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EVALUATION OF THE WESTERN KANSAS WEATHER MODIFICATION PROGRAM

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Abstract - Weather modification activities began in Western Kansas in 1972 and several cloud seeding operations were conducted from 1972 through 1978. The centerpiece of weather modification activities in Kansas is represented by the Western Kansas Weather Modification Program that has operated from 1975 to the present time under the leadership of the Western Kansas Groundwater Management District No. 1. The primary objective of the Program has been to reduce hail damage, although a significant effort has also been made to increase precipitation. The Program has been evaluated on several previous occasions by various entities. However, the previous evaluation methodology and/or results have been viewed as somewhat inconclusive by the Kansas Water Office. The precipitation component as per the recent evaluation by the Kansas Water Office showed that precipitation declined by 0.25 inches in the target area from the pre-cloud seeding time period of 1941 to 1970 to the cloud seeding time period of 1979-1993. This amount of change in rainfall is well within normal precipitation variation and was determined to be of no practical economic significance. In contrast, the Kansas Water Office evaluation of the hail suppression component of the Program was very positive. The estimated percentage decrease in hail damage to crops in the target area was 27 percent, and resulted in an estimated benefit of approximately $60,000,000 to the six county target area for the 1979-1993 time period or $4,000,000 per year, after the expenses to operate the Program have been deducted. These figures are based on reduced hail damage to crops and do not include any estimate of the savings due to reduction in hail damage to dwellings, personal property, wildlife or other natural resources.

1. EVALUATION OF THE PRECIPITATION COMPONENT

1.1 Selection of an Operational Time Period

Two time periods were chosen for this evaluation effort. One time period was selected to represent a period of time during which the Western Kansas Weather Modification Program was operational. Although the Western Kansas Weather Modification Program began cloud seeding operations in 1975, the initial years of the operation from 1975-1978 were excluded from this analysis because cloud seeding operations were also being conducted within a 90-mile radius of Sherman County during 1975-1978. Hence, if this time period for analysis were to begin in 1975, it would be necessary to exclude Sherman County and several other Northwest Kansas counties from the control area discussed below. Therefore precipitation records were analyzed for the time period from 1979-1993, which represents a time period during which annual cloud seeding activities were taking place, in the target area counties, as a result of the Western Kansas Weather Modification Program and no such activities were occurring in the control area counties, listed below, or in any location that might have an impact on precipitation in the control counties.

1.2 Selection of a Historical Time Period

A historical time period from 1941-1970 was selected for comparison purposes, which represented a period of time during which no weather modification activities occurred in the vicinity of the control or target areas. Since cloud seeding operations occurred from 1972-1978 in portions of the control area, it was necessary to end the historical period in 1971 or before.

1.3 Study Areas

A target area and a control area were selected as study areas for precipitation analyses. The target area consisted of all counties that have fully participated in the Weather Modification Program each year from 1979-1993. These six counties were: Finney, Ford, Greeley, Haskell, Kearny and Lane.

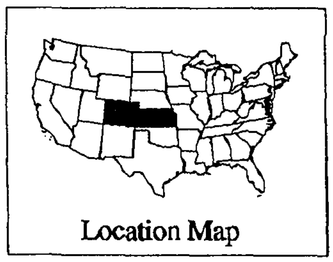
Figure 1 shows the target area in dark shading and the control area in light shading. No portion of the control area received any cloud seeding activity during either of the two time periods used for this study and it was not likely that any of the control area would have been impacted by any cloud seeding activities occurring outside of the control area or within the target area during either of the two time periods.

