Illinois State Water Survey
at the
University of Illinois
Urbana, Illinois

"A Study of Crop-Hail Insurance Records for Northeastern Colorado with Respect to the Design of the National Hail Experiment"

by

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and

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FINAL REPORT TO
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INTRODUCTION

In the early planning stages of the National Hail Research Experiment (NHRE), a decision was made by NCAR officials that project seeding operations would involve the daily unit in a single target area. The Illinois State Water Survey which has made extensive studies of hail climatology and the design aspects for hail suppression experiments in Illinois (Changnon, 1969; Changnon and Schickedanz, 1969; Schickedanz and Changnon, 1970) proposed a study of the various aspects of the random daily design with the use of crop-hail insurance records from Colorado. The period of the study was from June 1, 1970 to December 1, 1970. Other possibilities, such as crossover, target-control, and paired or individual storm designs were not included in the proposed research because the choice of seeding on a random daily basis in a single target area had already been made.

Thus, the specific purpose of the proposal was the evaluation of selected statistical tests and experimental designs related to the daily experimental unit in a single area through use of historical crop-hail loss data. This purpose was originally intended to be accomplished by evaluating the sampling requirements for three basic experimental designs utilizing the daily experimental unit and crop insurance data for crop-damage seasons. These designs included: 1) random-experimental, in which days are randomized over a single target area into seeded and non-seeded days with the non-seeded days being the control; 2) random-historical, in which a random choice is made of days to be seeded over a single target area with the historical record being the control; and 3) continuous-historical in which all the hail days over a single target area are seeded with the historical record being the control. The statistical analyses were to involve both the non-classical (sequential) and classical (non-sequential) analyses. The resulting sample sizes were to be computed for both the 1- and 2-sample tests.

In the course of this study, it was decided to also include other information that would be helpful for operational planning purposes plus additional statistical analyses in respect to variations in the designs and tests unaer study. The additional information involving descriptive climatology of hail days from U. S. Weather Bureau records and that of radar echoes are included in Appendix A. Additional statistical tests, namely the optimal C(a) tests as recommended by Neyman and Scott (1967b), are included in the main body of this report.

In an effort to increase the precision and power of detecting an effect from the hail suppression experiment, a search was made for independent meteorological predictor variables that might be incorporated into the single area design. These predictor variables were derived from the radiosonde soundings at Denver, and a description of their use in tests of hypotheses are included in this report. Additional information and results concerning the use of these predictor variables for the study area chosen for the National Hail Suppression Experiment will be included in Appendix C which is not completed and will not be attached to this report. Thus, in addition to the original objectives of the proposed study other useful and pertinent information for NHRE have been prepared.

BASIC DATA

1. Source of Data

Location of the three counties supplying basic data for the various studies in this report are shown in Fig. 1. The proposed target area for the NHRE is also shown in the figure and labeled as the "study area." The county areas were chosen as the basic unit for the insurance studies because the crop-hail insurance data were only available on a county basis. Logan county consisted of 1827 mi^2, Morgan county consisted of 1282 mi^2, and Weld county consisted of 4004 mi^2. An area incorporating the three counties combined is used often in this report and is designated as the Tri-county area. The Tri-county area consisted of 7113 mi^2, and was used along with the other three areas to provide information concerning the effect of areal size upon sampling requirements for the proposed hail suppression experiment. In many of the analyses it was important to know the number of square miles of crop land in each county. These values were obtained from the U. S. Bureau of Budget (1964), and the crop land area was 364 mi^2 for Logan county, 274 mi^2 for Morgan county, 880 mi^2 for Weld county, and it was 1518 mi^2 for the Tri-county area.

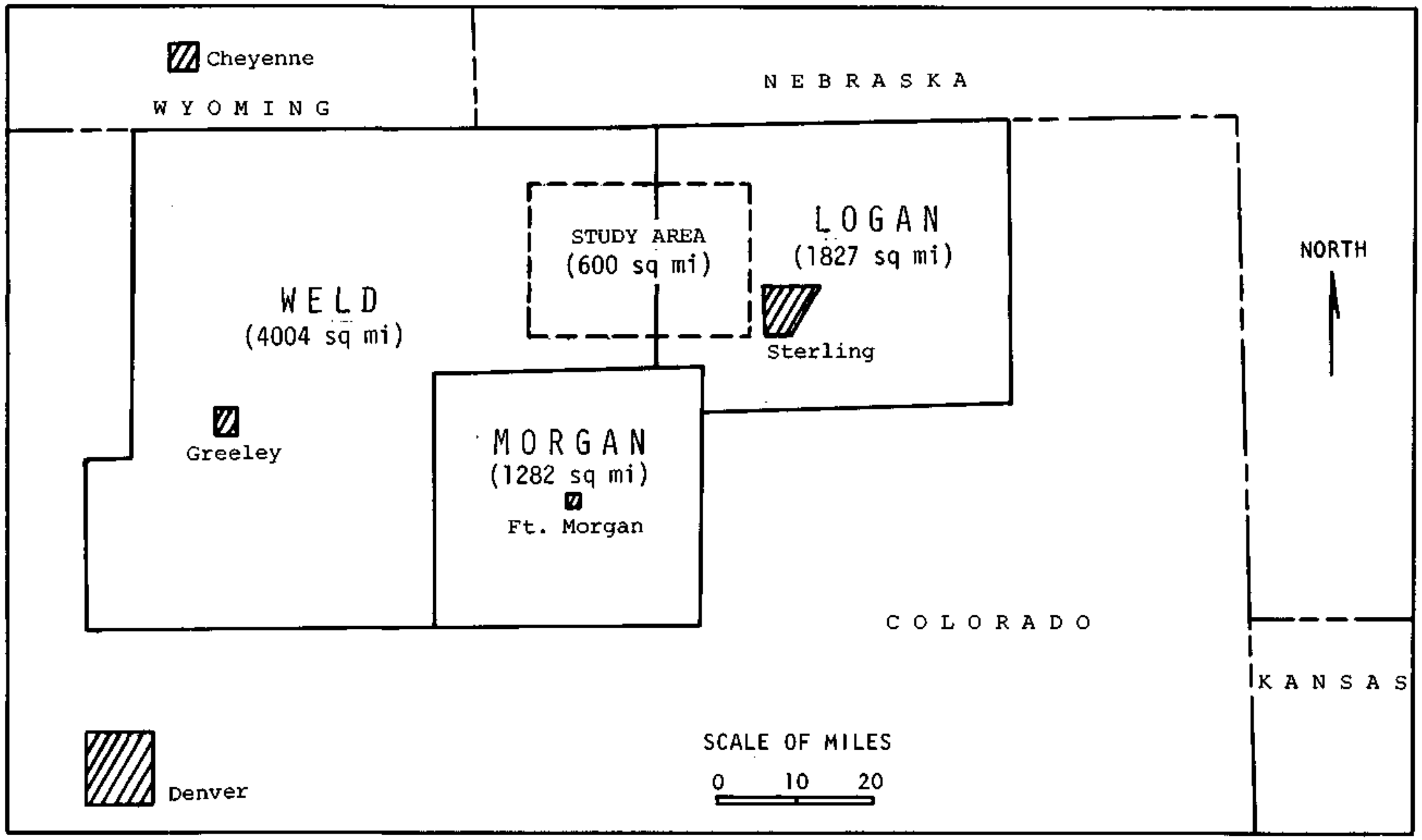

Figure 1. Location of the study area and the counties used in the study of the crop-hail insurance records

The basic insurance data used in this report were supplied at no cost by the Crop-Hail Actuarial Insurance Association. Data from the association of insurance companies were used to develop the areal pattern of total township insurance liability for the 1931-1962 period in the Tri-county area (Fig. 2). The figure shows that the southeastern half of the proposed study area had more than $25,000 (cumulative) liability per township, while the extreme northwestern area has liability that totaled less than $5,000 per township. Among the individual counties, Logan county appears to have had the greatest areal coverage of liability with cumulative amounts greater than $25,000 for most of its area. Morgan and Weld counties have approximately half of their areas with more than $25,000 (cumulative) liability per township. The scarcity of liability in the northwestern part of the study area illustrates the need of a relationship between the hailfall parameters (energy, volume of ice and momentum) from detection devices and the crop-insurance damage in order to utilize the crop-insurance data to its fullest in the research area and to estimate crop. losses with these devices during the experiment.

The daily insurance records were available for the period May-October, 1957-1969. The total county liability (yearly) for the four areas is listed in Table 1. Logan county has the greatest amount of liability per square mile, and Fig. 2 indicates that it also has the best areal coverage of the 4 analytical areas. Logan county also contains half of the study area and thus results from Logan county should be more representative of the study area than the other counties. However, Logan county is three times larger than the study area.

There is a tendency for the yearly amounts of county liability to be less during the mid-sixties than during any other time in the 13-year period. Table 1 and Fig. 3 imply that some of the years with high losses near the ends of the 13-year period are partially explained by the greater amounts of liability at those times. The reasons for the fluctuations involve crop successes and variations in hail losses. That is, there is a tendency to decrease liability after periods of good yields and low hail losses and a strong tendency to increase liability after years of heavy losses.

Included in Fig. 3 is a plot of the dollar loss. This graph implies that as the number of damaging hail days increases, the amount of damage also

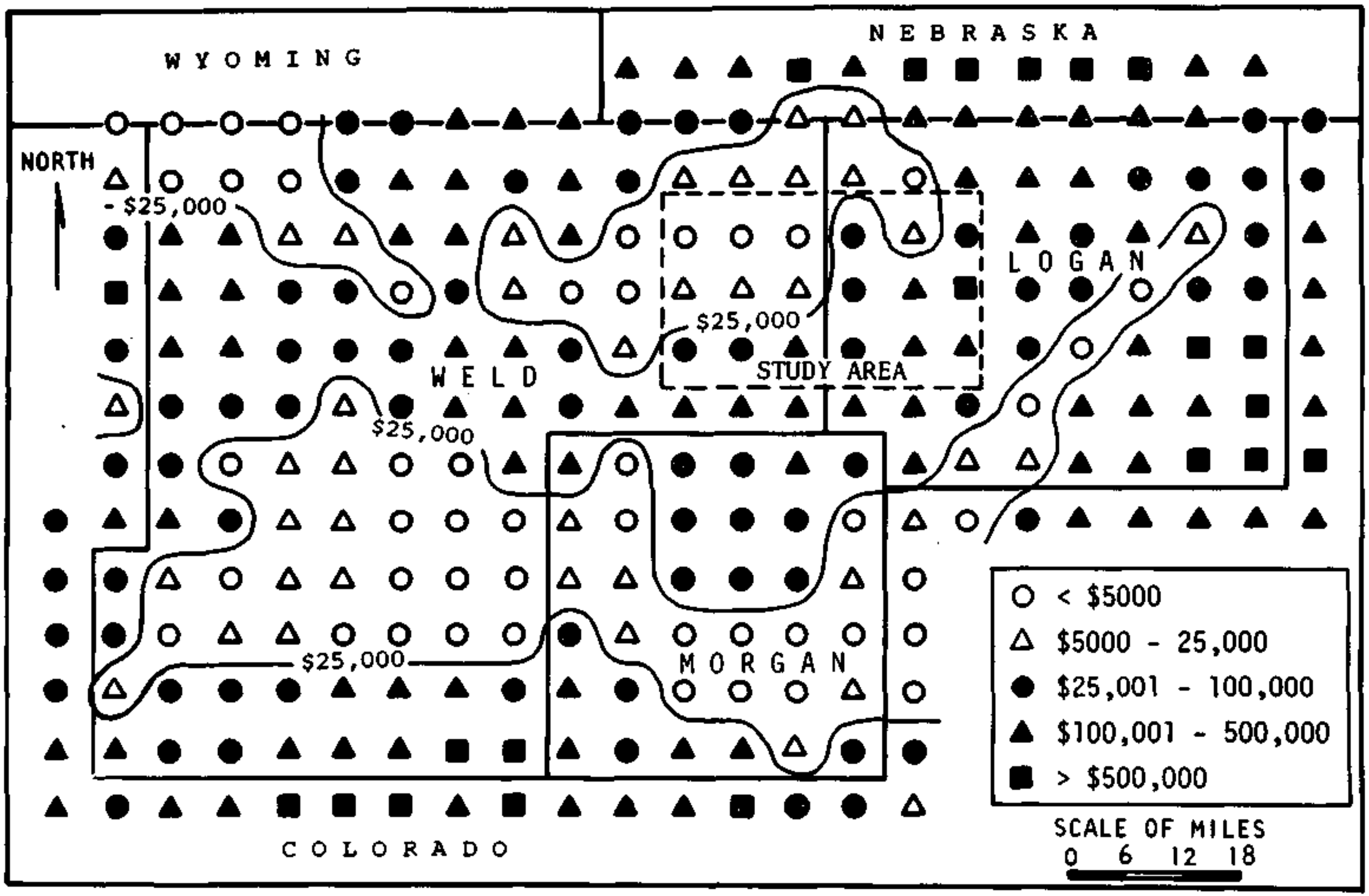

Figure 2. Pattern of total township liability (1931-62) in Weld, Morgan, and Logan counties and environs in Colorado. Township value plotted in center of township (6x6 miles)

Table 1. Total county liability for each year of the basic data period and the average liability per square mile.

