conclude 1) that the target (McLean County) had received 15 to 20% more rainfall than control areas (locale unspecifed); 2) that seeded echoes, as compared to non-seeded echoes, lasted 46% longer and produced 51% more areal coverage (Atmospheric Incorporated, 1977). We did not judge the 1977 radar data to be suitable for such analysis. The modification firm's assessment of its 1978 efforts leads to a conclusion that, "there is again a suggestion that individual clouds and systems which were treated with silver iodide did produce precipitation which

Table 5. Mean and Standard Deviation of 0700 Reporting Stations in Each Area, McLean County Project.

| | 1977 | 1978 | 1977 and 1978 |
|---|---|---|---|
| Number of seeded days | 9 | 7* | 16 |
| Areas | Mean rainfall (and standard deviation) inches | | |
| W | 0.29 (0.33) | 0.11 (0.17) | 0.21 |
| N | 0.40 (0.58) | 0.41 (0.71) | 0.41 |
| S | 0.37 (0.46) | 0.17 (0.39) | 0.28 |
| E | 0.37 (0.46) | 0.43 (0.88) | 0.40 |
| Target | 0.35 (0.42) | 0.13 (0.28) | 0.26 |
| T/C average | 0.99 | 0.48 | 0.79 |
| Number of non-seeded days | 12 | 13* | 25 |
| Areas | Mean rainfall (and standard deviation) inches | | |
| W | 0.11 (0.35) | 0.08 (0.22) | 0.09 |
| N | 0.08 (0.18) | 0.09 (0.33) | 0.09 |
| S | 0.08 (0.27) | 0.10 (0.23) | 0.06 |
| E | 0.01 (0.05) | 0.04 (0.12) | 0.03 |
| Target | 0.06 (0.15) | 0.05 (0.15) | 0.06 |
| T/C average | 0.88 | 0.65 | 0.75 |
| Double ratio** | 1.13 | 0.74 | 1.06 |

*13 July 1978 was classified as non-seeded day

**Double ratio is computed as $(T_{seeded}/C_{average\ seeded})/(T_{non\text{-}seeded}/C_{average\ non\text{-}seeded})$.

Table 6. Ratios and Double Ratios of Daily Rainfall (Seeded vs. Non-Seeded) in McLean County.

| | 1977 | 1978 | 1977 and 1978 |
|---|---|---|---|
| Seeded/Non-Seeded | | | |
| West Control | 2.57 | 1.47 | 2.24 |
| North Control | 4.86 | 4.45 | 4.67 |
| South Control | 4.40 | 1.77 | 3.11 |
| East Control | 26.36 | 11.13 | 14.20 |
| Target | 5.52 | 1.86 | 2.05 |
| $({}^{T}s/{}^{T}Ns)/({}^{W}s/{}^{W}Ns)$ | 2.15 | 1.86 | 2.05 |
| $({}^{T}s/{}^{T}Ns)/({}^{N}s/{}^{N}Ns)$ | 1.14 | 0.61 | 0.98 |
| $({}^{T}s/{}^{T}Ns)/({}^{S}s/{}^{N}s)$ | 1.26 | 1.54 | 1.48 |
| $({}^{T}s/{}^{T}Ns)/({}^{E}s/Ns)$ | 0.21 | 0.25 | 0.32 |

covered a larger area and lasted a longer time period than precipitation echoes in adjacent areas of a similar size" (Atmospheric Incorporated, 1978). However, no percentage changes in echoes or rainfall are offered for 1978. Results from our analysis did not agree, generally suggesting either no change or a decrease in rain area and amount in 1978.

Our evaluations based on the seasonal rainfall totals for 1977, for 1978, and for 1977-1978 combined essentially show no seeding effect. The target area average rainfall in 1977-1978 is lower than the average of the four surrounding control areas. Two statistical tests (2-sample Wilcoxon and binomial) were applied to the 1977+1978 area totals, and the rainfall in the target was not significantly greater than that in the 4-area control. Comparisons of seasonal values between the target and individual control areas also showed no significant differences, although the differences in 1977 were greater than those in 1978.

Assessments based on daily rainfall values essentially gave similar results, but with some suggestions of both increases and decreases in rainfall on seeded days. Comparison of target/control area rainfall ratios on the 16 seeded days with those for the 25 non-seeded days provided informative double ratios. These indicated a 13% rain increase in 1977 (similar to that claimed by the seeding firm), a 26% decrease in the target in 1978, and a net 2-year increase of 6%. Comparisons of the target rain with the various control area values suggest an increase in target rainfall (on seeded days) in relation to the west (upwind) area, but a decrease in the target rain versus the east area rain. Two-sample tests of these target-control differences showed none to be significant at the 5% level.

The radar film data from the 1978 seeded period were analyzed to evaluate the effect of the seeding by studying the sizes of the seeded echoes before and after seeding. No other echo characteristics (lifetime, echo intensity, and echo height) or comparisons to non-seeded echoes could be evaluated satisfactorily because of the limitations in the operations and hence data. However, Water Survey studies have shown that echo size is a reasonably good estimate of rainfall yield.