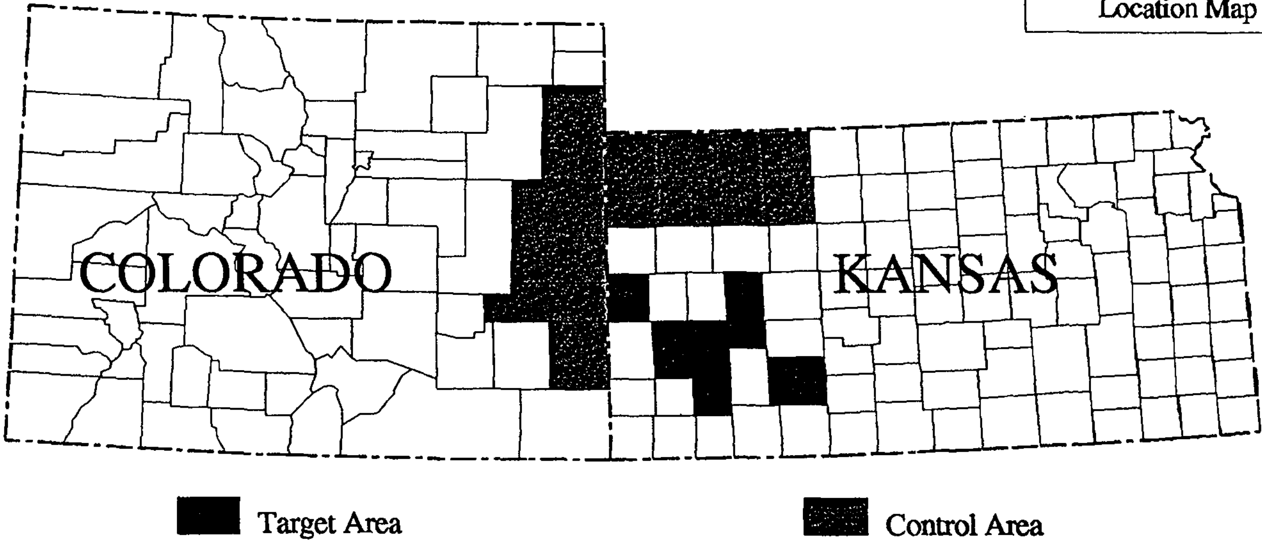
The northern portion of the control area consisted of Cheyenne, Rawlins, Decatur, Norton, Sherman, Thomas, Sheridan and Graham counties in Kansas. the control area did not include an eastern portion because the prevailing westerly winds cause a downwind effect of cloud seeding to the east of the target area. There was no southern portion of the control area because extensive cloud seeding operations in northwest Oklahoma and some in northwest Texas, preclude the selection of any control area counties that lie close to the southern portion of the target area. The western portion of the control area was located in Colorado and includes Yuma, Kit Carson, Cheyenne, Kiowa and Prower counties.

1.4 Seasonal Precipitation Data

U.S. Department of Commerce Climatological seasonal precipitation data were used for the months of May-August. These four months were active cloud seeding months for each year of the Weather

FIGURE 1
Target and Control Areas for
Precipitation Enhancement





Modification Program during the 1979-1993 time period. Seasonal precipitation data were obtained for each year from 1941-1970, and from 1979-1993.

There were 28 precipitation stations within the 13 control area counties that were operational during most of the 1941-1970 and 1979-1993 time periods. There were 10 precipitation stations within the 6 target area counties that were operational during most of the 1941-1970 time period and 12 precipitation stations within the 6 target area counties that were operational during most of the 1979-1993 time period. Every county had at least one precipitation station throughout both time periods.

1.5 Analysis of Seasonal Precipitation Data

Step 1: Monthly precipitation data from multiple precipitation stations were averaged for each year by county, so that each county (control and target) had only one precipitation data value per month per year.

Step 2: An average seasonal precipitation value was calculated each year for the control area and for the target area.

Step 3: The control area average seasonal precipitation was calculated for the 1979-1993 time period by adding the 15 annual control area averages, calculated in Step 2, and dividing by 15.

Step 4: The control area average season precipitation for the 1941-1970 time period was calculated by adding the 30 annual control area averages, calculated in Step 2, and dividing by 30.

Step 5: The target area average seasonal precipitation was calculated for the 1941-1970 and the 1979-1993 time periods, as described in Steps 3 and 4 for the control area.

If the (1979-1993 target area average seasonal precipitation) minus the (1941-1970 historical target area average seasonal precipitation) exceeds the similar calculated value for the control area, by a significant amount, then it would appear likely that weather modification activities in the target area have had a positive effect on precipitation enhancement.