Year	Logan	Morgan	Weld	Tri-county
1957	680,000	86,000	819,000	1,585,000
1958	754,000	162,000	1,199,000	2,115,000
1959	582,000	303,000	1,016,000	1,901,000
1960	515,000	98,000	612,000	1,225,000
1961	512,000	166,000	774,000	1,452,000
1962	239,000	186,000	761,000	1,186,000
1963	164,000	102,000	150,000	416,000
1964	162,000	66,000	169,000	397,000
1965	156,000	174,000	395,000	725,000
1966	379,000	228,000	291,000	898,000
1967	740,000	561,000	1,012,000	2,313,000
1968	582,423	213,207	935,393	1,731,023
1969	582,423	213,207	935,393	1,731,023
Ave Per Crop Land mi^2	16,615	9,337	10,305	11,643
Ave Per County mi^2	3,310	1,996	2,265	2,485
Ave Per Crop Land mi^2 (Yearly)	1,278	718	793	896
Ave Per County mi^2 (Yearly)	255	154	174	191

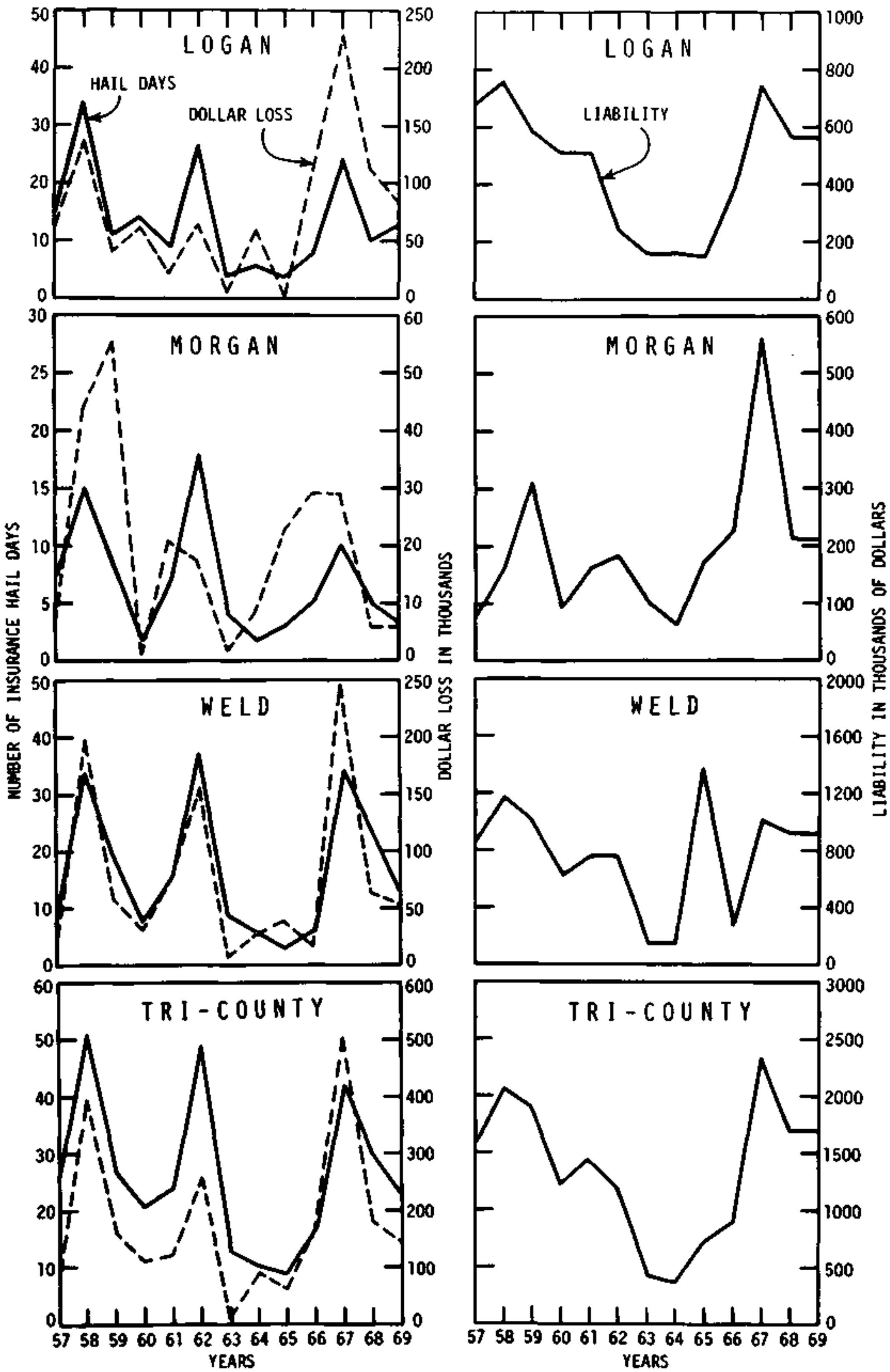

Figure 3. Yearly amounts of hail days, dollar loss, and liability for the four areas

increases. This gives some credibility to the hypothesis that if damage is decreased by seeding, there should also be a corresponding decrease in the number of hail days. Thus, in the statistical analysis, considerable attention was given to sample sizes obtained under conditions in which it was hypothesized that 1) the probability of hail on a given day was effected by seeding, and 2) the amount of damage on a given day was altered.

The basic data in this project were the detailed county records based on paid crop-hail insurance claims recorded on a daily basis for the May-October periods of 1957-1969. The daily data available per county included the actual dollar amount (dollar loss) paid (on a given day of hail damage), the number of acres damaged, the number of claims for which payment was made, and the amount of insurance liability in force for the areas which received damage.

The average maximum and minimum monthly and seasonal numbers of loss for each area are shown in Table 2. The number of loss days tend to increase as the size of the area increases. The fact that the smallest area has a minimum value of 2 hail days indicates that the study area (a smaller area) may have some years when there are no hail damage days. The maximum of hail damage days concentrated in June and July agree well with the peak hail activity period as revealed from U. S. Weather Bureau hail day records (Appendix A).

The average and extreme seasonal values of dollar loss and acre loss for all four areas are listed in Table 3. Inspection of loss reveals that the values of loss in Logan and Weld counties are nearly the same, while those in Morgan county are much smaller and those in the Tri-county area are much higher. Thus the areal trend in the loss data is somewhat masked by the loss values in Morgan and Weld counties. The reversal (average per loss day and acreage data) is most likely attributed to the fact that Logan county has more liability per square mile than the other areas (Table 1), although it is not the largest area. Thus when the areas are not greatly different in areal size, the greater amount of liability outweighs the tendency for the larger area to have more hail storms within its boundaries.

Table 2. Average and extreme number of days of hail per month.

	Morgan	Logan	Weld	Tri-County
May				
Average		1 2	2	4
Maximum	5	7	5	9
Minimum	0	0	0	0
June				
Average	3	6	6	10
Maximum	9	18	19	22
Minimum	0	1	1	3
July				
Average	2	5	7	10
Maximum	8	16	21	24
Minimum	0	0	1	3
August				
Average	<1	<1	2	2
Maximum	2	2	9	10
Minimum	0	0	0	0
Total May-August				
Average	7	14	17	26
Maximum	18	34	37	51
Minimum	2	4	3	9

Table 3. Seasonal (May-September) and daily loss values.

	Morgan	Logan	Weld	Tri-County
Dollars				
Seasonal Average	18,691	76,388	79,954	173,915
Seasonal Maximum	56,617	227,822	248,100	505,164
Seasonal Minimum	808	724	9,011	15,081
Average Per Loss Day	2,701	5,610	4,812	6,712
Maximum Per Loss Day	36,215	111,234	62,951	150,222
Minimum Per Loss Day	24	8	7	7
Acres				
Seasonal Average	2,406	12,656	11,627	26,690
Seasonal Maximum	10,148	30,931	41,911	79,299
Seasonal Minimum	101	656	1,075	1,992
Average Per Loss Day	347	9 30	700	1,023
Maximum Per Loss Day	5,514	14,701	6,760	18,675
Minimum Per Loss Day	13	12	8	8

2. Adjustment Indices

Although hail insurance data are a realistic practical measure for the evaluation of hail suppression activities, direct comparison of the loss in one month with that of another, or the comparison of the data in one year with that of another, cannot be accomplished without certain adjustments to the data. These problems of change during a crop season and between years involve these factors:

1) A given crop's susceptibility to hail damage fluctuates considerably during the crop season.
2) The amount of liability changes from year to year.
3) The value of the dollar changes from year to year.

In order to make valid areal comparisons of the dollar and acreage values of different areas, another adjustment is required to allow for the fact that the data areas were unequal in size (Schickedanz and Changnon, 1970).

For the present project, the following adjustment procedures were used:

Susceptibility adjustment. The crop susceptibility-to-damage adjustments were made for the months of May, June, July, August, and September. The value for the month of April was taken to be the base month, and all other months were adjusted relative to the month of April. The susceptibility relative* was obtained by dividing the monthly hail intensity index (Appendix B, Table 1) for the state of Colorado determined for each month by the monthly hail intensity index for the month of April. The susceptibility index was then defined as the reciprocal of the susceptibility relative (see Appendix B, Table 1).

Liability adjustment. The average yearly liability for the county of interest during the years of 1957-1959 was used as the base, and the liability during the other years was adjusted relative to the 1957-1959 base. The liability relative for each year was obtained by dividing the total county liability for a particular year by the 1957-1959 (base) liability. The liability index was then defined to be the reciprocal of the liability relative for each year (see Appendix B, Table 2).

* The word relative in this report is defined as the ratio of a quantity in a given year to the quantity in a base year or period.

Price adjustment. Price relatives for each year were obtained from the U. S. Department of Agricultural Statistics (1969). The price relatives used were the prices received by farmers in the United States relative to the base period of 1910-1914. The price index was defined to be the reciprocal of the price relative for each year (see Appendix B, Table 3).

Areal size adjustment. In an earlier study, Schickedanz and Changnon (1970) used an areal index to allow for variations in the size of the areas of comparison. In the present project, the areal size adjustment was made by simply expressing the monetary and acreage values in terms of the dollar loss or number of acres damaged per 100 mi^2 of crop land. The number of square miles in crop land for each county was obtained from the U. S. Department of Agriculture (1964).