Comparison of the behavior of the seeded echoes before and after seeding was revealing. Half of the seeded echoes decreased in size after seeding. The average size of echoes was 71 mi before seeding, but 54 mi after seeding, a 24% decrease.

The limited echo analyses indicated that seeding had little or no effect for increasing echo sizes, and suggest an effect leading to a decrease in echo size. This agrees with the daily rain analyses for 1978 which also suggest a decrease in rainfall in the target area on seeded days.

The 1978 echo size results, indicating a decrease in echoes after seeding, do not agree with the 1976 echo studies from the 5-county modification project (table 4). There, the seeded echoes grew relatively more than non-seeded echoes and were about 35% larger after seeding. However, it is critically important to realize that the rain and echo samples from 1976 and 1978 are woefully small. The size is too small to develop conclusive statistical indications of a seeding effect.

Two factors are important in deriving a generalized interpretation of the results of the two McLean County modification projects. First, most percentage changes discerned in the several seed versus no-seed comparisons are small, less than 25%, and are well within the "noise" of normal rain variability. Importantly, they do not indicate a sizable shift (in rain or echoes) that would suggest statistically significant (major) changes (in a small, 2-month sample) were achieved. The second relevant factor relates to the mixed sign of the rain and echo percentages; some were pluses (increases) and some were minuses (decreases). Collectively, these two factors indicate little or no effect in changing the rainfall in McLean County in the 1977 and 1978 summer periods.

## Southeastern Illinois Projects of 1979 and 1980

In the late summer of 1978 a group interested in cloud seeding to enhance rainfall was organized (Southeastern Rain, Inc.) in Saline and Gallatin Counties (figure 1) where the 1978 summer rainfall had been deficient. As can be noted in table 1, this group got organized late in the season, and the 1978 project was conducted from early August to early September. The Water Survey and local County Extension Agents did manage to get a dense network of volunteers with nonrecording raingages installed. However, the shortness of the operational season coupled with few rain events did not offer a situation deemed worthy of an evaluation.

In 1979 and 1980, this project was expanded 1) to encompass parts of 6 counties and a 1300 mi area, and 2) to include nearly 2 months of operations in each summer (table 1). In these two summers, and in the more limited 1978 period, the cloud seeding was performed under contracts with Atmospherics Incorporated. The 1979 and 1980 projects were directed from the Marion Airport, located west of the target, where the weather radar and 2 cloud seeding aircraft were located. The aircraft were outfitted with seeding devices capable of either cloud base or in-cloud (mid level) delivery of seeding material. The contracts and project plans called for seeding to enhance rainfall by static (microphysical processes) seeding and by dynamic modification. The plan called for operations on a 24-hour per day basis, 7 days a week. All seedable conditions, night or day, were to be seeded.

As can be noted in table 1, the 1979 and 1980 projects were both halted temporarily during the operational period. Both cessations were as a result of very wet soil conditions (including flooding in 1979) in parts of the target area. The sponsors, in concert with the Water Survey advisors and the AI project directors deemed such stoppages to be in the best interests of the local public. The only other non-seeded rain periods, other than those deemed by the project directors as unsuitable for modification, were those when severe storm conditions existed in the target (excluded by Illinois law).

Data and Analysis. The primary data utilized in the evaluation of both years were the daily rain values of the National Weather Servioe. Daily values were used to draft isohyetal (rain) maps for discrete periods, which in turn were defined as seeded rains (figure 5), or non-seeded rains for various seasons (figure 6). The dense raingage network of 92 gages operated in 1979 allowed preparation of these detailed maps. The target area was also the basis for defining four control areas of equal size to the north, west, south, and east (figure 7). Seasonal totals for the entire operational periods, less the

