# USING HISTORICAL DATA TO EVALUATE TWO LARGE-AREA OPERATIONAL SEEDING PROJECTS

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Abstract. Two large-area operational seeding projects conducted in the Great Plains were evaluated statistically to determine if any seeding effects could be detected. Historical data were used in the evaluation, and statistiscal tests using permutational procedures were applied to the data in obtaining the significances of estimated seeding effects. The findings indicate a singificanct reduction of hail loss/cost values in the Muddy Road project, and nonsignificant rainfall changes in the Muddy Road project and the other project in northwestern Oklahoma.

## 1. INTRODUCTION

Large-area seeding projects have become common during the past few years (Hsu, 1981) and will continue to be so in the future as a viable means for managing water resources and reducing hail losses. However, evaluation of operational projects extending over 10,000 sq km or more produces complex spatial and temporal control problems relating to climatic homogeneity and temporal variability.

In the present paper, two large-area operational seeding projects conducted in the Great Plains were evaluated statistically to determine if any seeding effects could be detected using rainfall data from the National Weather Service's Cooperative Raingage Network and the hail insurance data furnished by the Crop Hail Insurance Actuarial Association. These projects included an aircraft-seeding program in southwestern Kansas called Muddy Road (hereafter called MR), and an operation using ground-based generators for seeding in northwestern Oklahoma (hereafter called OK). These 2 projects were evaluated as a part of an NSF-sponsored research - project called Operational Seeding Evaluation Techniques (OSET) for testing statistical techniques developed in the project.

## 2. USE OF HISTORICAL DATA

In evaluating the seeding effect of a weather modification operation, the response deemed as caused by the seeding must be compared with other responses not affected by the seeding. For a randomized experiment, these other "responses" are usually those of the "unseeded" units in the target area during the operational period set aside randomly in the project design. However, in a non-randomized operation it is statistically undesirable to make such a similar comparison for two reasons: 1) there might exist natural rainfall excess in favor of the seeded units over unseeded units in the target area (Gabriel, 1979; Hsu el al, 1984); and 2) there might exist a natural rainfall excess in favor of the selected seeded units in the target than those in the neighboring control areas (Hsu el al., 1981b). An approach which accounts for these two "selection biases" has to be used to properly address the evaluation of non-randomized operations (WMAB, 1978; Hsu and Changnon, 1983).

The approach presented in this paper for evaluating non-randomized seeding operations uses a relatively long sampling unit as well as historical climatic data. A sampling unit as long as a month or a season lumps together the responses of both seed and unseed occasions. Use of such long units eliminates the first kind of bias and still allows for the detection of seeding effect, although their use might render the statistical test conservative (i.e., less powerful in detecting a seeding effect). Use of historical climatic data provides a partial answer to the second kind of bias by adjusting target values with control values. It is this issue of adjusting target values using historical data that our research has been focused on.

The use of a long sampling unit and historical climatic data therefore provides a solution for reducing potential biases in evaluating non-randomized projects. A critical question concerning such an approach is the temporal stationarity, i.e., whether the historical (unseed) target-control relationship holds in the seed periods had no seeding been done (Brownlee, 1967). Recent simulation studies (Hsu et al., 1981; Gabriel and Petrondas, 1983) have shown that in the worst possible scenario the significance values of the statistical tests using regression were twice as much as what would be expected. Thus, use of historical comparison would be appropriate if the critical value of the test is selected to correspond to half of the nominal significance level.

## 3. MUDDY ROAD AIRCRAFT SEEDING PROJECT

The Muddy Road project was conducted in southwestern Kansas and encompassed a target area varying between 12 to 15 counties over the years studied (Fig. 1). The project was intended for both rainfall enhancement and hail suppression in the warm season of April to September. It began in 1975 and continues to the present. A description of the project and a summary of the seeding operations can be found in a report by Kostecki (1978). The 1975-1979 operations were selected for evaluation in the present study.