If T_1 = the 1979-1993 target area average seasonal precipitation, T_2 = the 1941-1970 historical target area average seasonal precipitation and C_1 and C_2 represent the corresponding control area averages, then the estimated change in the target area average seasonal precipitation due to weather modification activities, is calculated by:

$$Y = (T_1 - T_2) - (C_1 - C_2).$$

1.6 Precipitation Evaluation Results

The results of the analysis of precipitation data are presented in Table 1. It may be seen from Table 1 that the average seasonal precipitation for the target area was slightly less at 11.38 inches for the cloud seeding period from 1979-1993, in comparison to 11.63 inches for the pre-cloud seeding time period of 1941-1970. Hence, there was a decrease in precipitation of 0.25 inches. In contrast, the average seasonal precipitation for the control area was slightly higher at 12.00 inches for the cloud seeding period from 1979-1993, in comparison to 11.54 inches in the pre-cloud seeding time period of 1941-1970. The estimated change in the target area average seasonal precipitation, in inches, due to weather modification activities is determined from Table 1 as (11.38 - 11.63) - (12.00 - 11.54) = (-0.25) - (0.46) = -0.71 inches, which is very small in comparison to the annual variation in average seasonal precipitation, as may be seen from Figures 2 and 3.

Figure 2 shows the average seasonal precipitation by year and study area for the 1941-1970 time period. It is apparent from Figure 2 that the control and target area lines move pretty much in harmony, that is a wet year for the control area corresponds to a wet year for the target area and the same is true for dry years. A further review of the precipitation data shows that the control area average seasonal precipitation was higher than the target area average seasonal precipitation during 15 of the 30 years in the pre-seeding time period. Hence, there was a very close historical relationship in regard to seasonal precipitation for the two study areas.

Figure 3 shows the average seasonal

TABLE 1
AVERAGE SEASONAL PRECIPITATION BY TIME PERIOD AND STUDY AREA
KANSAS 1941-1970, 1979-1993

Study Area	Average Seasonal Precipitation By Time Period (Inches)		Difference (Inches)
	1979-1993	1941-1970	
Target	11.38	11.63	-0.25
Control	12.00	11.54	+0.46

FIGURE 2
Average Seasonal Precipitation by Year and Study Area, 1941-1970

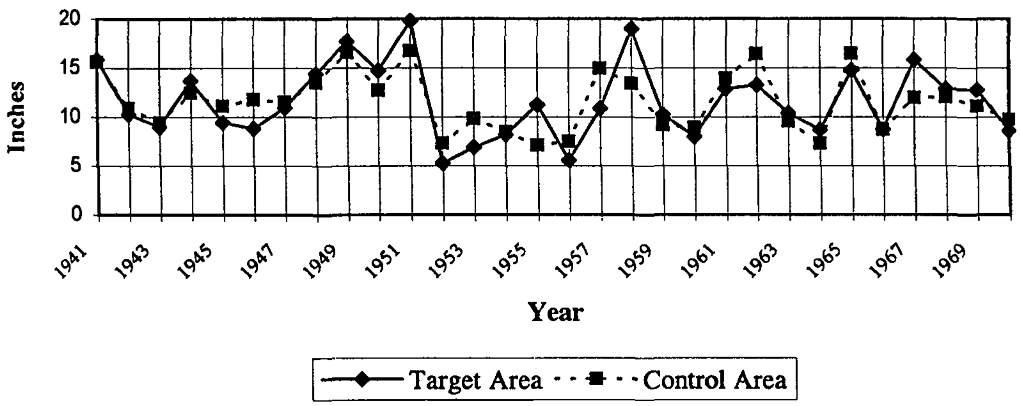
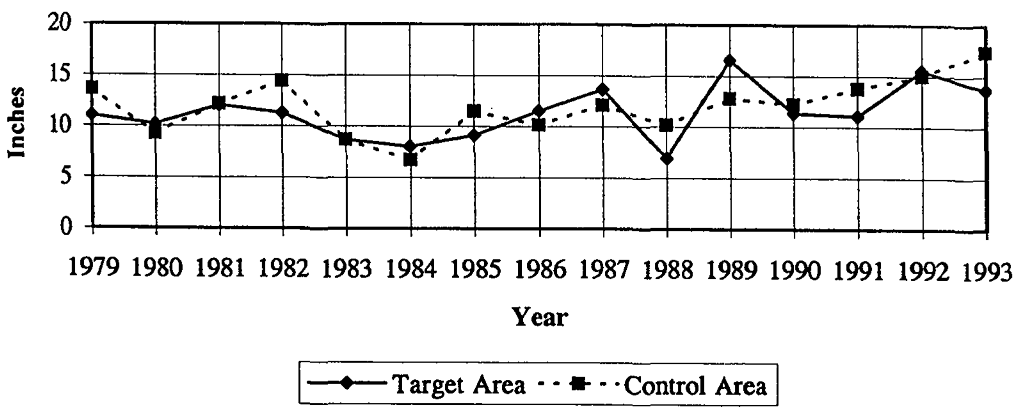


FIGURE 3
Average Seasonal Precipitation by Year and Study Area, 1979-1993



precipitation by year and study area for the 1979-1993 time period. As in Figure 2, it appears that the control and target area lines pretty much move in concert with one another. A closer examination of the precipitation data in Figure 3, shows that the control area average seasonal precipitation was higher than the target area average seasonal precipitation during eight of the 15 years in the cloud seeding time period.