Adjustment indices for susceptibility, liability, and price were then computed for each year or month of the period 1967-1969 and are tabulated in Tables 1 and 2 of Appendix B. The adjustment index for the dollar loss values was then defined by Equation 1:

$$ADL = SSI \times LI \times PI \times 5 \times 10 \qquad (1)$$

where:

ADL = adjustment value for dollar loss values for a given month and year

SSI = seasonal susceptibility index

LI = liability index

PI = price index

5×10^6 = empirical adjustment for convenient magnitude

The adjustment index for the acres damaged values was then defined by Equation 2:

$$AAL = SSI \times LI \times 5 \times 10^4 \qquad (2)$$

where:

AAL = the adjustment value for acres of loss in a given month and year

SSI = seasonal susceptibility index

LI = liability index

5×10^4 = empirical adjustment for convenient magnitude

The price index was not employed in the acreage adjustment formula since the dollar change did not directly affect the temporal variability in acreage. The dollar and acreage adjustment indices are shown in Tables 4a and 4b of Appendix B. The daily dollar and acreage values per 100 mi^2 were adjusted by the ADL and AAL indices and then used in the subsequent statistical analyses. It should be realized that these adjustments cannot totally account for all the factors involved. However, the indices were developed from the only county yearly data available for adjusting the insurance data series. Inherent in the insurance data are the factors such as changing farm practices and crop types which are not measured on a county basis and cannot be adjusted for. Also, generally inherent in the data is a ± 5-percent variation due to subjectivity in the field measurements of loss.

In order to obtain a further refinement of the intensity of the hailstorm, and to circumvent some of the adjustment difficulties inherent in the adjustment process, two additional sets of data were derived. First, the dollar and acreage data were expressed in terms of the average dollar loss per claim (dollar extent) and the average number of acres damaged per claim (areal extent). It was believed that these would be relatively free of liability and area size variability problems since the number of claims should vary with the amount of liability and the amount of area in crop land. Secondly, the dollar loss was divided by the amount of liability to obtain the percent loss. It was believed that this expression would be relatively free of liability, changing dollar, and areal size problems.

3. Definitions

Operational days. These are defined in this report as those days on which hail is forecasted to occur. This definition was chosen because it was believed that the design of the experiment should be such that the forecasting scheme would be sure to include all of the hail days. Thus, it is a foregone conclusion that forecasting will be imperfect and some of the operational days will in fact have no hail. For computational purposes it was assumed that

62% of the operational days will have hail. This number is based on the 1969 and 1970 forecasting experience in the region of NHRE (Goyer*).

Seeded and non-seeded days. These days were designated to be seeded or non-seeded by random choice. It was assumed that random choices will be made from the operational days after they are chosen by the forecasting scheme. In this report sample sizes are computed for varying ratios of seeded to non-seeded days.

The *experimental unit* is defined to be an operational day in the experiment. Thus, the term "hail damage per experimental unit" refers to both the hail and non-hail days. *Liability* is defined to be the total dollar amount of insurance in force. Daily liability refers to only the liability on claims which had actual damage, whereas the total county liability for the year refers to the total amount of insurance in force irrespective of the amount of loss.

Alpha (a) is the probability of asserting that there is a seeding effect present, when in fact, there is not. *Beta* (3) is the probability of asserting that there is no seeding effect present, when in fact there is a seeding effect. The *power* (1-6) of the test refers to the probability of detecting a seeding effect when the effect is present.

4. Limitations

The reason for examination of historical climatological data in the area of the proposed hail experiment is to help establish useful elements of the design such as the observational unit, desirable predictor variables, the hail parameter, the size of target, and the proper tests to use in the evaluation. The method essentially is one of trial and error (Neyman and Scott, 1967a). The analyses then provide information on the expected duration for a specified precision level and particular test under the assumption that the future experiment will be performed in conditions like those reflected in the historical data. Thus, one limitation is that the weather conditions of the historical period will not necessarily be duplicated during the period of the experiment,

* Personal communication

and thus, sample size will not be exactly as estimated. But, projection of past experience into the future is still the best estimate available.

The use of results presented in this report to evaluate actual results from the field experiment is affected by the fact that only half of the proposed study area has cumulative liability greater than $25,000 for the period 1931-1962. To translate the field project results into crop-loss values applicable to those in this report some degree of correlation must exist between the hail sensing devices to be installed and the damage to crops. Another alternative might be to use Logan county as the study area, since it has widespread liability and is larger than the present study area.

All results are presented under the assumption that 62% of the forecasted hail days will in fact have hail. In the analyses, this value was used for all three counties and the Tri-county area. It is very likely that the forecast accuracy will vary according to the size of the area involved, but this factor was not considered in the analyses.

Also, the results in this report concern only the daily experimental unit and designs involving that unit over a single area. Other designs are possible, including 2-area crossover, target-control, or random individual storm, but, the design was chosen by NCAR before this study began and the sole purpose was to evaluate the various ramifications of using the daily experimental unit and a single target area.

ANALYTICAL PROCEDURES

1. Theoretical Frequency Distributions for Insurance Data

The log-normal distribution and gamma distribution were fitted to the seven hail insurance parameters derived. These distributions were then tested for "goodness of fit" by methods employed by Schickedanz and Changnon (1970). The distributional parameters for the log-normal and gamma distributions along with sample sizes, means and standard deviations are presented in Table 4. The probability of the goodness of fit test is also given in Table 4.

From Table 4, it is seen that the log-normal distribution is a reasonable probability model for dollar loss, adjusted dollar loss, acres damaged, and

Table 4. Distributional parameters for the log-normal and gamma distributions.

Data Parameter	Log-Normal: Log-Mean	Log-Normal: Standard Deviation	Gamma: Gamma	Gamma: Beta	Goodness of Fit Probability*: Log-Normal	Goodness of Fit Probability*: Gamma	Mean	Standard Deviation	Sample Size
Morgan County									
Dollar loss	6.63	1.66	.540	5004.	.59	<.01	2701.	5240.	90
Adj dollar loss	6.14	1.99	.343	15425.	.40	<.01	5292.	23003.	90
Dollar extent	5.57	1.13	1.365	335.	.05	.19	458.	598.	90
Percent loss	-1.51	.72	2.428	.115	.80	.32	.278	.185	90
Number of acres damaged	5.02	1.29	.753	461.	.91	.10	347.	662.	90
Adj # of acres damaged	5.43	1.56	.496	1917.	.89	<.01	951.	2669.	90
Areal extent	3.96	.76	2.267	30.	.02	.54	68.	48.	90
Logan County									
Dollar loss	6.87	2.04	.426	13159.	.44	<.01	5606.	14280.	177
Adj dollar loss	6.32	2.08	.416	8280.	.09	<.01	3443.	10082.	177
Dollar extent	5.21	1.10	1.436	209.	.32	.11	300.	295.	177
Percent loss	-1.32	.76	2.354	.145	.52	.93	.340	.219	177
Number of acres damaged	5.68	1.49	.572	1659.	.24	<.01	949.	2112.	177
Adj # of acres damaged	6.03	1.62	.519	3075.	.97	<.01	1595.	4517.	177
Areal extent	4.02	.51	4.605	13.	<.01	.02	62.	28.	177

Table 4. Distributional parameters for the log-normal and gamma distributions (cont.).

Data Parameter	Log-Normal: Log-Mean	Log-Normal: Standard Deviation	Gamma: Gamma	Gamma: Beta	Goodness of Fit Probability*: Log-Normal	Goodness of Fit Probability*: Gamma	Mean	Standard Deviation	Sample Size
Weld County									
Dollar loss	7.08	1.78	.503	9534.	.56	<.01	4792.	9749.	217
Adj dollar loss	5.80	1.98	.389	6374.	.09	<.01	2478.	9467.	217
Dollar extent	5.72	1.09	1.381	380.	.02	<.01	524.	654.	217
Percent loss	-1.26	.76	2.366	.152	<.01	.11	.359	.225	217
Number of acres damaged	5.48	1.46	.615	1133.	.62	<.01	697.	1243.	217
Adj # of acres damaged	5.11	1.64	.471	1629.	.46	<.01	767.	2467.	217
Areal extent	4.12	.68	2.682	28.	.07	.14	76.	49.	217
Tri-County									
Dollar loss	7.13	1.97	.441	15079.	.90	<.01	6655.	16114.	342
Adj dollar loss	5.35	2.08	.376	4662.	.33	<.01	1753.	6395.	342
Dollar extent	5.54	1.12	1.355	330.	.20	.05	447.	599.	342
Percent loss	-1.33	.78	2.221	.154	<.01	.54	.342	.254	342
Number of acres damaged	5.68	1.58	.544	1886.	.19	<.01	1025.	2237.	342
Adj # of acres damaged	4.81	1.68	.481	1118.	.20	<.01	545.	1407.	342
Areal extent	4.08	.65	2.714	27.	<.01	<.01	73.	60.	342

* Probability that the observed differences between the data sample and the given distribution could have occurred by random chance.

the adjusted number of acres damaged (goodness of fit probabilities ≥ .09 in all 16 cases, ≥ .20 in 13 out of 16 cases, and ≥ .40 in 10 out of 16 cases). On the other hand, the gamma distribution provides a very poor fit for the four hail parameters described above. This was a most interesting result, since similar results were obtained for fitting probability distributions to daily hail insurance records in Illinois (Schickedanz and Changnon, 1970), which is considered to have a different hail climate.

The tendency for the gamma distribution to fit weather data in cases where the log-normal does not fit, and visa versa, has been experienced in other studies (Huff et al., 1969). This tendency is evident for the Colorado percent loss data also. Table 4 reveals that the gamma distribution describes the percent loss data very well (goodness of fit probabilities ≥ .10 in all cases). On the other hand, the log-normal distribution fits the percent loss data in the smaller areas (counties) but not in the larger areas. For the dollar extent data both distributions fit the data in all areas except Weld county. For the areal extent data, neither distribution described the data well, but the gamma was slightly better.

Table 4 was presented to give the reader an idea of how well the log-normal and gamma probability models will describe the data because resulting computations of sample size are based upon the assumption that one or both are reasonable models. The conclusion reached here is that at least one and in some cases both of the models can be used with the hail parameters in Table 4.

2. Design Considerations

Only designs involving the daily experimental unit were investigated. This was based on a decision by the NCAR authorities regarding NHRE to use the daily unit as the experimental unit for the experiment. Thus, only three designs are considered. These designs are based first of all, upon the use of data during the experimental period and secondly based upon the use of historical data in the design. These designs are as follows: 1) random-experimental which involves randomization of days over a single target area and into seeded and non-seeded days with the non-seeded days being the control; 2) random-historical in which a random choice is made of days to be seeded over a single target with the historical record as the control; 3) continuous-historical in which all rain days within a given stratification are seeded with the historical record as a control.

In Appendix C, another modification is considered. It is one in which predictor variables from the upper air soundings at Denver are used in the random-experimental design in an effort to increase the power and precision of the experiment. This design is referred to simply as the random-experimental design with predictor variables.

3. Tests of Hypotheses and Computation of Sample Sizes

Several assumptions were made in regard to various hypotheses and tests of hypotheses employed in this study. Some of the assumptions are as follows: 1) whether seeded or not, to each experimental unit there is a positive probability of no-hail, and that this probability may be affected by seeding. That is, seeding may stop hail damage that would have occurred on a given day or seeding may create hail damage on a day where it would normally not have occurred; 2) when hail damage does occur, the daily hail damage is distributed according to either the log-normal or gamma probability distributions. In the case of predictor variables, it is assumed that the hail damage has a linear regression on the predictors; and 3) the effect of seeding is to produce a scale change in the hail damage distributions. No other change is assumed, with the exception of complete elimination or creation of hail as in assumption 2 above. Thus, the shape parameters of seeded distributions are assumed to be the same as the shape parameters of the non-seeded distributions.