Two sets of data were employed in the evaluation: (1) monthly and seasonal rainfalls, with data from 1931-1971 used as historical controls, and (2) annual hail insurance loss-cost ratios (L/C), defined as 100 x hail damage / insurance liability, with data from 1948-1971 used as historical controls. The (historical) years of 1972-1974 were not included in the study mainly to avoid the possibility of contamination due to other cloud seeding activities carried out to the south of the MR target areas during this period.

To discern possible geographical differences in seeding effects, the target was divided into a west (W) and an east (E) sub-targets. Controls having sizes similar to the 2 sub-targets were selected from the neighboring counties and grouped into near-upwind (N-U), mid-upwind (M-U), far-upwind (F-U), and downwind (D) controls (Fig. 1). The N-U control consisted of areas 1, 2, 3, 4, 5, 6, and 7; the M-U control consisted of areas 8, 9, 10, 11, and 12; the F-U control consisted of areas 13, 14, 15, and 16; and the D control consists of areas 17, 18 and 19.

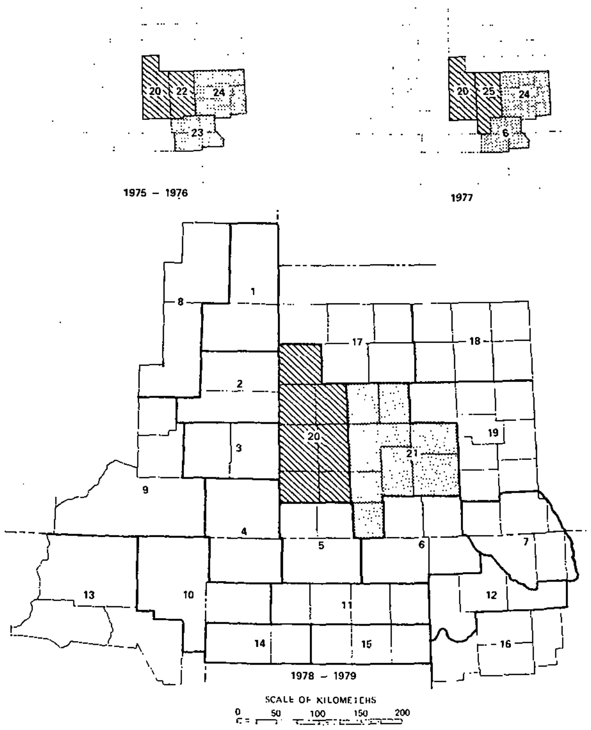


*Figure 1. Muddy Road Project Area.*

### 3.1 Evaluation of the Hail Suppression

Ratios of seeded average L/C (1975-1979) to historical average L/C (1948-1971) show that the ratios in the target were all less than 1.0 except two small areas in the northwestern and southeastern corners, where they were between 1.0 and 2.0 (Fig. 2). Portions of the south and west controls also had ratios less than 0.5. A large portion of the target ratios were less than 0.5, part of which was significant at the .10 level using a 2-sample Wilcoxon test. Some control ratios were also significant at the 0.10 level.