These results provide strong evidence that there has been no change of practical significance in regard to the average seasonal precipitation between the control and target areas, as a result of the cloud seeding operations that have been carried out in Western Kansas.

It should be emphasized that there was tremendous natural variability in precipitation events. Weather stations were very widely scattered in the control and target areas and rainfall enhancement was not the primary focus of the Program during the 1979-1993 time period. Consequently it was not possible to place a high degree of reliability on the methodology used for this evaluation being able to detect any small impact that the Program had on precipitation in the target area.

1.7 Economic Significance

A linear regression analysis was run to determine if there was a statistically significant linear relationship between the average seasonal precipitation and annual crop values in the target area during the 1979-1993 time period. It was found that less than 10 percent of the variability in crop values could be explained by average seasonal precipitation, which was far from being a statistically significant relationship. Hence, it was concluded that the estimated decrease of -0.71 inches in the amount of average seasonal rainfall due to cloud seeding activities was of no practical economic significance. Apparently other factors, such as intensity of rainfall events, soil moisture level, timing of rainfall events with crop moisture needs, seasonal temperatures and crop prices may be much more important factors in determining crop value than simply the average seasonal precipitation.

2. EVALUATION OF THE HAIL SUPPRESSION COMPONENT

2.1 Selection of an Operational Time Period

Crop hail insurance records were analyzed for the time period from 1979-1993, which represents a time period during which annual cloud seeding activities were taking place as a result of the Western Kansas Weather Modification Program and no such activities were occurring in the control area counties, listed below, or in any location that might have an impact on hail suppression in the control counties.

2.2 Selection of a Historical Time Period

A historical time period from 1948-1970 was selected for comparison purposes, which represented a period of time during which no weather modification activities occurred in the vicinity of the control or target areas. The years from 1942-1947 were not included in this evaluation because the U.S. Bureau of Reclamation has indicated that hail loss records have improved considerably just after World War II in terms of both coverage and standardization.

2.3 Study Areas

A target area and a control area were selected as study areas for the hail suppression evaluation. The target area consisted of all counties that have fully participated in the Weather Modification Program each year from 1979-1993. These six counties were: Finney, Ford, Greeley, Haskell, Kearny and Lane.

Figure 4 shows the target area in dark shading and the control area in light shading. No portion of the control area received any cloud seeding activity during either of the two time periods used for this study and it was not likely that any of the control area would have been impacted by any cloud seeding activities occurring outside of the control area or within the target area during either of the two time periods. The control area lies entirely in Kansas and consists of Cheyenne, Rawlins, Decatur, Norton, Sherman, Thomas, Sheridan and Graham counties.

The control area did not include an eastern portion because the prevailing westerly winds cause a downwind effect of cloud seeding to the east of the target area. There was no southern portion of the control area because extensive cloud seeding operations in Northwest Oklahoma and some in Northwest Texas, precluded the selection of any control area counties that lie close to the southern portion of the target area. There was no western portion of the control area since the Kansas Water Office was unable to acquire crop hail insurance data for Colorado counties for each year of each of the two time periods.

2.4 Crop Hail Insurance Data

The National Crop Insurance Services in Overland Park, Kansas, was the source for crop hail insurance data.

Table 2 shows the minimum, average and maximum amount of crop hail liability insurance by study area, county and time period. In general, the amount of crop hail liability insurance sold may vary a considerable amount from year to year and is higher when crops are good.