These assumptions led to the formulation of three hypotheses which are likely to be tested during the hail reduction experiment. Under these hypotheses, various tests and designs involving the daily experimental unit over a single target area were considered as probable during the operational period. The number of experimental units necessary to insure detection of various assumed seeding decreases for a given precision level were then determined. The following null hypotheses were formulated.

Hypothesis A, seeding does not affect the conditional distribution of hail damage, given that hail occurs. For this hypothesis several tests were used in conjunction with the three designs. An optimal C(a) test was used which assumed that the hail-damage was gamma distributed or that there was a linear regression on the predictor variables. The test involved two cases: one without predictor variables and one with predictor variables. Formulas for these cases are given by Neyman and Scott (1967b) and were only employed with the random-experimental design. The log-normal (non-sequential) tests were used with all three designs without predictor variables. The log-normal sequential test was used with the random-historical and continuous-historical designs without predictor variables. Relationships necessary for the computation of sample size for the log-normal tests are given by Schickedanz et al. (1969) and are also listed in the Appendix B, Table 5.

Hypothesis B, seeding does not affect the probability of hail in the target. For this hypothesis an optimal C(a) test which is a modification of the classical X (Neyman and Scott, 1967b) was used. Formulas for the number of experimental units with hail necessary to insure a given power and significance level are given by Neyman and Scott (1967b) and are also listed in Appendix B, Table 5. This hypothesis by itself, is simply a test of whether the hail damage is eliminated completely or is created on a particular day, and it was considered only for the random-experimental design. The reduction in hail damage on a particular day is not considered under this hypothesis.

Hypothesis C, seeding does not affect the hail damage averaged per experimental unit. This is a combined test of whether the probability of hail on a given day and the amount of hail damage is reduced simultaneously. A C(a) optimum test was used which assumed that the distribution of hail damage is either gamma distributed or has a linear regression on the predictor variables. The test involved two cases: one without predictor variables and one with predictor variables. Formulas for these cases were given by Neyman and Scott (1967b) and were only used with the random-experimental design.

In the computation of sample sizes the "single-sided" alternative hypothesis was used throughout the report.

RESULTS

The results pertaining to Hypothesis A and the random-experimental design are emphasized. However, results are also presented for the random-historical design, random-continuous design, areal size, effect of randomization and the other two hypotheses.

1. Results Pertaining to Hypothesis A

Table 5 presents the number of experimental units (or days) required to obtain significance for a 1-tail test, a = .05 significance level and for desired power levels of .50 and .70. These are presented without regard to the number of experimental units expected per year or the ability of the forecast scheme to detect them.

When the results are compared on this basis (detection ability) it is seen that there are large differences in duration (length of experimental time required) according to the choice of hail parameter being used. For all areas, the percent loss, areal extent, and the dollar extent produce the smallest sample sizes. This is an expected result because the division (loss per claim) required to obtain these parameters removes much of the variability inherent in the adjusted loss data. In a sense, it is also a more meaningful figure for individual farmers because it is more representative of circumstances on a individual farm rather than the gross amount of loss per county area. Inspection of the values in Table 5 indicates that there is no apparent trend with areal size. For example, the number of hail days required for detecting a 20% decrease in dollars (optimal C(a) test, power = .5) for Morgan, Logan, Weld and the Tri-county areas are 403, 510, 432, and 493, respectively.

The optimal C(a) test produces smaller sample sizes than the log-normal test. This was an expected result from theoretical considerations and was one of the reason for using the C(a) tests in this study.

To convert the number of experimental units to the number of years required for detection of a given decrease under the Hypothesis A, the number of units expected per year per area and the ability of the forecast scheme to predict hail must be considered. Based on prior experience, it is expected that 62% of the operational days (forecasted hail days) will in fact have hail. It will be assumed that this figure will be applicable to all four areas. From the historical insurance records, there was an average of 6.9 hail days per year for Morgan county, 13.6 for Logan county, 16.7 for Weld county, and 26.3 in the Tri-county area (an obvious reflection of the areal size of the four areas). Furthermore, it is assumed that the forecasting scheme will be such

Table 5. The number of hail days required for the detection of varying decreases under Hypothesis A, random-experimental design.

(1-tail test, a = .05, randomization = 1/2)

Log-Normal Test (Non-Sequential)

Morgan County (1282 mi^2)

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	1033	11+91	479	193	620	916	216
	.50	596	859	276	111	357	528	124
40	.70	197	284	91	37	118	175	41
	.50	114	164	53	21	68	101.	24
60	.70	61	88	28	11	37	54	13
	.50	35	51	16	7	21	31	7
80	.70	20	29	9	4	12	18	4
	.50	11	17	5	2	7	10	2

Optimal C(a) Test

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	700	1102	277	156	502	762	167
	.50	403	634	159	90	289	438	96
40	.70	134	210	53	30	96	145	32
	.50	77	121	30	17	55	84	18
60	.70	42	65	16	9	30	45	10
	.50	24	38	9	5	17	26	6
80	.70	13	21	5	3	10	15	3
	.50	8	12	3	2	6	8	2

Table 5. The number of hail days required for the detection of varying decreases under **Hyp**othesis A, random-experimental design (cont.).

Log-Normal Test (Non-Sequential)

Logan County (1827 mi^2)

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	1176	1615	456	219	834	980	99
	.50	678	931	263	126	481	565	57
40	.70	224	308	87	42	159	187	19
	.50	129	178	50	24	92	108	11
60	.70	70	96	27	13	49	58	6
	.50	40	55	16	7	29	34	3
80	.70	23	31	9	4	16	19	2
	.50	13	18	5	2	9	11	1

Optimal C(a) Test

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	887	908	263	161	661	728	82
	.50	510	523	151	92	380	419	47
40	.70	169	173	50	31	126	139	16
	.50	97	100	29	18	73	80	9
60	.70	53	54	16	10	39	43	5
	.50	30	31	9	5	.23	25	3
80	.70	17	17	5	3	13	14	2
	.50	10	10	3	2	7	8	1

Table 5. The number of hail days required for the detection of varying decreases under Hypothesis A, random-experimental design (cont.).

Log-Normal Test (Non-Sequential)

Weld County (4004 mi^2)

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	1187 .	1469	446	218	804	1007	173
	.50	684	847	257	126	464	580	100
40	.70	227	280	85	42	153	192	33
	.50	131	162	49	24	88	111	19
60	.70	70	87	26	13	48	60	10
	.50	41	50	15	7	27	34	6
80	.70	23	28	9	4	15	19	3
	.50	13	16	5	2	9	11	2

Optimal C(a) Test

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	752	972	274	160	614	803	141
	.50	432	559	157	92	353	462	81
40	.70	143	185	52	30	117	153	27
	.50	83	107	30	18	67	88	15
60	.70	45	58	16	9	36	48	8
	.50	26	. 33	9	5	21	27	5
80	.70	14	19	5	3	12	15	3
	.50	8	11	3	2	7	9	2

Table 5. The number of hail days required for the detection of varying decreases under Hypothesis A, random-experimental design (cont.).

Log-Normal Test (Non-Sequential)

Tri-County (7113 mi^2)

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	1457	1623	471	227	933	1052	160
	.50	840	935	271	131	538	607	92
40	.70	278	310	90	43	178	201	31
	.50	160	178	52	25	103	116	18
60	.70	86	96	28	13	55	62	10
	.50	50	55	16	8	32	36	5
80	.70	28	31	9	4	18	20	3
	.50	16	18	5	3	10	12	2

Optimal C(a) Test

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	857	1005	279	170	695	786	139
	.50	493	578	160	98	400	452	80
40	.70	164	192	53	32	133	150	27
	.50	94	110	31	19	76	86	15
60	.70	51	60	17	10	41	47	8
	.50	29	34	10	6	24	27	5
80	.70	16	19	5	3	13	15	3
	.50	9	11	3	2	8	9	2

that all hail days will be forecasted although 38 percent of these days will, in fact, have no hail. Thus, it is assumed that the number of operational days required per year would be 11.2, 22.0, 26.9, and 42.4 days, respectively for the four areas. In order to convert the number of hail days required for a given decrease (Table 5) to the number of years required for Hypothesis A, it is sufficient to divide the number of hail days by the expected (average) number of hail days per year. These data are presented in Table 6.

Before converting to years, there was no indication of trend between sample size and areal size. However, since the yearly data allow for the number of hail days in a particular area, the trend in the yearly data with areal size is quite evident. For example, the numbers of hail days required for detecting a 20 percent decrease in percent loss (optimal C(a) test, power = .70) for Morgan, Logan, Weld, and the Tri-county areas are 23, 12, 10, and 6, respectively.

For a 70 percent chance of detection (power = .70) it is seen from Table 6 that 40 percent decreases in percent loss can be detected in approximately 5 years or less for all areas except Morgan. Percent loss and areal extent are similar in respect to duration and both require approximately one-half of the duration of dollar extent data. The actual dollar and acreage data requires approximately 5 times or more years than the percent loss. This is also true for the adjusted dollar and acre data. It would appear that loss extent, areal extent, and percent loss are the most efficient hail insurance parameters to use in verifying reduction of hail in Colorado. Therefore, most of the results are presented for these three parameters.

The numbers of years required to detect various decreases in an 600 mi^2 area (size of study area) were estimated and are presented in Table 7. To obtain the estimates the trend between the two smaller areas (Morgan and Logan counties) was extrapolated linearly to obtain an estimate of sample size in a 600 mi^2 area (size of study area). The table implies that with one of the best parameters, percent loss, a 40 percent decrease would require approximately 4 years for a power level of 0.5 and 7 years for a power level of 0.7. Thus, under the Hypothesis A (reduction of hail damage on hail days), the decrease in hail damage must be more than 40 percent in the study area if it is to be detected in a 5-year period using the random-experimental design. However, note from Table 6 that for areas the size of 2,000 mi^2, a 40 percent decrease

Table 6. The number of years required for the detection of varying decreases under Hypothesis A, random-experimental design.

(1-tail test, a = .05, randomization = 1/2)

Log-Normal Test (Non-Sequential)

Morgan County (1282 mi^2)

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent.	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	150	216	69	28	90	133	31
	.50	86	124	40	16	52	77	18
40	.70	29	41	13	5	17	25	6
	.50	17	24	8	3	10	15	3
60	.70	9	13	4	2	5	8	2
	.50	5	7	2	1	3	4	1
80	.70	3	4	1	1	2	3	1
	.50	2	2	1	<1	1	1	<1

Optimal C(a) Test

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent.	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	101	160	40	23	73	110	24
	.50	58	92	23	13	42	64	14
40	.70	19	30	8	4	14	21	5
	.50	11	18	4	2	8	12	3
60	.70	6	9	2	1	4	7	1
	.50	3	5	1	1	2	4	1
80	.70	2	3	1	<1	1	2	<1
	.50	1	2	<1	<1	1	1	<1

Table 6. The number of years required for the detection of varying decreases under Hypothesis A, random-experimental design (cont.).

Log-Normal Test (Non-Sequential)

Logan County (1827 mi^2)

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	86	119	34	16	61	72	7
	.50	50	68	19	9	35	42	4
40	.70	16	23	6	3	12	14	1
	.50	9	13	4	2	7	8	1
60	.70	5	7	2	1	4	4	<1
	.50	3	4	1	1	2	3	<1
80	.70	2	2	1	<1	1	1	<1
	.50	1	1	<1	<1	1	1	<1

Optimal C(a) Test

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	65	67	19	12	49	54	6
	.50	38	38	11	7	28	31	3
40	.70	12	13	4	2	9	10	1
	.50	7	7	2	1	5	6	1
60	.70	4	4	1	1	3	3	<1
	.50	2	2	1	<1	2	2	<1
80	.70	1	1	<1	<1	1	1	<1
	.50	1	1	<1	<1	1	1	<1

Table 6. The number of years required for the detection of varying decreases under Hypothesis A, random-experimental design (cont.).