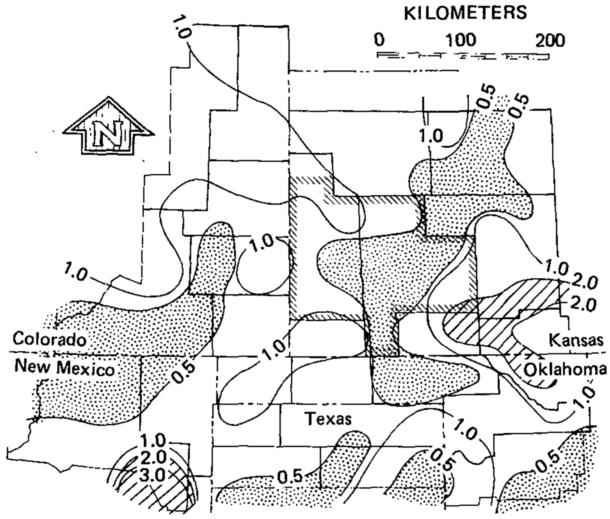


*Figure 2. Ratio of Hail LOST-COST, 1975-1979 Average to 1948-1971 Average, MR.*

Fig. 3 shows a plot of ratios of the west sub-target L/C to the N-U L/C. No noticeable trend existed. Most ratios were larger than 1.0. The ratio in 1954 was considerably more than the others, and thus might render the mean 1948-1971 ratio (shown in the plot as the dashed line) unrealistically high. However, four out of five seed years experienced ratios well below the historical mean and were very close to the minimum. Thus, the reduction appeared to be real. Similar

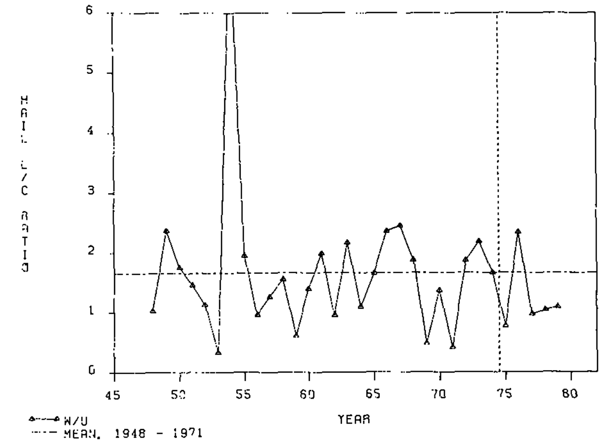


*Figure 3. Ratio of Hail LOST-COST, West Target to Upwind Control Average, MR.*

plot for the east sub-target (E/U) is shown in Fig. 4. No trend was indicated. The 1954 ratio was also high. Four out of 5 ratios were below historical mean, though only 3 appeared to be real.

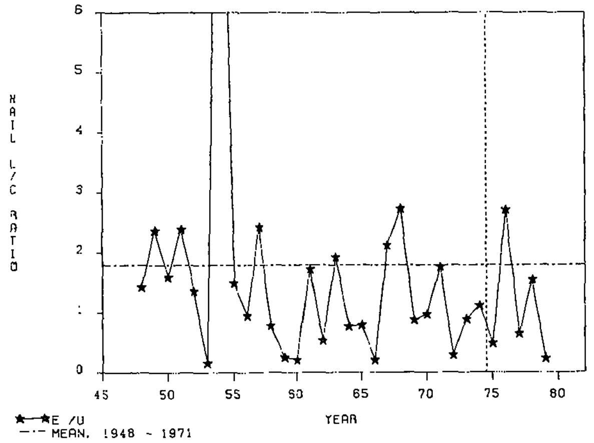


*Figure 4. Ratio of Hail LOST-COST, East Target to Upwind Control Average, MR.*

The correlation coefficients between the sub-targets and controls varied from 0.0 to 0.7 according to the distances (Hsu and Chen, 1981). The techniques of multiple regression (MREG) and principal component regression (PCR[3]), as described in Hsu et al (1981), were applied to the L/C data. The mean differences between the estimated and observed seeded values, and their permutational significances (Gabriel and Hsu, 1983) are shown in Table 1 for the east and west sub-targets compared with N-U controls, N-U and M-U controls, and All controls.