FIGURE 4
Target and Control Areas for Hail Suppression

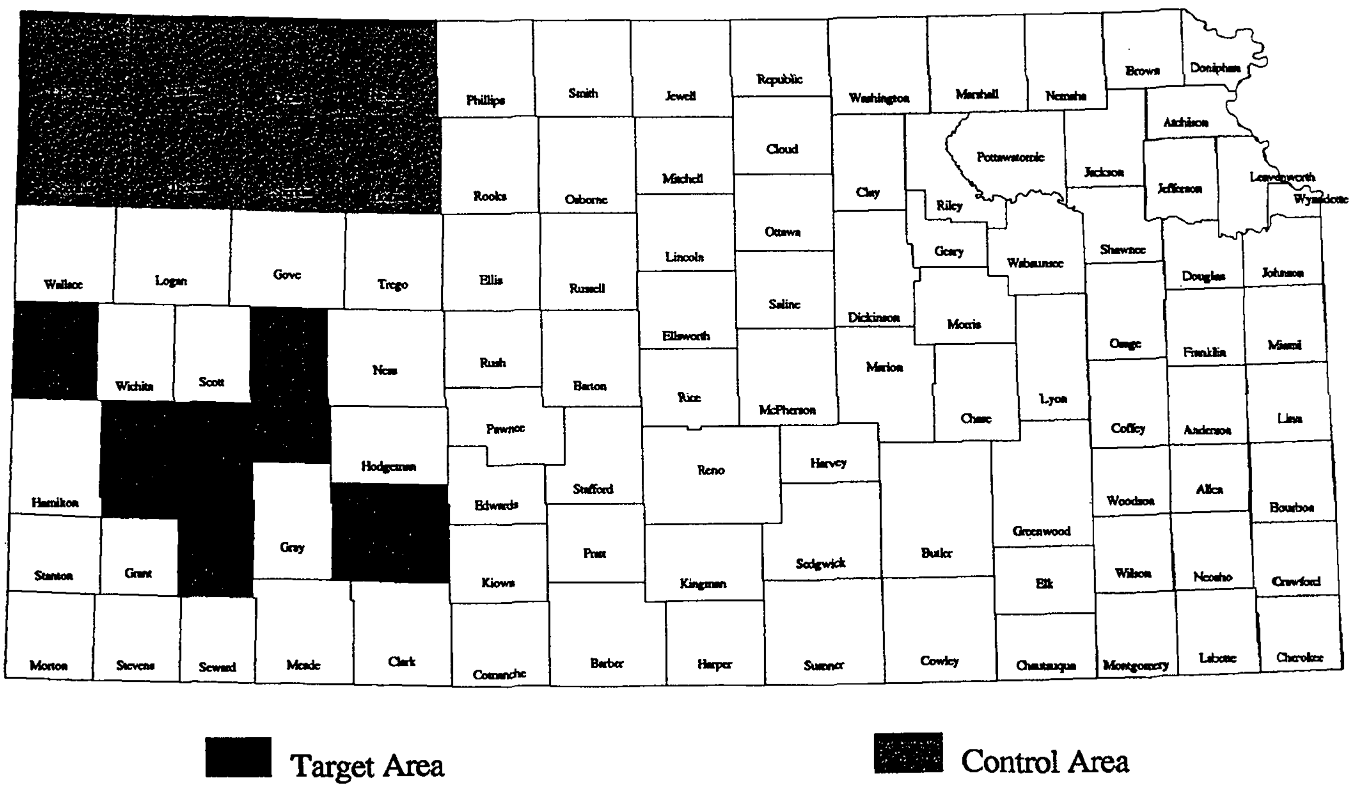


TABLE 2
MINIMUM, AVERAGE, AND MAXIMUM AMOUNT OF CROP HAIL LIABILITY INSURANCE BY STUDY AREA, COUNTY AND TIME PERIOD KANSAS, 1948-1970, 1979-1993