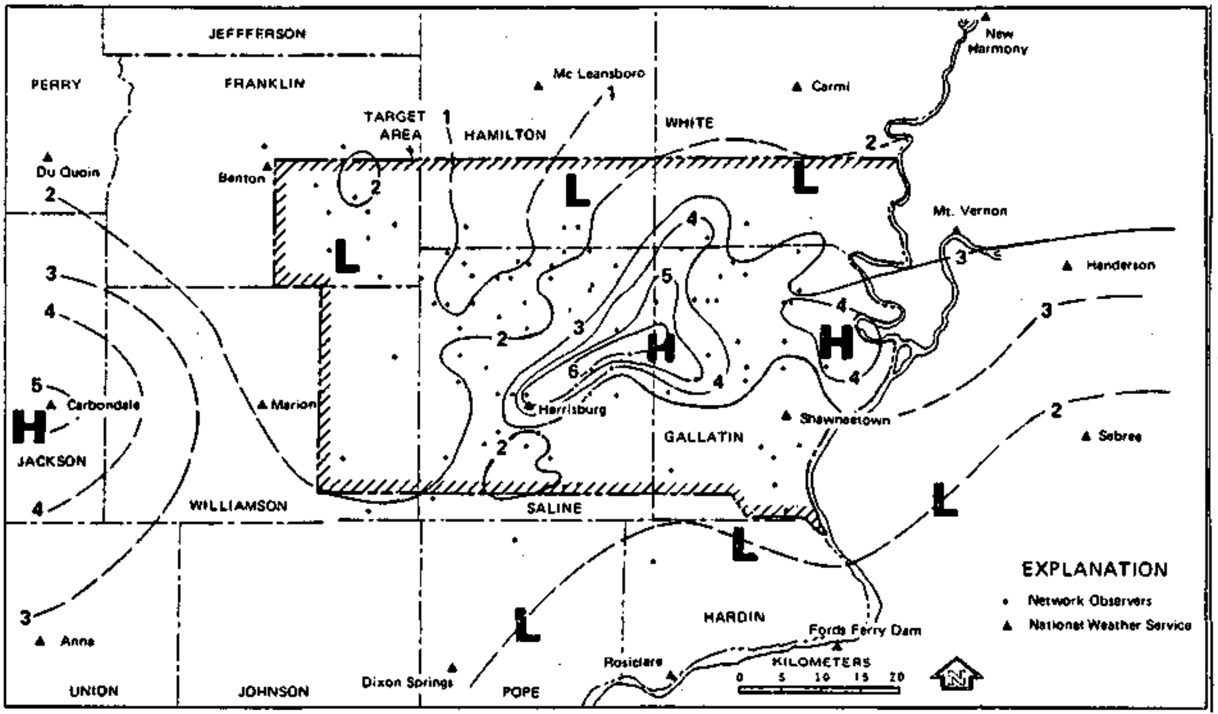


*Figure* 5. *Rainfall (inches) from rains when cloud seeding occurred in 1979.*

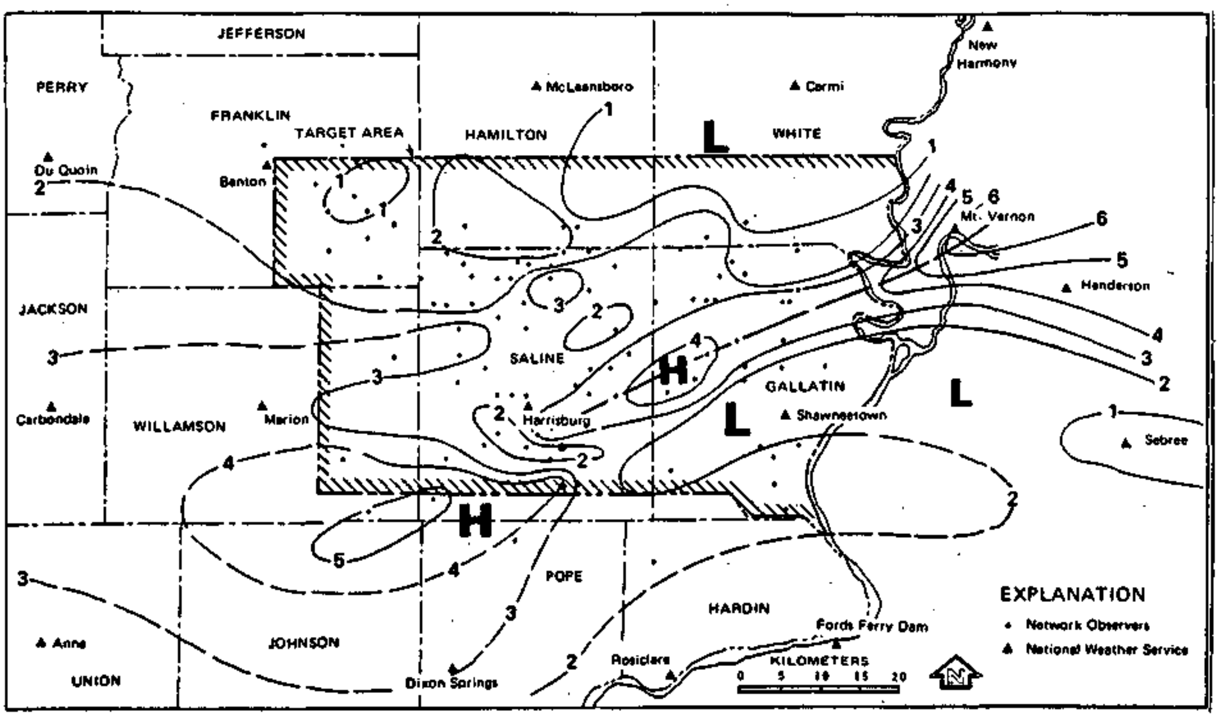


*Figure 6. Rainfall (inches) from rains when no cloud seeding occurred but with aircraft cloud observations in 1979.*