Log-Normal Test (Non-Sequential)

Weld County (4004 mi^2)

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	71	88	27	13	48	60	10
	.50	41	51	15	8	28	35	6
40	.70	14	17	5	3	9	11	2
	.50	8	10	3	1	5	7	1
60	.70	4	5	2	1	3	4	1
	.50	2	3	1	<1	2	2	<1
80	.70	1	2	1	<1	1	1	<1
	.50	1	1	<1	<1	1	1	<1

Optimal C(a) Test

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	45	58	16	10	37	48	8
	.50	26	33	9	6	21	28	5
40	.70	9	11	3	2	7	9	2
	.50	5	6	2	1	4	5	1
60	.70	3	3	1	1	2	3	1
	.50	2	2	1	<1	1	2	<1
80	.70	1	1	<1	<1	1	1	<1
	.50	1	1	<1	<1	<1	1	<1

Table 6. The number of years required for the detection of varying decreases under Hypothesis A, random-experimental design (cont.).

Log-Normal Test (Non-Sequential)

Tri-County (7113 mi^2)

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	55	62	18	9	35	40	6
	.50	32	36	10	5	20	23	3
40	.70	11	12	3	2	7	8	1
	.50	6	7	2	1	4	4	1
60	.70	3	4	1	1	2	2	<1
	.50	2	2	1	<1	1	1	<1
80	.70	1	1	<1	<1	1	1	<1
	.50	1	1	<1	<1	<1	<1	<1

Optimal C(a) Test

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	33	38	11	6	26	30	5
	.50	19	22	6	4	15	17	3
40	.70	6	7	2	1	5	6	1
	.50	4	4	1	1	3	3	1
60	.70	2	2	1	<1	2	2	<1
	.50	1	1	<1	<1	1	1	<1
80	.70	1	1	<1	<1	1	1	<1
	.50	<1	<1	<1	<1	<1	<1	<1

Table 7. The number of years required for the detection of varying decreases under Hypothesis A, random-experimental design, study area estimate.

(1-tail test, a = .05, randomization = 1/2)

Log-Normal Test (Non-Sequential)

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	229	338	114	43	126	209	61
	.50	132	195	66	25	72	120	35
40	.70	44	64	22	8	24	40	12
	.50	25	37	13	5	14	23'	7
60	.70	13	20	7	2	8	12	4
	.50	8	12	4	2	4	7	2
80	.70	4	7	2	1	2	4	1
	.50	2	4	1	<1	1	2	1

Optimal C(a) Test

Percentage Decrease	Power	Dollar Loss	Adjusted Dollar	Dollar Extent	Percent Loss	Acres Damaged	Adjusted Acres Damaged	Areal Extent
20	.70	147	276	66	36	103	182	47
	.50	85	159	38	21	59	104	27
40	.70	28	53	13	7	20	35	9
	.50	16	30	7	4	11	20	5
60	.70	9	16	4	2	6	11	3
	.50	5	9	2	1	3	6	2
80	.7	3	5	1	1	2	4	1
	.50	2	3	1	<1	1	2	1

could be detected in 2 years using percent loss for the verifying parameter. A comparison of Tables 6 and 7 also indicates that the size of area becomes a more important factor as the decrease becomes smaller.

Because of the superiority of the percent loss, dollar extent, and areal extent hail parameters (Tables 6 and 7) subsequent presentation of results will only involve these three parameters.

Table 8 shows the effect of varying the randomization from seeding 1/2 of the days to seeding 1/5, 2/5, 3/5, and 4/5 of the days under Hypothesis A, random-experimental design. In terms of years, it makes very little difference whether the randomization is 2/5, 1/2, or 3/5 although 1/2 requires the shortest duration. However, when only 1/5 of the days are seeded, there is an appreciable difference in the number of years required for the 20 and 40 percent decreases, and practically no difference for the larger decreases. Thus, if one is going to use the random-experimental design, the ratio between seeded and non-seeded experimental units should be either 50-50 or 60-40.

One possible method of reducing the sample size required for the experiment is to use the historical record in the test itself. Therefore, two other designs were considered under the Hypothesis A. These were the continuous-historical and random-historical designs. Both designs depend upon certain assumptions in order for them to be valid. Historical designs involve the use of non-seeded hail amounts observed during a historical period preceding the actual experiment. Thus, it is possible that the historical method may bias the evaluation by the fact that the historical period may be dominated by storms either favorable or unfavorable to seeding. However, during the seeding period the opposite storm type may prevail. In the Colorado experiment, historical data for the hail sensing devices will not be available and unless a good relation is established between damage and sensing data, the designs involving historical data can not be used. However, in absence of bias, a continuous-historical design does yield small sample sizes. To circumvent the difficulty of bias, Schickedanz and Changnon (1970) suggested the use of a random-historical design where the random non-seeded days would be used as a control to check on trends during the experimental period. Subsequently, Huff and Schickedanz (1970) have suggested the use of the historical comparison as supplementary data to the random-experimental design. The merit of this

Table 8. The number of years required for the detection of varying decreases under Hypothesis A, random-experimental design according to varying degrees of randomization for Logan county (1-tail test, a = .05).

Logan County

1/2 Randomization

		Log-Normal Test			Optimal C(a) Test		
Percentage Decrease	Power	Dollar Extent	Percent Loss	Areal Extent	Dollar Extent	Percent Loss	Areal Extent
20	.70	34	16	7	19	12	6
	.50	19	9	4	11	7	3
40	.70	6	3	1	4	2	1
	.50	4	2	1	2	1	1
60	.70	2	1	<1	1	1	<1
	.50	1	1	<1	1	<1	<1
80	.70	1	<1	<1	<1	<1	<1
	.50	<1	<1	<1	<1	<1	<1

1/5, 4/5 Randomization

		Log-Normal Test			Optimal C(a) Test		
Percentage Decrease	Power	Dollar Extent	Percent Loss	Areal Extent	Dollar Extent	Percent Loss	Areal Extent
20	.70	52	25	11	30	18	9
	.50	30	14	7	17	11	5
40	.70	10	5	2	6	4	2
	.50	6	3	1	3	2	1
60	.70	3	1	1	2	1	1
	.50	2	1	<1	1	1	<1
80	.70	1	<1	<1	1	<1	<1
	.50	1	<1	<1	<1	<1	<1

Table 8. The number of years required for the detection of varying decreases under Hypothesis A, random-experimental design according to varying degrees of randomization for Logan county (l-tail test, o = .05) (cont.).

2/5, 3/5 Randomization

		Log-Normal Test			Optimal C(a) Test		
Percentage Decrease	Power	Dollar Extent	Percent Loss	Areal Extent	Dollar Extent	Percent Loss	Areal Extent
20	.70	35	17	8	20	12	6
	.50	20	10	4	12	7	4
40	.70	7	3	1	4	2	1
	.50	4	2	1	2	1	1
60	.70	2	1	<1	1	1	<1
	.50	1	1	<1	1	<1	<1
80	.70	1	<1	<1	<1	<1	<1
	.50	<1	<1	<1	<1	<1	<1

type of combination is that one can take advantage of the lack of assumptions involved in the random-experimental design and yet at the same time make use of the smaller sample sizes possible although less valid in regard to assumptions involved in the random-experimental design. In the continuous-historical design, there is simply no way to insure that the seeding period does not have a different weather regime than during the historical control. If the regime is different a fictitious seeding effect may be created because there are no control days in the experimental period. Thus, it appears that some randomization must be employed.

The number of years required for the random-historical design under Hypothesis A and using the log-normal, 1-sample test are presented in Table 9. It is immediately obvious that the required number of years is approximately 1/2 of that required for the random-experimental design. For a continuous-historical design the number would be 1/2 as much as those in Table 9.

The table shows that the sequential test procedure does reduce the sample sizes beyond that of the non-sequential test procedure. However, the sequential test is known to be very sensitive to trends in the data and considerable caution should be exercised in its use. Therefore, two tests were performed to check for trends and cycles in the 13-year records of yearly dollar loss and the annual number of hail-damage days in the four areas. It was found that there were no significant cycles or trends in the 13-year record. However, examination of longer period U. S. Weather Bureau hail-day records indicates the existence of trends and cycles at some stations in the general area (Appendix A). Thus, it is possible that a 5-year field program in this area could easily occur during a period of significant decrease or increase in hail. For these reasons, the sequential analysis should not be used as the chief verifying method.

The overall conclusion from Table 9 is that if the sequential procedure were used, and all <u>assumptions were met</u>, a 40 percent decrease would have a 70 percent chance of detection in 2 years in an area the size of the target using the percent loss parameter. With the non-sequential test, a 40 percent decrease would have approximately a 70 percent chance of detection in 4 years.

Table 9. The number of years required for the detection of varying decreases under Hypothesis A, random-historical design (1-tail test, a = .05, 1/2 randomization).

		Non-Sequential			Sequential		
Percentage Decrease	Power	Dollar Extent	Percent Loss	Areal Extent	Dollar Extent	Percent Loss	Areal Extent
Logan County							
20	.70	17	8	4	7	3	2
	.50	10	5	2	4	2	1
40	.70	3	2	1	1	1	<1
	.50	2	1	<1	1	<1	<1
60	.70	1	<1	<1	<1	<1	<1
	.50	1	<1	<1	<1	<1	<1
Morgan County							
20	.70	35	14	16	14	6	6
	.50	20	8	9	7	3	3
40	.70	7	3	3	3	1	1
	.50	4	2	2	1	1	1
60	.70	2	1	1	1	<1	<1
	.50	1	1	1	<1	<1	<1
Study Area (Estimated)							
20	.70	57	21	31	24	9	13
	.50	33	12	18	12	5	7
40	.70	11	4	6	5	2	2
	.50	6	2	3	2	1	1
60	.70	3	1	2	1	1	1
	.50	2	1	1	1	<1	<1

2. Results Pertaining to Hypothesis B

The equations used in the computation of sample size under Hypothesis B yield the total number of experimental units required for a given decrease (Appendix B, Table 5). In order to convert the number of experimental units required for a given decrease to the number of years required, it is sufficient to divide the number of units by the average number of operational days per year (see page 26).

Using the operational day conversion, the numbers of years required for the detection of varying decreases in the probability of a day having hail were computed and are listed in Table 10 for varying degrees of randomization. It is seen that again there is little difference between the number of years required for randomization factors of 1/2, 2/5, or 3/5, but large differences result when the randomization factor is either 1/5 or 4/5. Values estimated for the study area (Table 10) indicate it would be difficult to detect differences in the probability of hail between seeded and non-seeded experimental units. For a 40 percent reduction, in order to have a 70 percent chance of detection, approximately 10 years would be required, and to have a 50 percent chance of detection 6 years would be required. Thus, there is little hope that an experiment with a 5-year duration would detect the effect of seeding on the probability of hail occurrence per experimental unit unless the effect produces decreases of 60 percent or greater. However, the combination of this effect with a corresponding reduction in hail damage, may be much easier to detect. This combined effect is considered under the Hypothesis C.

3. Results Pertaining to Hypothesis C

The number of years required for the detection of varying decreases in the probability of hail combined with varying decreases in damage are listed in Table 11 (the yearly conversion is the same as for Hypothesis B). If the reduction in damage is 40 percent and the number of hail days are reduced by 20 percent there would be a 70 percent chance of detection in 8 years in the study area. A 40 percent reduction in damage with a 40 percent reduction in hail days would have a 70 percent chance of detection in 4 years. However, if the study area were the size of Logan county, a 20 percent decrease in damage with a 20 percent reduction in hail days would have a 70 percent chance

Table 10. The number of years required for the detection of varying decreases under Hypothesis B, (decrease in probability of hail days) random-experimental design according to varying degrees of randomization (1-tail test, a = .05).