Table 1. Mean Difference and 1-Sided Permutational Significance Level, Muddy Road Project, Hail Loss-Cost

| Target | Control | MREG | PCR |
|---|---|---|---|
| West | N-U | -1.09 (.33) | -1.70 (.23) |
| | N-U & M-U | -1.94 (.30) | -1.76 (.26) |
| | All | -1.16 (.41) | -0.75 (.39) |
| East | N-U | -3.79 (.14) | -4.39 (.06) |
| | N-U & M-U | -6.09 (.09) | -3.98 (.09) |
| | All | -4.97 (.16) | -2.62 (.16) |

All the estimated mean differences were negative. The decrease in the east sub-target was more significant than the west sub-target in all comparisons, and we have no explanation for this. When the D controls were excluded in the evaluation, the estimated decreases were more pronounced and were more significant, an indicattion that there might have existed a downwind seeding effect. Generally, the results by PCR[3] were more significant than MREG, as expected in the previous simulation studies (Hsu et al, 1984); though MREG showed larger decrease of L/C values in the cases of N-U and M-U controls and All controls.

## 3.2 Evaluation of the Rainfall Enhancement

Seasonal rainfall was computed as the mean of May-August monthly rains. Ratios of average seed seasonal rains (1975-1979) to average historical seasonal rains (1931-1971) show that most of the ratios in the target area were above 1.0 (Fig.5). The ratios in the eastern part of the target were higher than those in the western part. Outside of the target area, most rain ratios were not much different from 1.0 except one area in northern Oklahoma and one area in eastern Colorado where the ratios were larger than the target's.

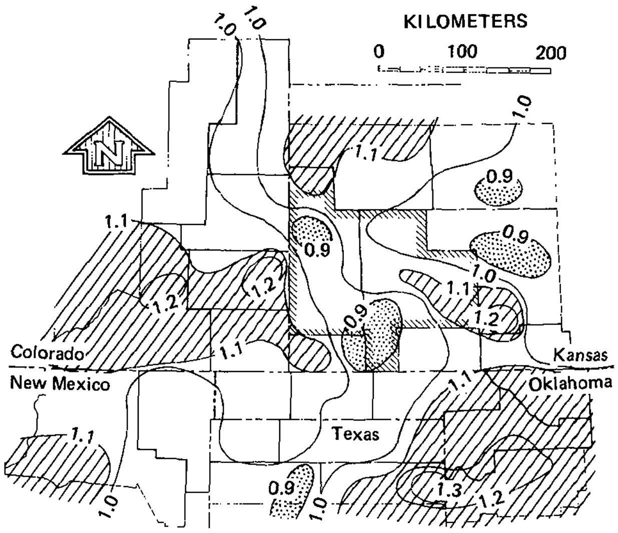


*Figure 5. Ratio of Seasonal Rain, 1975-1979 Average to 1931-1971 Average, MR.*

Fig. 6 shows a plot of ratios of W vs N-U seasonal rains. No noticeable trend existed. Most ratios were close to 1.0. The 1931-1971 mean (shown in the plot as the dashed line) was very close to 1.0. Three out of 5 seed years had ratios slightly above the historical mean; while one ratio (1979) was very close to the minimum. A similar plot for the east sub-target is shown in Fig. 7. No trend was indicated. The variability in this plot was noticeably larger than that in

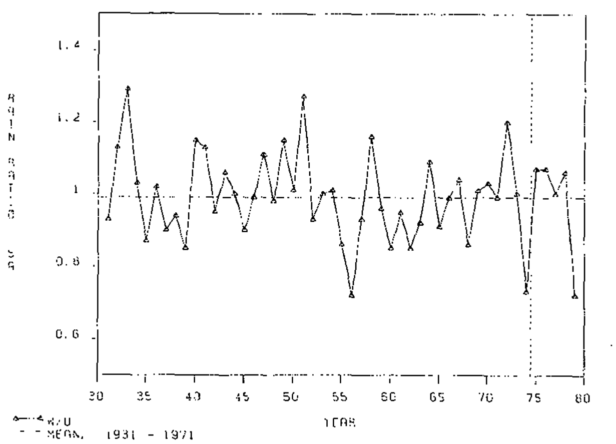

*Figure 6. Ratio of Seasonal Rain, West Target to Upwind Control Average, MR.*

Fig. 6. Two years (1949 and 1971) had high ratios, and thus rendered the historical mean larger than 1.0. Only 2 (1975 and 1977) out of 5 ratios in seeded years were above the historical mean, and one (1976) was very close to the minimum.