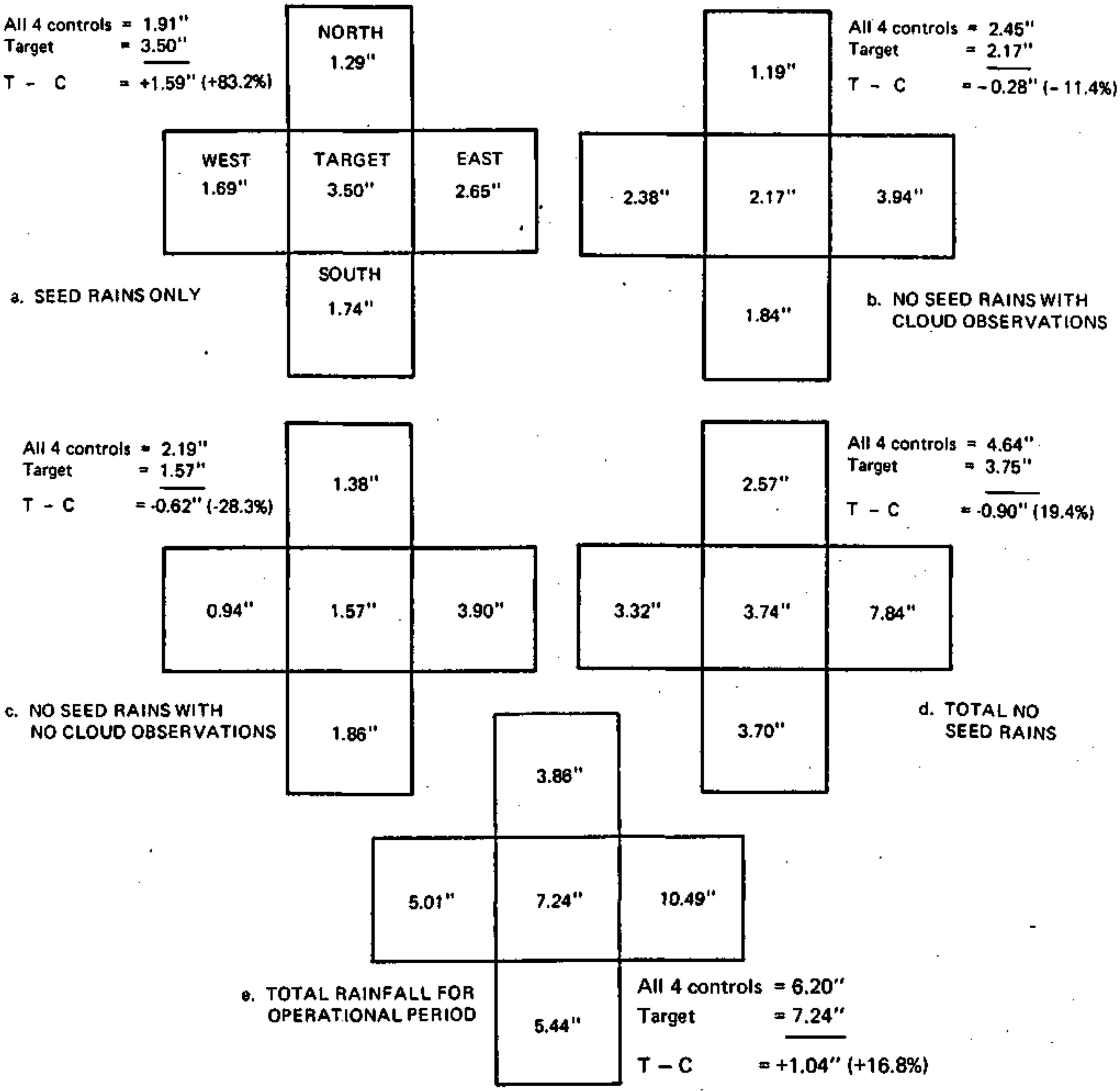


*Figure 7. Area mean rainfall in target and control areas during the Southeastern Illinois Cloud Seeding Project in 1979. Values are based on MS data.*

rain in "wet cessation" periods, were also determined and evaluated (Changnon and Hsu, 1980; Hsu and Changnon, 1981). Target-control relationships for 1979 and for 1980 were compared with historical relationships for. 1949-1978 when there was no cloud seeding. In 1979 and 1980 the no-seed rain events included two categories; those when the aircraft flew and decided no seed on the basis of cloud observations, and those when the meteorological conditions were considered too poor for seeding to allow launching of aircraft.

The radar data in 1979 were not assessed because the Water Survey had no personnel available for the complex effort. The 1980 radar data were carefully scanned as to quality and a lack of gain threshold measurements kept us from an echo evaluation.

Results of Study of Rain Data. In order to make an unbiased comparison (unbiased by different raingage densities), the rainfall data from only the available National Weather Service raihgages in and around the target area were used in 1979 and 1980. One notes from figure 5 that there were very few such gages. For example, the only National Weather Service gages in the target area were at Harrisburg and Shawneetown. Although the density of gages is poor, it is relatively uniform in the target and control areas. Each had the same general raingage density, approximately one gage in 400 square miles.

The 1979 area averages (figure 7) allow one to compare and assess differences between regions. For example, in figure 7a, based on the 1979 seed rains only, one finds the target area average of 3.50 inches with lesser area averages in all of the four surrounding control regions. Shown beside figure 7a is the average of all four control areas, a value of 1.91 inches, and the target average of 3.50 inches. Their difference, labeled T-C (or target minus control), is 1.59 inches. This difference, expressed as a percent of the control area value, indicates 83.2% more rainfall in the target than in the 4-area control. Again, caution is urged. This does not necessarily reflect any cloud seeding effect. It simply says that 83% more rainfall fell in the target area than in the surrounding control, and the cause for this is not established. It could be nature, man, or both.