Percentage Decrease	Power	Randomization 1/2	1/5, 4/5	2/5, 3/5
Morgan				
20	.70	26	41	27
	.50	15	23	15
40	.70	6	10	7
	.50	4	6	4
60	.70	3	4	3
	.50	2	3	2
80	.70	2	3	2
	.50	1	1	1
Logan				
20	.70	13	21	14
	.50	8	12	8
40	.70	3	5	3
	.50	2	3	2
60	.70	1	2	2
	.50	1	1	1
80	.70	1	1	1
	.50	<1	1	<1

Table 10. The number of years required for the detection of varying decreases under Hypothesis B, (decrease in probability of hail days) random-experimental design according to varying degrees of randomization (1-tail test, a = .05) (cont.).

Percentage Decrease	Power	Randomization 1/2	1/5, 4/5	2/5, 3/5
Weld				
20	.70	11	17	11
	.50	6	10	6
40	.70	3	4	3
	.50	2	2	2
60	.70	1	2	1
	.50	1	1	1
80	.70	1	1	1
	.50	<1	1	<1
Study Area (Estimated)				
20	.70	42	66	44
	.50	24	37	25
40	.70	10	16	11
	.50	6	9	6
60	.70	5	7	5
	.50	3	4	3
80	.70	3	4	3
	.50	2	2	2

Table 11. The number of years required for the detection of varying decreases under Hypothesis C, random-experimental design using percent loss data (1-tail test, a = .05, randomization = 1/2).

Percent Damage Decrease	Decrease in Hail-Day Probability	Power	Number of Years: Study Area	Morgan	Logan	Weld	Tri-County
20	20	.70	17	11	6	5	3
		.50	10	6	3	3	2
	40.	.70	8	5	2	2	1
		.50	4	3	1	1	1
	60	.70	4	3	1	1	1
		.50	2	2	1	1	<1
	80	.70	3	2	1	1	<1
		.50	2	1	1	<1	<1
40	20	.70	8	5	2	2	1
		.50	4	3	1	1	1
	40	.70	4	3	1	1	1
		.50	2	2	1	1	<1
	60	.70	3	2	1	1	<1
		.50	2	1	1	<1	<1
	80	.70	2	1	1	1	<1
		.50	1	1	<1	<1	<1
60	20	.70	4	3	1	1	1
		.50	2	2	1	1	<1
	40	.70	3	2	1	1	<1
		.50	2	1	1	<1	<1
	60	.70	2	1	1	1	<1
		.50	1	1	<1	<1	<1
	80	.70	1	1	<1	<1	<1
		.50	1	1	<1	<1	<1

of being detected in 6 years. A 20 percent decrease in damage with a 40 percent decrease in hail damage (or visa versa), would have a 70 percent chance of detection in 2 years for Logan county. Thus, the restraints placed on the detection of effect by the small areal size chosen are clearly evident.

4. Overall Results

Overall results for various combinations of hypothesis testing and designs are shown in Table 12 where all values are based on 50-50 randomization. The historical-random design (sequential test) requires the shortest length of time for detection (2 years for a 70 percent chance of detecting a 40 percent decrease in the study area). Of the three tests involving the experimental-random design, that combining the test of damage and hail days is the most powerful. There is a 70 percent chance of detecting a 40 percent decrease in damage in 4 years when combined with a 40 percent decrease in the number of hail days. Since it is believed that the historical design should not be the principle verifying technique, the experimental-random design is deemed necessary.

If hail damage in the study area is decreased 40 percent and no allowance is made for a possible reduction in hail days (experimental-random reduction in damage), there is a 70 percent chance of detecting the effect in 7 years, and a 50 percent chance in 4 years. If the frequency of hail days in the study area is reduced 40 percent and no allowance is made for a possible corresponding reduction in damage, there is a 70 percent chance of detection in 10 years and a 50 percent chance in 6 years.

It is natural to consider the effect of using a lower significance level. If the level of significance is reduced, thereby increasing the chance of asserting that a seeding effect exists when in fact it doesn't (Type 1 error, a), there is a corresponding increase in the probability of detecting the seeding effect. Thus, if a is chosen to be .10, (1 chance in 10 of wrongly asserting the existence of an effect) there is a corresponding decrease in the number of years required. Table 13 is a comparison of the number of years required for 3 different levels of a for the experimental-random design. With a 1-tail a level of .025 (2-tail, a = .05) test, 6 years would be required in the study area for a 70 percent chance of detecting a 40 percent decrease in damage when combined with a 40 percent decrease in the number of hail days.

Table 12. The number of years required to detect 20-, 40-, and 60-% decreases for various combinations of hypothesis testing and designs, using percent loss and probability of hail data (1-tail test, a = .05, randomization = 1/2).

		Experimental-Random Reduction in Damage			Historical-Random (Non-Sequential) Reduction in Damage			Historical-Random (Sequential) Reduction in Damage			Experimental-Random Reduction in Hail Days			Experimental-Random Reduction in Damage and Hail Days*		
Decrease	Power	Logan	Morgan	Study Area	Logan	Morgan	Study Area	Logan	Morgan	Study Area	Logan	Morgan	Study Area	Logan	Morgan	Study Area
20	.70	12	23	36	8	14	21	3	6	9	13	26	42	6	11	17
	.50	7	13	21	5	8	12	2	3	5	8	15	24	3	6	10
40	.70	2	4	7	2	3	4	1	1	2	3	6	10	1	3	4
	.50	1	2	4	1	2	2	<1	1	1	2	4	6	1	2	2
60	.70	1	1	2	<1	1	1	<1	<1	1	1	3	5	1	1	2
	.50	<1	1	1	<1	1	1	<1	<1	<1	1	2	3	<1	1	1

* Reduction in probability of hail are the same as those specified for reductions in damage

Table 13. A comparison of the number of years required for detection of varying decreases and varying significance levels for the experimental-random design using percent loss data (randomization = 1/2).

		Reduction in Damage			Reduction in Hail Days			Reduction in Damage and Hail Days"		
Decrease	Power	Logan	Morgan	Study Area	Logan	Morgan	Study Area	Logan	Morgan	Study Area
		1 tail a = 0.025, 2 tail a = 0.05								
20	.70	16	30	47	17	34	54	7	14	23
	.50	10	18	29	11	21	34	4	9	14
40	.70	3	6	9	4	8	14	2	4	6
	.50	2	3	6	3	5	8	1	2	3
60	.70	1	2	3	2	4	6	1	2	3
	.50	1	1	2	1	2	4	1	1	2
		1-tail a = 0.05, 2-tail a = 0.10								
20	.70	12	23	36	13	26	42	6	11	17
	.50	7	13	21	8	15	24	3	6	10
40	.70	2	4	7	3	6	10	1	3	4
	.50	1	2	4	2	4	6	1	2	2
60	.70	1	1	2	1	3	5	1	1	2
	.50	<1	1	1	1	2	3	<1	1	1
		1-tail a = 0.10, 2-tail a = 0.20								
20	.70	8	16	25	9	17	29	4	8	13
	.50	4	8	13	5	9	14	2	4	6
40	.70	2	3	5	2	4	7	1	2	3
	.50	1	1	2	1	2	4	<1	1	2
60	.70	<1	1	1	1	2	3	<1	1	1
	.50	<1	<1	1	1	1	2	<1	<1	1

* Reductions in probability of hail are the same as those specified for reductions in damage

With a 1-tail α level of .10 (2-tail, α = .20), only 3 years would be required to have a 70 percent chance of detecting the same decrease combination.

It should be noted that when the percentage reduction in hail damage is equal to the reduction in the frequency of hail days (in the combined test), an optimum condition for detecting a decrease exists. If the percentage differences are not the same, the sample sizes for the combined test will be larger than when they are equal. If the percentage differences are greatly different, the values presented for reduction in damage alone or reduction in frequency of hail days alone may be smaller than that required by the combined test. More detailed information concerning sample sizes when the percentage differences of damage and hail probability are different, can be gleaned from Table 11.

As mentioned earlier, it is possible in some circumstances to reduce sample sizes somewhat by the inclusion of predictor variables. The analysis concerning predictor variables will be presented in Appendix C.

SUMMARY AND CONCLUSIONS

1. Summary

If a test is made on damage reduction using the experimental-random design and no allowance is made for the probability of hail on a particular day, there is a 70 percent chance of detecting a 40 percent decrease in hail damage in 7 years and a 50 percent chance in 4 years (percent loss data).

If a test is made for reduction in the probability of hail on a day (reduction in hail days) there is a 70 percent chance of detecting a 40 percent decrease in 10 years, and a 50 percent chance in 6 years.

There are possibilities of decreasing these required sample sizes. If one uses a non-sequential test with historical data and <u>all assumptions are satisfied</u>, there would be a 70 percent chance of detecting a 40 percent decrease in 4 years, and a 50 percent chance of detection in 2 years. Using the sequential test, there would be a 70 percent chance of damage detection in 2 years. However, there are many limitations associated with utilizing the sequential procedure based on historical data alone.

If a "combined" test is made on reduction in damage and reduction in probability of hail treated together, there is a 70 percent chance of detecting a 40 percent decrease in 4 years (50 percent in 2 years), if the percentage reduction in the damage is the same as the percentage reduction in probability of hail. It is also possible to reduce the sample size somewhat by the inclusion of predictor variables (see Appendix C).

The results stated above are all based on a 1-tail, *a* - .05 (2-tail, a = .10) test of significance. This indicates that there is a 5 percent chance of wrongly asserting the existence of an effect when it in fact does not exist (1-tail test). In order to have the same precision with a 2-tail, a = .05 test, sample sizes would be 9 years for a 40 percent decrease in damage alone, and 6 years when a 40 percent decrease in damage and probability are combined in the same test (70 percent chance of detection).

On the other hand, if one is willing to risk a 10 percent chance (1-tail, *a* = .10) of wrongly asserting an effect when in fact it does not exist, then the number of years required would be 5 for damage alone, and 3 years for the combined test (70 percent chance of detection).

It was found that percent crop loss, dollar extent, and areal extent were the most efficient hail parameters to use to detect decreases in the region of NHRE.

All results are based on an assumed ability to forecast the hail days with 62 percent accuracy. It is further assumed that the forecasting capability will be such that all hail days will be included in the operational days with 38 percent of the operational days having no hail.

The above results are also based on an assumed randomization factor of 50-50. For the experimental-random design it was found that the randomization factor could be 60-40 and the sample size would be nearly the same. However, if the randomization factor were 20-80 there would be an appreciable increase in sample size.

It is important to note that the "study area" estimates represent an extrapolation of required sample sizes from values of larger areas, and thus these study area estimates may be subject to some error.

2. Recommended Design and Evaluation Procedure

It would seem that the use of the historical data in conjunction with the experimental-random design is the best choice for the design and eventual evaluation of NHRE results. Based on the established relationship between crop damages and the hail pad data (Changnon, 1970), the following design-evaluation procedure is recommended.

The seeding design should be developed in the context of the experimental-random design with a randomization factor of either 50-50 or 60-40. The data from the non-seeded days could then be compared with the historical record as a test in addition to the usual test comparison between random samples of the seeded and non-seeded data during the experimental period. Also, the non-seeded data could be compared with the historical data to test for a trend and the representativeness of the historical record in relation to the experimental period. It is also possible that the historical non-seeded comparison could be used to remove any serious trend found in the data. Thus, even though the recommended experiment would not be conducted in a sequential manner, there is no reason why the sequential test could not be monitored along with the other tests. The authors believe this would enhance the chance of detecting a seeding effect, over the sole use of the experimental-random design, and at the same time utilize the statistical advantage of the experimental-random design. In this manner, allowances could also be made to include any useful predictor variables since they would provide detection of lesser decreases in the 5-year NHRE period.