Study Area		Pre-Cloud Seeding Time Period 1948-1970			Cloud Seeding Time Period 1979-1993		
	County	Minimum	Average	Maximum	Minimum	Average	Maximum
Target	Finney	$172,662	$1,055,070	$1,854,398	$4,125,000	$9,122,667	$14,540,000
	Ford	$100,933	$681,244	$1,797,555	$4,861,000	$8,377,000	$17,978,000
	Greeley	$19,683	$420,041	$1,119,563	$235,000	$1,196,600	$2,940,000
	Haskell	$38,540	$819,295	$2,528,289	$11,756,000	$21,182,333	$30,563,000
	Kearny	$153,749	$448,581	$1,076,626	$1,417,000	$4,132,867	$8,371,000
	Lane	$121,085	$557,086	$1,272,967	$1,024,000	$2,289,867	$4,301,000
Control	Cheyenne	$289,645	$731,299	$1,392,399	$957,000	$1,470,067	$1,841,000
	Decatur	$377,220	$708,001	$1,266,614	$1,163,000	$2,671,400	$5,277,000
	Graham	$263,118	$514,736	$866,273	$1,015,000	$2,914,267	$5,233,000
	Norton	$383,533	$671,023	$1,008,131	$1,275,000	$2,574,933	$4,446,000
	Rawlins	$157,737	$578,722	$1,308,117	$684,000	$2,135,400	$3,923,000
	Sheridan	$375,692	$855,930	$1,558,570	$4,980,000	$9,427,933	$18,488,000
	Sherman	$72,185	$763,018	$1,838,125	$757,000	$2,133,533	$5,704,000
	Thomas	$206,325	$771,914	$1,550,113	$5,876,000	$7,317,733	$9,659,000

2.5 Analysis of Hail Suppression Data

The effectiveness of the cloud seeding operations in suppressing hail damage was measured by using a hail-damage loss cost analysis. Loss cost is a ratio found by dividing the insured crop hail-damage loss by the insured crop hail-damage liability and multiplying the result by 100.

Historical records show that hail-damage loss cost percentages decrease from west to east across Kansas. The double ratio analysis, used below, screens out differences between the target and control areas that may be due to regional differences in hail-damage intensity.

The following three equations were used to determine if the Western Kansas Weather

Modification Program has been effective in reducing hail damage in the target area.

$$R_1 = T_1 \div C_1 \text{, where} \quad (1)$$

T_1 = the average hail-damage loss cost ratio for the target area during the time period from 1979-1993, during which cloud seeding occurred in the target area and

C_1 = the average hail-damage loss cost ratio for the control area during the time period from 1979-1993.

$$R_2 = T_2 \div C_2 \text{, where} \quad (2)$$

T_2 = the average hail-damage loss cost ratio for the target area during the 1948-1970 time period, during which no cloud seeding occurred and

C_2 = the average hail-damage loss cost ratio for the control area during the 1948-1970 time period.

$$DR = R_1 \div R_2 \text{, where} \quad (3)$$

ratio R_1 reflects the results of cloud seeding on the target area hail-damage loss cost ratio for the 1979-1993 time period, as compared to no cloud seeding in the control area for the same time period. Ratio R_2 reflects differences in hail-damage loss cost ratios between the target and control area for the 1948-1970 time period, during which no cloud seeding occurred.

The following conclusions may result from this analysis:

1) $DR = 1$ This result would imply that the cloud seeding operations have had no effect on hail damage to crops in the target area.

2) $DR < 1$ This result would imply that the cloud seeding operations may have been effective in reducing crop-hail damage in the target area.

3) $DR > 1$ This result would imply that the cloud seeding operations may have caused an increase in crop-hail damage in the target area.

2.6 Hail Suppression Evaluation Results

The effectiveness of the cloud seeding operation in suppressing hail damage was measured by using a hail-damage loss cost ratio analysis, as described above where the loss cost ratio is defined below:

$$\text{Loss cost ratio} = \frac{\text{insured crop hail-damage loss}}{\text{insured crop hail-damage liability}} \times 100$$

The results of the analysis of crop hail data are presented in Table 3. For the cloud seeding time period of 1979-1993, the ratio $R_1 = (3.77 / 5.55) = 0.68$ is an indication that the magnitude of crop hail damage is less in the target area than in the control area, since the ratio is less than one. However, there was very little difference in the magnitude of crop hail damage between the target and control areas in the pre-seeding time period of 1948-1970, as the ratio $R_2 = (7.57 / 8.11) = 0.93$ is close to 1.00. The double ratio $DR = R_1 / R_2 = 0.68 / 0.93 = 0.73$ leads to the conclusion that the cloud seeding operations appear to have been effective in reducing crop-hail damage in the target area. The estimated percentage of reduction in crop-hail damage is $(1 - 0.73) \times 100 = 27$ percent for the 1979-1993 time period in the six county target area.

The loss cost ratios can also be illustrated graphically to show the differences between the two study areas and time periods. Figure 5 shows the average loss cost ratio by year and study area for 1948-1970, which was the pre-cloud seeding time period. During this 23 year time period, the target area had a higher loss cost ratio than the control area for 12 years or 52 percent of the time.