Similar comparisons for the two no-seed rain categories appear in figures 7b and 7c. These both show that the target area received less rainfall, in both categories, than did the average of the four control areas. Figure 7d presents the area average rainfall values combined for both categories of no-seed conditions. The target area received more rainfall than did the north, west, and south control areas, but noticeably less than did the east control areas.

Comparable results for 1980 appear in table 7. On the seed occasions, the target area received 5.48 inches (table 7c), and the average rainfall for all 4 control areas is 3.82 inches. Their difference, labeled T-C (or target minus control), is equal to +1.66 inches. This difference, expressed as a percent of the control average rainfall, represents 43.5% more rainfall in the target than in the control areas. Similar comparisons for the two periods appear in tables 7a and 7b. They also show that the target area received more rainfall on the seed occasions than did the average of the four control areas. The rainfall increases on seeded occasions for periods 1 and 2 were respectively +0.35 and +1.31 inches; and the percentage increases were respectively +20.0%, and +63.3%.

Table 7. Areal Rainfall in the Target and Control Areas, 1980, Values Are Based on NWS Raingages.

| | Control Area North | West | South | East | Avg. | Target Area | T-C | Percent Change |
|---|---|---|---|---|---|---|---|---|
| | **a. 23 June - 2 July (Period 1)** | | | | | | | |
| Seed | 2.37 | 1.13 | 2.50 | .98 | 1.75 | 2.10 | + .35 | +20.0% |
| No Seed | .33 | 1.75 | 1.90 | .67 | 1.16 | .80 | - .36 | -31.0% |
| Total | 2.70 | 2.88 | 4.40 | 1.65 | 2.91 | 2.90 | - .01 | - 0.3% |
| | **b. 14 July - 20 August (Period 2)** | | | | | | | |
| Seed | 2.07 | 2.32 | 1.55 | 2.35 | 2.07 | 3.38 | +1.31 | +63.3% |
| No Seed | 1.49 | 2.82 | .50 | 1.48 | 1.57 | .88 | - .69 | -43.9% |
| Total | 3.56 | 5.14 | 2.05 | 3.83 | 3.64 | 4.26 | + .62 | +17.0% |
| | **c. Period 1 and Period 2 Combined** | | | | | | | |
| Seed | 4.44 | 3.45 | 4.05 | 3.33 | 3.82 | 5.48 | +1.66 | +43.5% |
| No Seed | 1.82 | 4.57 | 2.40 | 2.15 | 2.73 | 1.68 | -1.05 | -38.5% |
| Total | 6.26 | 8.02 | 6.45 | 5.48 | 6.55 | 7.16 | + .61 | + 9.3% |

On no seed occasions, the target area received less rainfall in either period than did all four control areas, except in the north and east control areas in period 1. The differences (T-C) between the target and the average control area represented 0.36, 0.69, and 1.05 inches less respectively in periods 1, 2, and the combined period; or 31.0%, 43.9%, and 38.5% less rainfall respectively in the target area than in the surrounding control areas.

The combinations of all the 1980 rains (table 7c) shows that the rainfall in the target areas (7.16 inches) easily exceeds the averages of four control areas (6.55 inches), and is larger, than each control area rainfall except that of the west control area. The target-average control difference is +0.61 inches, or +9.3%, a crude indication that the target area received more rainfall than did the control areas. However, this ratio cannot be used alone as indication of any seeding effect, as certain "selection bias" may have been introduced by the seeding operator in favor of more natural rainfall in the target on occasions chosen for seeding.

The 1979 and 1980 cloud seeding efforts were also assessed by comparing target area rainfall and control area rainfall with that from the past 30 years. Rain totals were defined to be that total during the period of actual operations in both years (table 1). Rain values of the) stations in the target and in each control area were averaged to form area averages for each year from 1949 to 1980. These averaged totals were used in the subsequent analyses.

A principal component analysis for the four control areas using 1949-1978 data was performed separately for 1979 and for 1980 and the components retained were used in turn as independent variables to run a regression on the target. This (historical) principal component regression was used to forecast 1979 and 1980 precipitation in the target area, which in turn was compared to the observed 1979 and 1980 target precipitation to assess the seeding effect.

The resulting forecasted precipitation for the 1979 target area using 1949-1978 principal component regression was 5.19 inches. The difference between this and the observed (7.24-5.19) value results in a rainfall increase of 2.05 inches, or 39%.

To assess the significance of this 1979 rainfall increase, a re-randomization (repetitive) principal component regression was performed. (For more details on re-randomization testing, see Hsu, 1979 and Gabriel and Hsu, 1980). One year from 1949 to 1978 was randomly selected as a hypothetical seeded year, and all other years (including 1979) were used as historical "control" years. Then a principal component regression was performed on this seeded-historical data, and a forecasted precipitation was obtained as described above, from which a rainfall increase was calculated. This process was repeated by selecting another year as "seeded" and so on, until a distribution of rainfall increases was obtained. For the 1979 and 1980 projects, 31 rainfall increases were obtained and those for 1979 and 1980 are shown in a "stem and leaf" distribution in table 8. Among these estimated rainfall increases, two are larger (3.03 and 4.12) than the 1979 value (indicated by an asterisk in the table), and the significance is thus 0.0968. That is, the chance that this sizable increase is due to nature (rather than to cloud seeding) is about one out of ten. Because of the very short duration (one year) of the 1979 project, the seeding effect, if any, is usually more difficult to detect than in longer projects, even using powerful evaluation techniques.