There would be a much better chance of detecting seeding effects if a larger area were used and, if possible, it is recommended that a larger study area be used, particularly if the experimental-random is used.

The recommended evaluation procedure described above (involving use of historical crop loss records) requires that a relationship between the hail parameters (as detected by surface hail sensors) and crop damage (percent loss) for the study area and environs is established since the study area has too little insurance coverage. Therefore, to supplement the Illinois crop-hail relationships and to check for regional differences, surface hail sensing devices should be operated adjacent to crops in Northeast Colorado prior to the beginning of the experiment.

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APPENDIX A

DESCRIPTIVE CLIMATOLOGY OF WEATHER BUREAU HAIL DAYS AND RADAR-HAIL ECHOES IN NORTHEASTERN COLORADO

CONTENTS

INTRODUCTION

In addition to the studies involving the insurance crop-hail loss data for the three counties, Tri-county area, and the proposed hail study area, two other forms of historical hail data were gathered and studied. These other hail data were studied primarily to provide a descriptive climatology of their occurrence, but were not analyzed in every conceivable format. These results should be useful information in the design, operations, and general evaluation aspects of the hail project proposed for northeast Colorado.

Historical records for U. S. Weather Bureau stations in the Colorado area and surrounding states had been obtained for a previous hail climatology study (Stout and Changnon, 1969). This earlier study, based on those stations with quality hail records during a portion of the 1901-1965 period, had identified all stations in northeastern Colorado and its surrounding area that could be used in this more localized climatic study. The hail-day records of the Weather Bureau stations, offer at least one salient advantage over the insurance records. They have longer length, and thus can be used to examine for long-term time trends.

The other climatic study performed and described in this Appendix was based on an analysis of 4 years (1961-1964) of radar echo data for Northeastern Colorado. Data available in a series of reports offered rather detailed records of hailstorm echoes , as determined from a 3-cm radar operated in northeastern Colorado. Data for echoes that occurred in the proposed hail study area were analyzed to develop a hail-echo climatology for the area.

CLIMATOLOGY OF HAIL-DAY DATA FROM WEATHER BUREAU RECORDS

1. Introduction

Based on the 1960-1969 studies of Stout and Changnon (1969) and the techniques of substation record evaluation (Changnon, 1967), records of stations in the northeastern one-fourth of Colorado and those in the surrounding states of Wyoming, Nebraska, and Kansas, were obtained and analyzed for this study. Most of these records were available from earlier studies, but new records for the 1964-1969 period had to be purchased and evaluated.

One phase of these studies was an investigation of hail-day areal patterns, both on a monthly and seasonal basis, and on an average and extreme frequency basis. The relationship between areal hail-day frequencies for different sized areas was another part of this phase. The second research phase involving the hail-day data concerned the temporal variations and included point and areal frequencies of hail-days per season, the temporal change or variations in hail-days, and the occurrence of hail by dates of the year.

In order to summarize the data seasonally, two seasons were chosen: the March-August period (which normally includes 90% or more of all hail-days in the area); and the 15 May-31 July period (which is the peak of the northeastern Colorado hail season and thus the 11-week period likely chosen as the operational period of the hail experiment). In analyzing and presenting certain regional statistics, a region surrounding the proposed hail study area was defined arbitrarily utilizing the nearest eight stations with hail data in the last 25 years (see Fig. 1). The data from this 8-station area were used to develop areal hail-day frequencies for the proposed hail study area.

2. Data

The utilization of U. S. Weather Bureau cooperative substation hail data in such a study required the development of a careful procedure to evaluate these stations which are manned by volunteers. This procedure is essentially a series of comparative analyses, and is described fully elsewhere (Changnon, 1967).

Since the substations in the general Colorado area had already been evaluated in an earlier study for insurance interest (Stout and Changnon, 1969) it only became necessary to secure the records for these stations beyond that available (generally 1901-1963 for most stations), and only the last 6 years of record (1964-1969) had to be evaluated.

The list of stations that were utilized in the presentation of hail-day data in this report are itemized in Table 1. This shows for each station the

Table 1. Sources of U. S. Weather Bureau Hail Data

Colorado	Period of Available Record	Periods with Quality Hail Records	Quality Years Total Years
Byers	1931-65	1931-65	35
Boulder	1901-65	1938-65, 1901-09	37
Denver CO.*	1901-65	1901-65	65
Denver Ap*	1934-65	1934-69	36
Ft. Collins	1901-65	1933-60	28
Ft. Lupton	1911-65	1912-46	35
Ft. Morgan	1901-69	1932-45, 1955-62	22
Greeley	1901-65	1901-09, 1935-51	26
Grover	1910-69	1910-21, 27-28, 1949-69	35
Idalia	1941-65	1941-50, 1961-65	15
Kauffman	1936-69	1938-39, 1946-69	26
Julesburg	1912-65	1915-38, 1945-58	38
LeRoy	1901-69	1901-69	69
Otis	1941-69	1942-69	28
Sedgwick	1908-65	1915-24, 1930-42, 1948-65	41
Sterling	1910-69	1912-26, 1955-69	30
Wray	1901-65	1901-10, 1920-33, 1948-65	42
Yuma	1901-65	1901-05, 1941-61	26
Nebraska			
Big Springs	1901-69	1941-69	29
Bridgeport	1901-65	1936-48	13
Crescent Lake	1935-65	1941-63	23
Dalton	1913-69	1936-69	34
Harrisburg	1910-63	1911-18, 26-27, 1942-44, 1951-62	25
Imperial	1910-63	1901-20	20
Kimball	1901-69	1901-28, 1936-45, 1954-69	51
Kingsley Dam	1940-69	1946-58	13
Madrid	1901-63	1904-10, 1915-19, 1954-63	22
Oshkosh	1901-63	1915-34, 1946-63	38
Scotts Bluff	1901-63	1907-17, 1944-63	31
Stratton	1901-63	1919-28, 1941-48	18
Wyoming			
Cheyenne*	1901-65	1901-65	65
Hecla	1909-65	1922-28, 1949-65	24
La Grange	1902-65	1911-18, 1940-65	34
Kansas			
Bird City	1901-65	1917-28, 1939-48	20
St. Francis	1901-65	1911-15, 1941-60	25

* First-Order Station

period of record available for study, the period/s evaluated as having quality-hail records, and then the total years of quality hail records. Inspection of these totals reveals that most stations utilized in this study had 20 years or more with quality records, and a goodly number had 35 years or more. Of interest is the fact that certain stations (co-operative substation) in the region including Kimball, Nebraska, and LeRoy, Colorado, had more than 50 years of quality records and both were substations.

The locations of the stations with quality hail records utilized in the hail-day investigations appear on Fig. 1. The proposed hail study area is also indicated, and the length of record of the stations were coded to reveal not only the station positions but the length of records available. This reveals a reasonably good density of stations around the study area, particularly along a west-east line through it. Stations with quality data to the north and south of the study area are not as prevalent. Considering the quality of the land use in the general area involved, finding several substations in the area with good quality historical hail records seems providential.

The hail reporting method of the U. S. Weather Bureau requires that hail has to fall at the observing site (raingage), and thus the reporting of hail and formulation of hail-day statistics are not dependent on population or other localized factors influencing many other severe weather statistics.

3. Areal Patterns

Average Seasonal and Monthly Patterns. Fig. 2 is the pattern of hail days based on the point frequency of hail in the March-August period. Because of the small numbers of hail days per year, the average values have been multiplied by 20 and are the number in an average 20-year period. The March-August period contains 90% of the hail days that occur in this region. The pattern is dominated by a high at Cheyenne of 169 (between 8 and 9 hail days per year), which is the highest average number of hail days in the central United States (Stout and Changnon, 1969). The pattern indicates that storms originate in this "Cheyenne High," and move eastward from it. Thus, the proposed rectangular hail study area, shown as a dashed line in Fig. 2, has on the average a much greater point frequency of hail in its northern edge (100 in 20 years or 5 per year) than on its southern edge (70-80 hail days per 20 years).

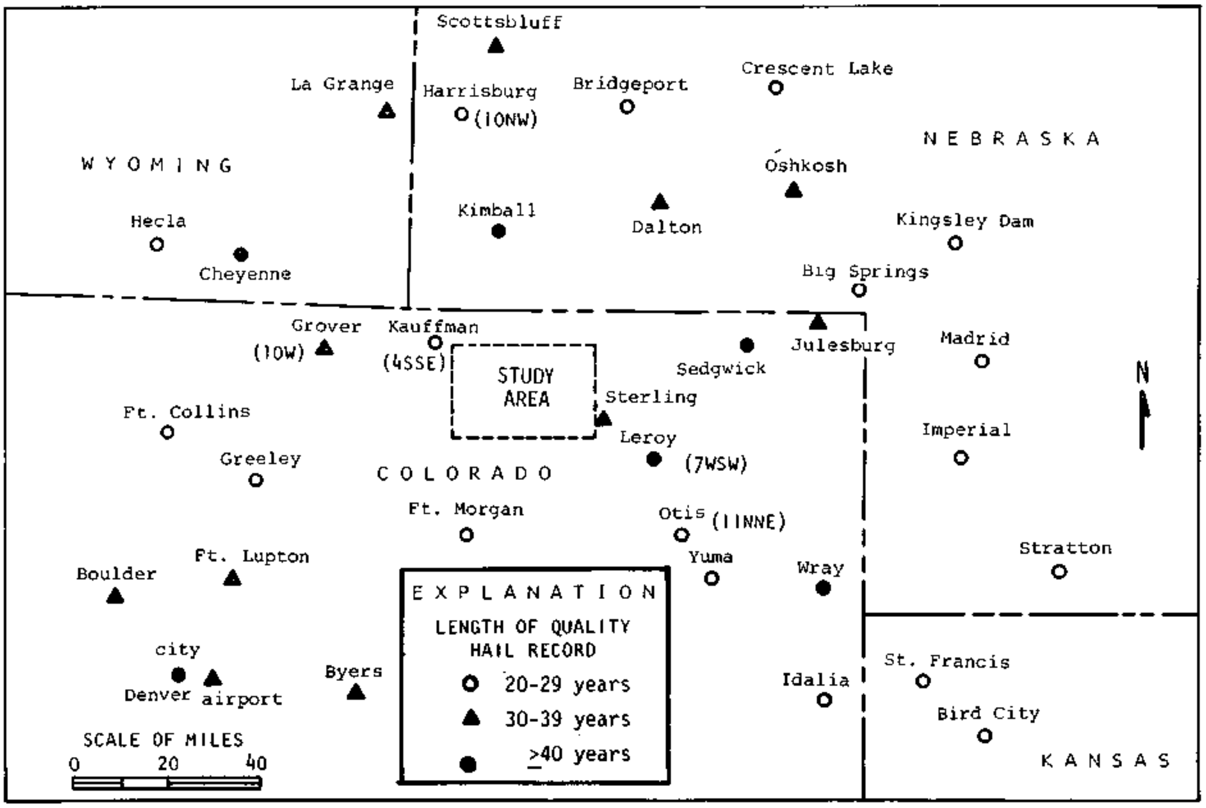


Figure 1. U.S. Weather Bureau stations in Colorado and environs and indications of length of quality hail records