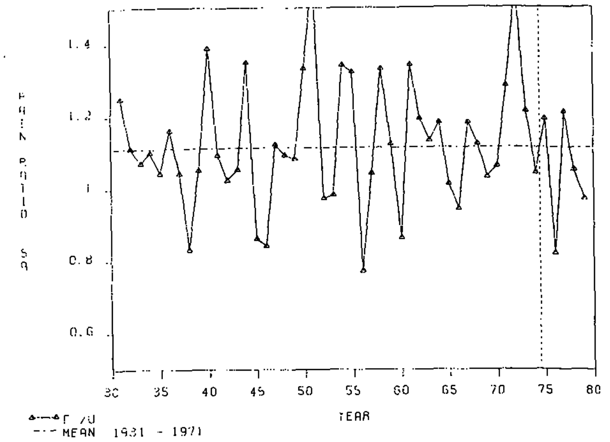


*Figure 7. Ratio of Seasonal Rain, East Target to Upwind Control Average, MR.*

The correlation coefficients between the the sub-targets and the controls seasonal rainfalls were in the range of 0.5 to 0.9 (Hsu and Chen, 1981), higher than those of the annual L/C values. The techniques of MREG and PCR[3] were applied to the seasonal and monthly rains for evaluation. The mean differences between the estimated and observed seasonal seeded rainfalls, and their permutational significances are shown in Table 2. All the estimated mean differences were negative and not statistically significant. The decrease of seasonal rainfall in the W vs N-U & M-U comparison, -0.25 cm, amounted to 4% of the 1931-1971 mean (6.45 cm); while that in the E vs N-U & M-U comparison, -0.20 cm, amounted to 3% of the historical mean (6.45 cm). Obviously, nothing was significant.

Table 2. Mean Difference and 1-Sided Permutational Significance Level, Muddy Road Project, May-August Average Rainfall (in cm).

| Target | Control | MREG | | PCR[3] | |
|---|---|---|---|---|---|
| West | N-U | -.36 | (.79) | -.28 | (.76) |
| | N-U & M-U | -.25 | (.68) | -.36 | (.79) |
| | All | -.71 | (.88) | -.31 | (.73) |
| East | N-U | -.46 | (.76) | -.53 | (.85) |
| | N-U & M-U | -.20 | (.61) | -.61 | (.84) |
| | All | -.23 | (.82) | -.61 | (.88) |

Results of the target-control comparisons for the monthly rainfall show that most estimated rain changes were statistically non-significant except for 3 cases: April in the east sub-target (rain increase), April in the west sub-target (rain decrease), and May in the east sub-target (rain decrease). In general, the technique of PCR indicated more increases or fewer decreases than the MREG. Overall, the results in the east sub-target were more favorable than the west sub-target in April, June, July and August.

Table 3. Mean Differences and One-Sided Permutational Significance Level, Muddy Road Project, Monthly Rainfall (in cm).