Figure 6 shows the average loss cost ratio by year and study area for 1979-1993, which was the cloud seeding time period. It appears from this graphical analysis that the cloud seeding has been beneficial for hail suppression, as the target area had a higher loss cost ratio than the control area for only four years or 27 percent of the time. It was also apparent that the annual difference in the loss cost ratios, between the target and control areas was much less during the cloud seeding time period.

TABLE 3
AVERAGE HAIL-DAMAGE LOSS COST RATIO BY TIME PERIOD AND STUDY AREA
KANSAS, 1948-1970, 1979-1993

Study Area	Average Hail-Damage Loss Cost Ratio By Time Period	
	1979-1993	1948-1970
Target	3.77 (T_1)	7.57 (T_2)
Control	5.55 (C_1)	8.11 (C_2)
Ratio	0.68 (R_1)	0.93 (R_2)

FIGURE 5
Average Loss Cost Ratio by Year and Study Area
1948-1970

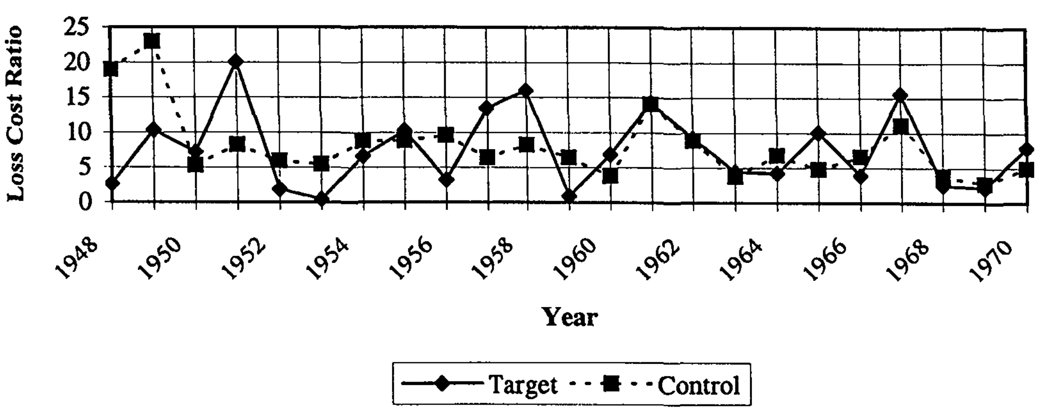
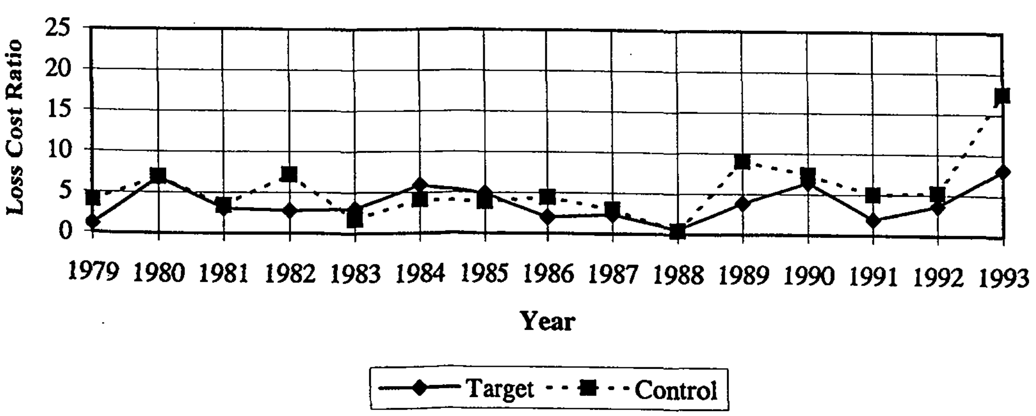


FIGURE 6
Average Loss Cost Ratio by Year and Study Area
1979-1993



2.7 Statistical Tests of Significance

A chi-square test of independence was conducted to test the null hypothesis that for the pre-cloud seeding time period (1948-1970) there was no relationship between the study areas (control and target) and the hail suppression loss cost ratio. The observed values for loss cost ratios for the pre-cloud seeding time period, were classified by size, as shown in Table 4 and represent county-year events. The 322 observations in the table represent the classification of annual loss cost ratios for each of the 14 study area counties and each of the 23 years in the 1948-1970 time period. The chi-square value was computed and found to be 0.16, which was not statistically significant and leads to acceptance of the null hypothesis that there is no relationship between the study areas (control and target) and the hail suppression loss cost ratio during the pre-cloud seeding time period.