Table 8. Re-Randomization Distributions of Estimated Precipitation Increases Using all Surrounding Control Areas for 1979 and for 1980.

## 1979

| Stem | Leaves | Cumulative No. | Cumulative % |
|---|---|---|---|
| -2.00 | 00, 04, 09 | 3 | 9 |
| -1.00 | 08, 09, 19, 60, 67, 70 | 9 | 29 |
| -0.00 | 11, 23, 42, 47, 57, 58, 74, 95 | 17 | 54 |
| 0.00 | 10, 19, 23, 43, 48, 48, 68, 69, 88 | 26 | 83 |
| 1.00 | 55, 75 | 28 | 90 |
| 2.00 | 05* | 29 | 93 |
| 3.00 | 03 | 30 | 96 |
| 4.00 | 12 | 31 | 100 |

*1979 value

## 1980

| Stem | Leaves | Cumulative No. | Cumulative % |
|---|---|---|---|
| -2.00 | 02, 95 | 2 | 6.5 |
| -1.00 | 00, 34, 55, 71, 97 | 7 | 22.6 |
| -0.00 | 04, 15, 18, 20, 29, 51, 54, 56, 98 | 16 | 51.6 |
| 0.00 | 03, 05, 28*, 46, 50, 68, 75, 92, 93 | 25 | 80.6 |
| 1.00 | 10, 19, 26, 99 | 29 | 93.6 |
| 2.00 | 45, 76 | 31 | 100.0 |

*1980 value

A similar principal component analysis for the 1980 data (again without 1979 values) was pursued. The difference between the historical-based prediction of 6.88 inches and the actual (7.16 inches) indicated an increase of 0.28 inch, or 4.1%. To assess the significance of this 1980 increase, a re-randomization of the principal component regression was performed (as with the 1979 data). The "stem and leaf" distribution for 1980 appears in table 8. Among the estimated rainfall increases, 12 are larger than the 1980 value, and the significance is thus 0.419. This is very non-significant. There are about four chances in ten that this increase is due to nature. Thus, the 1980 results did not sustain the significant differences found in 1979.

Figure 7e shows that the target area in 1979 had more rain than the control areas except for the east control. There, the average of 10.49 inches in 1979 is much above the other areal rainfall values. To estimate whether this large value occurred naturally or extremely (in other words, was an outlier), frequency distributions of the rainfall for each area were studied. The deviation in the east control area, whose 1979 precipitation was the second largest in a 31-year period, was exceptionally large. This raises a question of possible extra-area (downwind) seeding effects in the east control area. Without looking extensively into the detailed seeding operations and the corresponding meteorological conditions, this question of a downwind effect cannot be resolved. Therefore, it was decided to exclude the east control area from the 1979 control data, and to perform another evaluation (Changnon and Hsu, 1980). This second evaluation does not render the 4-area evaluation invalid; rather it only serves as an auxiliary piece of information.

The principal component regression was the evaluation technique used for these data. The estimated 1979 rainfall increase is 1.94 inches, which has a significance level of 0.0968. The estimated precipitation increase in 1979 is 36.6% using three control areas, compared to 39.5% using four control areas.

A similar analysis of the 1980 data was not pursued because the target-control differences were not large. Another assessment of the target and 4 control area values of 1980 focused on the ranking, or ordering, of the 1949-1980 (excluding 1979) values. Table 9 presents these 31 values for the five areas. The rank of 1980 rainfall values for the north, west, south, east, and target areas were respectively 20, 26, 20, 16, and 20. In general, the 1980 areal rainfall values were above the median values (16th observation). The rank of the target area rainfall, 20, was rather close to the average rank of the four control areas rainfall, 20.5; and it was not as extreme as that, 26, in the 1979 analysis (Changnon and Hsu, 1980).

For each National Weather Service station, a ratio of 1980 rainfall to the 30-year averaged rainfall was computed (figure 8). It can be seen that there was a region of high rainfall ratio located to the west of the target area. For the stations in the target area, the 1980 rainfall amount of Harrisburg was close to its historical average, the ratio being 0.95; while the 1980 rainfall amount of Shawneetown was above its historical average, the ratio being 1.27. However, a band of high rainfall ratio to the west, north, and southeast of the target area discounts the significance of this above-normal rainfall ratio at Shawneetown.