| | West Sub-Target vs | | | East Sub-Target vs | | |
|---|---|---|---|---|---|---|
| Month | N-U | N-U&M-U | All* | N-U | N-U&M-U | All |
| **Principal Component Regression** | | | | | | |
| April | -.86 | -.28 | -.08 | 1.60 | 2.11 | 2.13 |
| | (.87) | (.59) | (.47) | (.00) | (.00) | (.00) |
| May | .05 | .58 | .58 | -1.91 | -1.27 | -1.22 |
| | (.50) | (.25) | (.25) | (.97) | (.86) | (.82) |
| June | .23 | .25 | .15 | .33 | .36 | .03 |
| | (.40) | (.42) | (.47) | (.35) | (.34) | (.49) |
| July | -1.22 | -.91 | -.84 | -.58 | -.25 | -.08 |
| | (.92) | (.89) | (.87) | (.69) | (.57) | (.50) |
| Aug | .08 | -.15 | -.41 | .76 | .41 | -.10 |
| | (.44) | (.55) | (.67) | (.30) | (.32) | (.50) |
| Sept | -.48 | -.46 | -.38 | -.68 | -.53 | -.33 |
| | (.73) | (.69) | (.67) | (.74) | (.67) | (.61) |
| **Multiple Regression** | | | | | | |
| April | -1.37 | -1.65 | -2.03 | 1.47 | .69 | .18 |
| | (.95) | (.94) | (.96) | (.02) | (.16) | (.36) |
| May | -.08 | .05 | -.20 | -1.93 | -2.77 | 2.11 |
| | (.54) | (.49) | (.58) | (.96) | (1.00) | (.97) |
| June | -.25 | -.76 | -1.02 | .48 | -.08 | -.18 |
| | (.60) | (.76) | (.84) | (.32) | (.55) | (.63) |
| July | -.71 | -.18 | .08 | -.38 | -.18 | .28 |
| | (.82) | (.61) | (.47) | (.61) | (.57) | (.41) |
| Aug | .18 | .23 | .81 | .81 | .33 | .56 |
| | (.39) | (.35) | (.16) | (.31) | (.32) | (.21) |
| Sept | -.48 | -.33 | -1.09 | -.48 | -.61 | -1.19 |
| | (.72) | (.67) | (.93) | (.70) | (.71) | (.94) |

* "N-U", "M-U" denote respectively near- and mid-upwind controls, "All" denotes all controls.

## 4. OKLAHOMA PROJECT

The Oklahoma program encompassed a target area of 3 counties - Harper, Woodward, and Ellis (Fig. 8). It was carried out to increase the growing season (May-September) precipitation in 1972-1976. Monthly and seasonal rainfalls from 1935-1971 were used as historical controls. Rainfall data from Kansas, Oklahoma, and Texas were

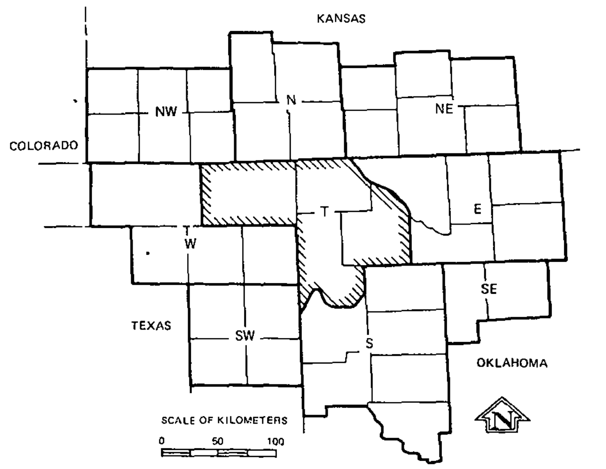


*Figure 8. Oklahoma Project Area.*

used to form 8 areal controls with size similar to the target's (Fig. 8). The climatic monthly rainfall normals in the area indicate that there existed relatively strong precipitation gradients in May and June, with a general east-to-west decrease; and much weaker gradients in July and August (Hsu et al., 1984).

Ratios of 1972-1976 seasonal rainfalls to historical seasonal rainfalls show that most of the study area received less rain during the seeding period than the historical period (Fig. 9). The differences among ratios were small, however. There was a general NW-SE gradient of rainfall ratios. The region of minimum ratios (<0.9) ran from southwest to northeast, and interestingly had a peak in the target area. The eastern portion of the target had higher rainfall ratios than the western portion. The highest ratios in the entire study area occurred in Kansas, north of the target area.