A chi-square test of independence was also conducted to test the null hypothesis that for the cloud seeding time period (1979-1993) there was no relationship between the study areas (control and target) and the hail suppression loss cost ratio. The observed values for the cloud seeding time period are shown in Table 5 and represent county-year events. The 210 observations in the table represent the classification of annual loss cost ratios for each of the 14 study area counties and each of the 15 years in the 1979-1993 time period. The chi-square value was computed and found to be 5.38, which was statistically significant ($P<0.05$) and leads to rejection of the null hypothesis. Hence, a statistically significant relationship does exist between the study areas and the loss cost ratios during the cloud seeding time period. This statistical test showed that the Western Kansas Weather Modification Program has been effective in suppressing crop hail damage in the target area.

Table 4
COMPARISON OF LOSS COST RATIO AND STUDY AREAS
PRE-CLOUD SEEDING TIME PERIOD, KANSAS 1948 - 1970

Study Area	Loss Cost Ratio		Row Total
	Less than 10	10 or more	
Target	101	37	138
Control	131	53	184
Column Total	232	90	322

Table 5
COMPARISON OF LOSS COST RATIO AND STUDY AREAS
CLOUD SEEDING TIME PERIOD, KANSAS 1979 - 1993

Study Area	Loss Cost Ratio		Row Total
	Less than 10	10 or More	
Target	84	6	90
Control	99	21	120
Column Total	183	27	210

2.8 Economic Significance

A determination of practical economic significance was calculated below and was based on the results of the double ratio analysis shown above and utilized the crop values published in the Kansas Board of Agriculture's FARM FACTS publication series.

Step 1: A = the total 1979-1993 crop value in the six county target area
= $4,196,675,514

Step 2: B = the estimated total 1979-1993 crop value in the six county target area if no crop-hail damage had occurred.
$= A/(1-T_1/100)$
= ($4,196,675,514)/(1-3.77/100)
= $4,361,088,552

Step 3: C = the estimated total 1979-1993 crop-hail damage in the six county target area.
= B - A
= $4,361,088,552 - $4,196,675,514
= $164,413,038

Step 4: D = the estimated proportion of decrease in crop-hail damage in the six county target area during 1979-1993.
= 1 - DR
= 1 - 0.73 = 0.27

Step 5: E = the estimated total 1979-1993 crop-hail loss in the six county target area if there had been no cloud seeding in the target area.
= C/(1-D)
= ($164,413,038)/(1-0.27)
= $225,223,340

Step 6: F = the estimated total 1979-1993 crop hail loss savings in the six county target area.
= E - C
= $225,223,340 - $164,413,038
= $60,810,302

Step 7: G = the total 1979-1993 funding for the Western Kansas Weather Modification Program
= $3,292,270

Step 8: H = the estimated total 1979-1993 funding for the six county target area portion of the Western Kansas Weather Modification Program.
= (G/average number of participant counties) x 6
= ($3,292,270 / 12.27) x 6
= $1,609,912

Step 9: EV = the estimated total 1979-1993 economic value of the cloud seeding activities to suppress hail for all crops in the six county target area.
= F - H
= $60,810,302 - $1,609,912
= $59,200,390

The estimated economic value of the Hail Suppression Component of the cloud seeding activities for all crops in the six county target area was approximately $60,000,000 for the 1979-1993 time period and represented a benefit to cost ratio of 37 to 1. It should be noted that the above estimate of economic value was an underestimate, since it did not include hail-damage savings for dwellings or personal property. Also, the Kansas Department of Wildlife and Parks did not have any estimate of annual wildlife losses due to hail in the target area. Hence, it was not possible to enumerate the wildlife benefits that have resulted from the cloud seeding activities in the target area from 1979-1993.

3. REFERENCES

Department of Commerce, U.S., National Oceanic and Atmospheric Administration, "Climatological Data," 1941-1970 and 1979-1993.

Kansas Board of Agriculture, Topeka, Kansas "Farm Facts 1979-1993"

National Crop Insurance Services, Overland Park, Kansas "Crop Hail Insurance Data 1948-1970, 1979-1993"