Table 9. Distribution of Ordered Areal Precipitation, 1949-1980 (Excluding 1979).

| No. | North | West | South | East | Target |
|---|---|---|---|---|---|
| 1 | 1.53 | 1.40 | 2.26 | 2.19 | 1.84 |
| 2 | 2.49 | 1.83 | 2.67 | 2.67 | 2.81 |
| 3 | 2.72 | 2.62 | 3.19 | 3.21 | 3.17 |
| 4 | 3.01 | 3.14 | 3.22 | 3.35 | 3.22 |
| 5 | 3.08 | 3.92 | 3.50 | 3.55 | 3.41 |
| 6 | 3.36 | 4.00 | 4.08 | 3.67 | 3.53 |
| 7 | 4.00 | 4.37 | 4.18 | 3.98 | 3.70 |
| 8 | 4.09 | 4.45 | 4.30 | 4.07 | 4.04 |
| 9 | 4.15 | 4.46 | 4.45 | 4.60 | 4.29 |
| 10 | 4.45 | 4.58 | 4.82 | 4.64 | 4.46 |
| 11 | 4.48 | 4.93 | 4.85 | 4.92 | 4.48 |
| 12 | 4.53 | 5.04 | 4.98 | 5.30 | 4.70 |
| 13 | 4.61 | 5.13 | 5.07 | 5.31 | 4.99 |
| 14 | 4.92 | 5.43 | 5.13 | 5.33 | 5.97 |
| 15 | 5.17 | 5.47 | 5.18 | 5.33 | 6.28 |
| 16 | 5.21 | 5.74 | 5.87 | 5.48* | 6.36 |
| 17 | 5.32 | 5.75 | 6.04 | 5.76 | 6.38 |
| 18 | 5.51 | 5.93 | 6.35 | 5.95 | 6.39 |
| 19 | 5.65 | 6.05 | 6.44 | 6.09 | 7.09 |
| 20 | 6.26* | 6.57 | 6.45* | 6.44 | 7.16* |
| 21 | 6.37 | 6.96 | 6.48 | 6.51 | 7.38 |
| 22 | 6.42 | 7.06 | 6.82 | 7.07 | 7.47 |
| 23 | 6.46 | 7.36 | 7.06 | 7.46 | 7.56 |
| 24 | 6.49 | 7.59 | 7.14 | 7.69 | 7.77 |
| 25 | 6.86 | 7.90 | 7.47 | 7.82 | 8.02 |
| 26 | 6.91 | 8.02* | 7.94 | 7.82 | 8.07 |
| 27 | 7.64 | 8.65 | 8.79 | 8.32 | 8.41 |
| 28 | 8.18 | 8.89 | 8.92 | 10.17 | 8.75 |
| 29 | 8.35 | 10.29 | 9.46 | 10.35 | 9.38 |
| 30 | 8.85 | 10.57 | 11.43 | 10.68 | 11.29 |
| 31 | 10.01 | 10.58 | 12.77 | 13.15 | 12.17 |