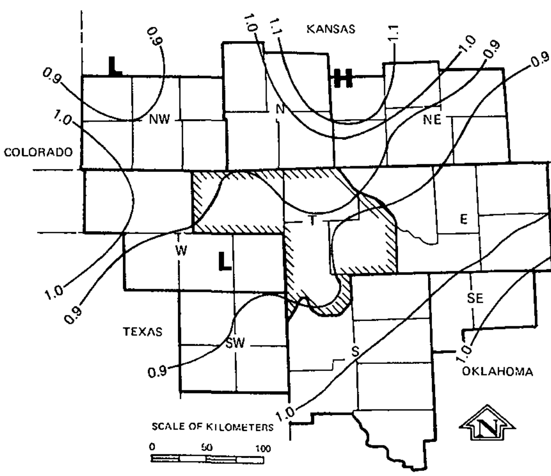


*Figure 9. Ratio of Seasonal Rain, 1972-1976 Average to 1935-1971 Average, OK.*

The techniques of multiple regression (MREG) and principal component regressions with 1 (PCR[1]) or 3 components (PCR[3]) were applied to the seasonal and monthly rains using the 8 areal controls (Fig. 8) and the 1935-1971 historical controls. The mean differences between the estimated and observed seeded values, and their permutational significances are shown in Table 4.

All the estimated mean differences were not statistically significant. There was a minor seasonal rainfall deficiency in the target greater than what would be expected. For the monthly rainfalls, most estimated rain differences were small and statistically non-significant. The biggest target rainfall excess, 0.66 cm, occurred in August when using All controls and PCR[1]. The largest rainfall decrease, all greater than 1 cm, occurred in June. Generally, the technique of PCR[1] indicated more increases or fewer decreases of target rainfalls than did MREG in June and August, but the opposite in May and July.

## 5. CONCLUSION

The evaluation of the hail suppression of the Muddy Road project indicated that there was a general reduction of annual hail loss-cost values

Table 4. Mean Difference and 1-Sided P-value, Oklahoma Ground Seeding Project, Monthly Rainfall (in cm).

| Month | MREG | PCR[1] | PCR[3] |
|---|---|---|---|
| | | All Controls | |
| May | -.10 | -.18 | -.30 |
| | (.54) | (.56) | (.63) |
| June | -1.78 | -1.30 | -1.42 |
| | (.96) | (.91) | (.92) |
| July | .08 | -.30 | -.15 |
| | (.50) | (.68) | (.61) |
| August | .25 | .66 | .36 |
| | (.50) | (.24) | (.38) |
| September | -.64 | -.66 | -.79 |
| | (.78) | (.80) | (.88) |
| Seasonal Average | .03 | -.25 | -.25 |
| | (.47) | (.71) | (.71) |
| | | West Controls Only | |
| May | .20 | .00 | .03 |
| | (.39) | (.48) | (.42) |
| June | -1.37 | -1.27 | -1.50 |
| | (.87) | (.84) | (.87) |
| July | .53 | .03 | .25 |
| | (.27) | (.51) | (.37) |
| August | .23 | .36 | .25 |
| | (.47) | (.38) | (.46) |
| September | .00 | .05 | -.36 |
| | (.49) | (.44) | (.62) |
| Seasonal Average | -.13 | -.18 | -.13 |
| | (.56) | (.60) | (.54) |

in the target area during the 1975-1979 seeding period. When compared with the historical data and the neighboring areas, the 39% decrease of hail loss/cost values in the eastern portion of the target area was statistically significant at 6%; however, the decrease of L/C values in the western portion was not significant. The evaluation of the rainfall in the Muddy Road project using historical data and target-control comparison indicated that, overall, there was a non-significant rainfall decrease in the target area. Rain excesses occurred largely in the east subtarget in April (significant), June and August.

The evaluation of the 1972-76 ground-based project in northwestern Oklahoma indicated that there was a non-significant 5% decrease of seasonal rain in the target area. Non-significant rain excesses in the target area occurred largely in August, and major rain decreases in June.

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