*1980 value

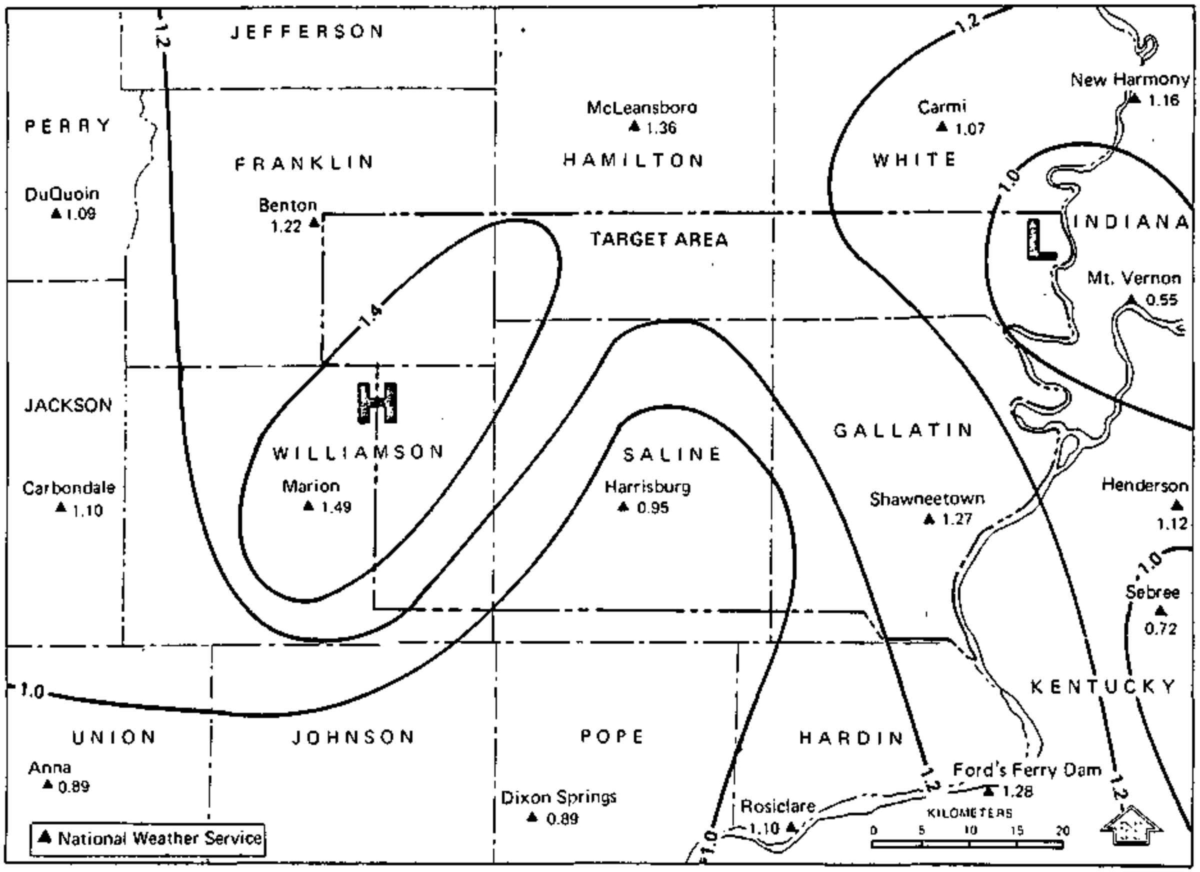


*Figure 8. Rainfall ratio pattern for 1980 rainfall compared to 1949-1978 average.*

The 5 area values in each year (1949, 1950, ... 1978, 1980) were compared and ranked 1 through 5. These 31 ranks of the five areas were averaged, showing the target to have a mean rank of 3.35 (the highest of the five areas). The significance of its second top rank in 1980 was shown to be 0.52 (half chances of occurring naturally).

Summary. The results indicate that the target area in 1979 and 1980 received more rainfall during the operational period than did surrounding areas. This was particularly true in 1979 when one compared the rainfall based solely on the rain periods which were seeded. Investigation of the 1979 rainfall (isohyetal) pattern within the target, based on the detailed dense raingage network data, shows that there were wide extremes, from very low to very heavy rainfall in the target.

The 1979 and 1980 data alone cannot be construed as evidence of any cloud seeding effect. The differences, however, when one compares the seeded rainfall values with the no-seed values, particularly as revealed in figure 7 and table 7, do suggest that a localized high in the target occurred in the seeded rain conditions. It was not present there in the no-seed conditions of 1979. However, as one final caution, one would expect that cloud seeding in the target would be attempted under conditions that were locally favorable for heavier rainfall there, again warning against an interpretation that the 1979 and 1980 target-control comparisons reflect any enhancement of rainfall due to cloud seeding.

Evaluations using surrounding control areas coupled with 30 years of historical data show that there was a significant precipitation increase in the target area in 1979 with a 40% precipitation increase during the 1979 cloud seed period. If the question of the east control (extra-area effect) is considered, then evaluation using the other control areas also shows a 37% precipitation increase. In both instances, the probability that this is due to chance is 1 in 10. The increase in 1980 was much less, 4%, reflecting nearly a 40% chance of occurrence by nature. The project personnel differed totally between the two years, and both years were relatively wet years.

## CONCLUSIONS

It must be stressed that these five projects (from 5 summers) have not had totally thorough analyses of all available data, nor has time and effort permitted all types of statistical or physical analyses. In fact, evaluation approaches used differed considerably between projects.

Results have been assembled in this report, as available at this time, to help provide generalized information, and to seek an overview of the general tendencies. In all instances, the 1-year (usually one or two months) projects were too short, regardless of the apparent increases or decreases of rainfall or echoes in the target areas, to draw any conclusions that have any statistical or physical significance when taken alone.

The general tendencies found in the target rainfall and echo characteristics are summarized in table 10. In general, the results reflect a quite mixed outcome. Two of the projects (years) indicate increases, signified by the pluses (1976 and 1979), in the target rainfall and/or echoes. One year (1978) indicates a rain decrease. The target echo results are also mixed.

Potentially relevant are the observations of Water Survey meteorological staff members who a) inspected the five projects during operations, and b) inspected the data logs and other forms supplied by the weather modification firms. This assessment is a mixture of subjective observations and more objective assessments of project data quality. In general, our staff members (7 professionals) concluded that two projects operated in the most professional manner were those of 1976 and 1979 (the two years with increases), and that operational quality in 1978 was the poorest of all projects. This was also the year of negatives. If one assumes that the +, 0, and - tendencies in table 10 partially reflect effects of cloud seeding, one could conclude that the quality of effort and expertise make a major difference.

The results also show that for various reasons the project radar data are often unusable for a meaningful evaluation of possible seeding effects. It is difficult to operate a radar to serve both operations and data collection, but the problems have often related to careless issues like improper scope photography or too limited operations before or after seeding.

Table 10. General Direction of Rainfall in the Target Area.

| Year | Target Rainfall | Target Radar Echoes |
|---|---|---|
| 1976 | not studied | + |
| 1977 | 0 to weak + | poor data |
| 1978 | - | - |
| 1979 | + | not studied |
| 1980 | 0 to weak + | poor data |

## ACKNOWLEDGMENTS

This assessment of rainfall could not have been possible without the considerable efforts of the County Extension Advisors in the 13 counties encompassed by the five project areas. We wish to thank them for their considerable assistance in establishing the raingage networks and in getting the data assembled and transmitted to the Water Survey. We also wish to thank the more than 500 persons who served as rainfall observers during these projects. The support and encouragement of Agricultural Experiment Station leaders are also appreciated.

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