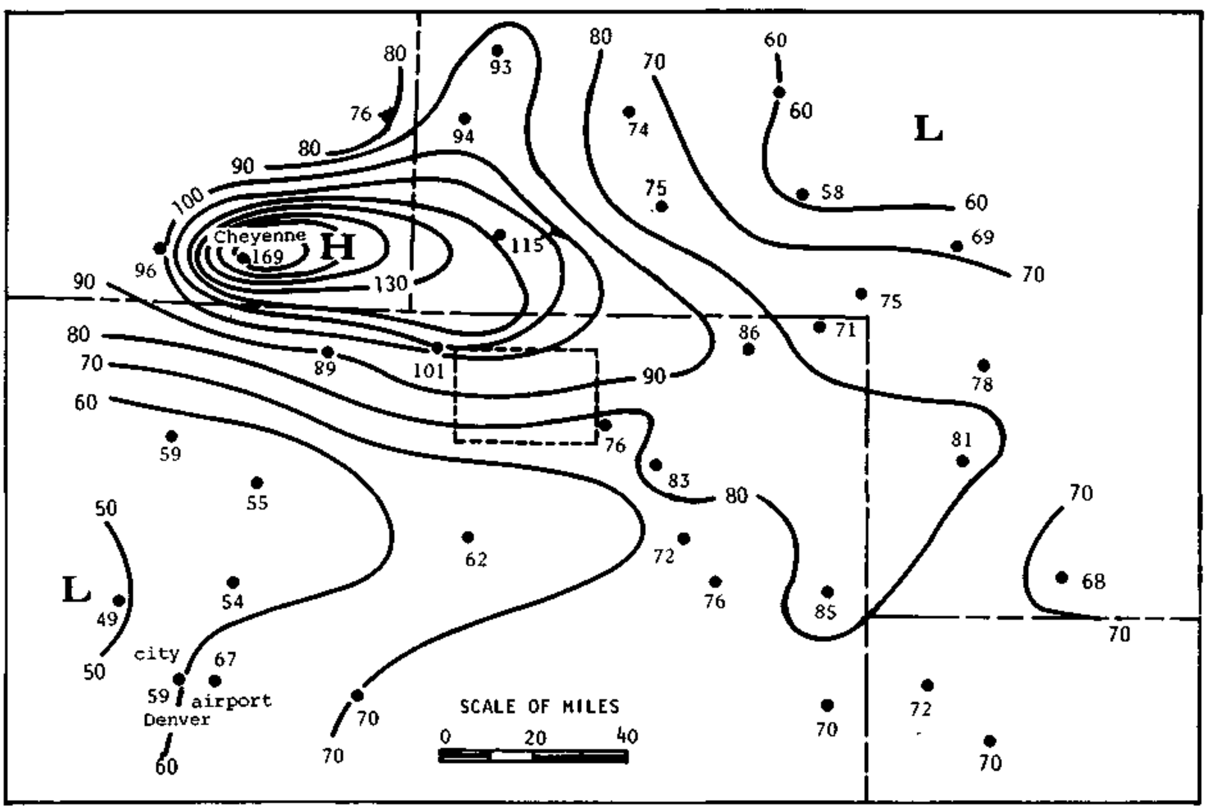


Figure 2. Number of March-August hail days in an average 20-year period

Fig. 3 is a presentation of the monthly average hail-day patterns for the six months that compose Fig. 2. The March pattern indicates the infrequency of hail in the entire northeastern Colorado region with point frequencies between 1 and 2 hail days per 20 years. The April map shows more in activity such that points in the area experience between 4 and 8 days per 20 years, and in May the Cheyenne High, that so dominates the March-August pattern, is first apparent. In May the 20-year averages throughout most of the region are sufficiently great to produce point frequencies of 1 to 2 hail days per May.

The June pattern is also dominated by the Cheyenne High, and comparison of the June values with those of the other five months indicates that June is the peak month of hail activity throughout most of the area. However, in the proposed hail study area, the point frequencies in May are equivalent to those in June, particularly in the southern part of the study area.

In July the average frequency of hail days begins to diminish. The Cheyenne High is still significant, but the high area has assumed WNW-ESE orientation, an orientation that dominates the seasonal map (Fig. 2). Again, although July is generally not the maximum hail month in northeastern Colorado and surrounding states, parts of the northern extremities of the study area average 30 hail days per 20 years which is equivalent to the average they have in June.

Thus, in the extreme northern portion of the proposed study area, the average point frequencies of hail days in June and July are similar (30 hail days per 20 years). The diminishment of hail activity is quite apparent in August although the Cheyenne High is still somewhat apparent, although now slightly elongated to the northeast.

Patterns Based on Frequency Distributions. The varying yearly numbers of hail days at any point can be used to establish the frequency distribution of hail at each point. The hail days per season or year are ranked, plotted, and fitted to a distribution (see Fig. 6). These frequency distributions for various stations were examined to discern the number of hail days expected to be equalled or exceeded at least once in a 10-year period. A pattern drawn using these frequency values for the 15 May-31 July period is portrayed in Fig. 4. This pattern reveals that stations such as Greeley and Fort Morgan

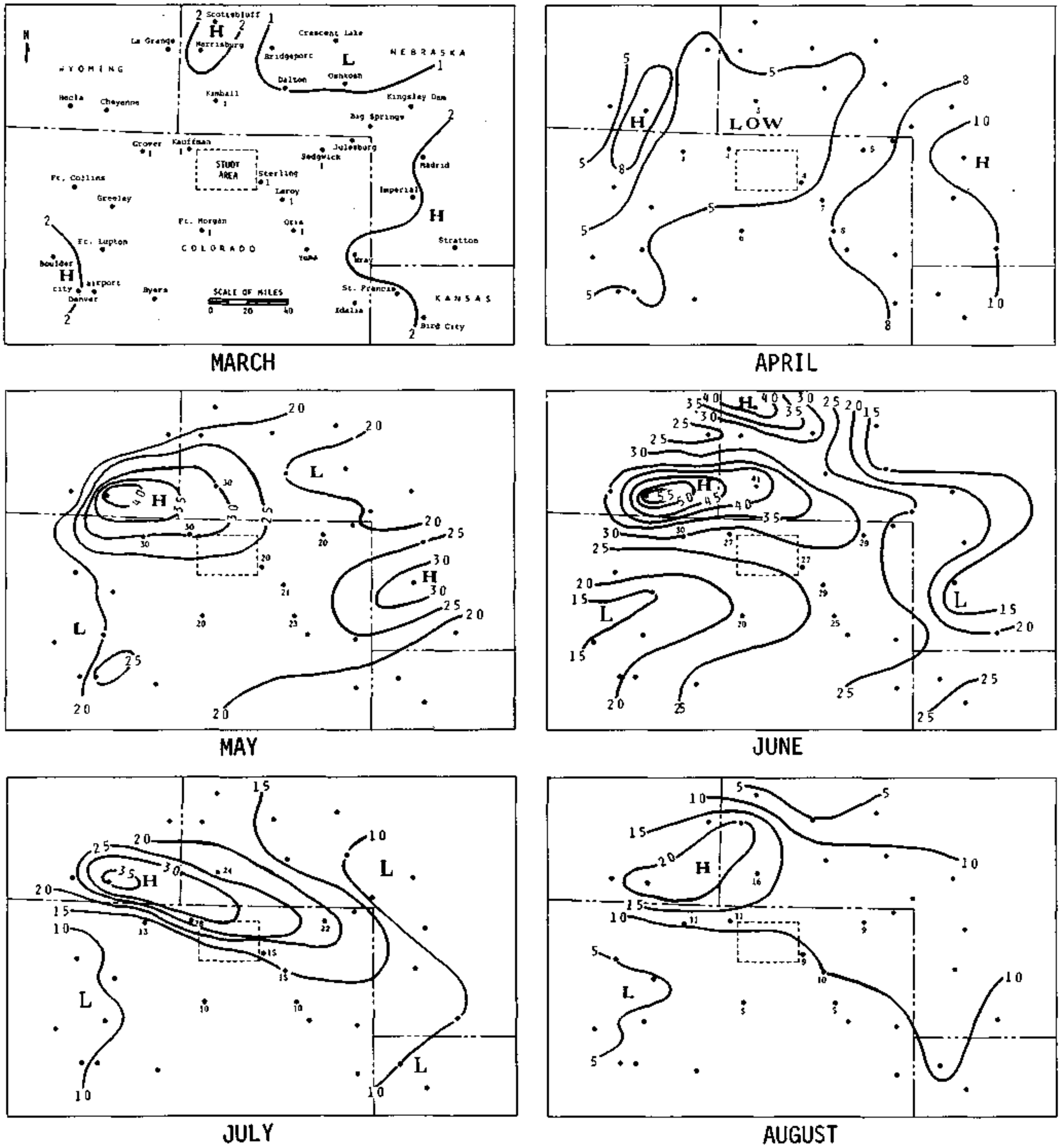
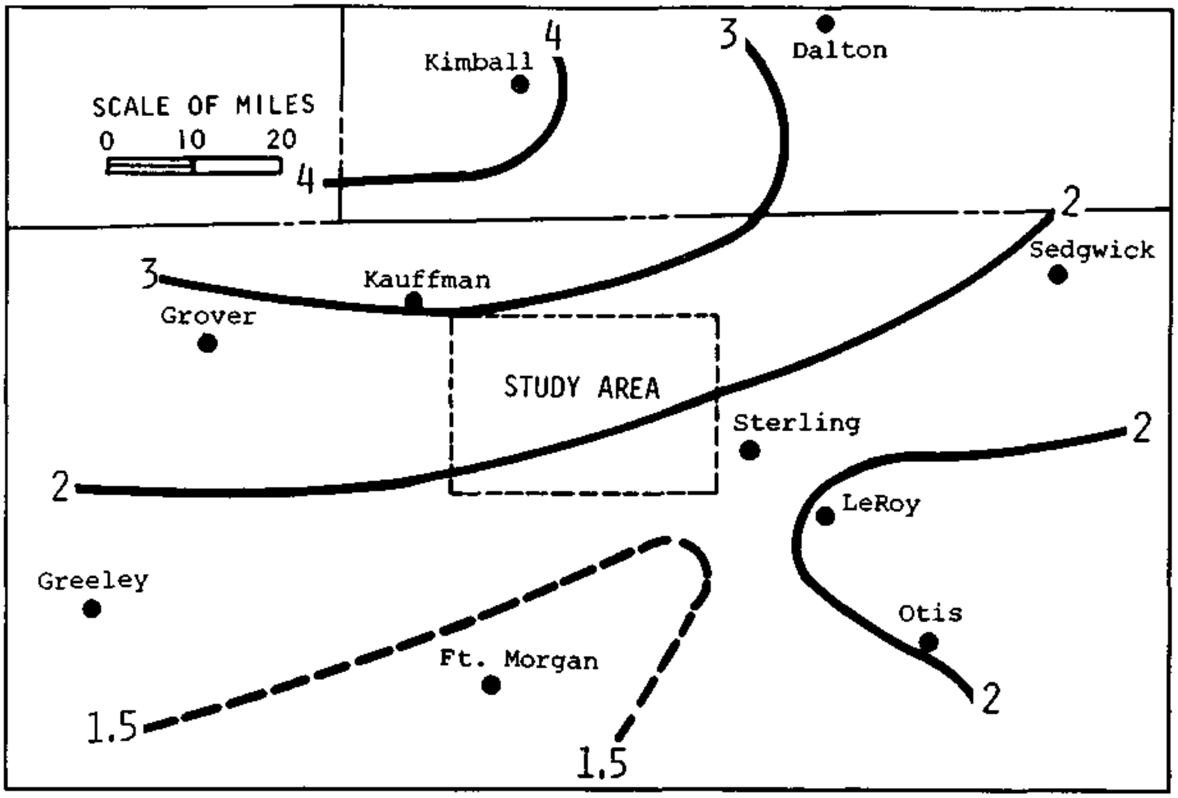
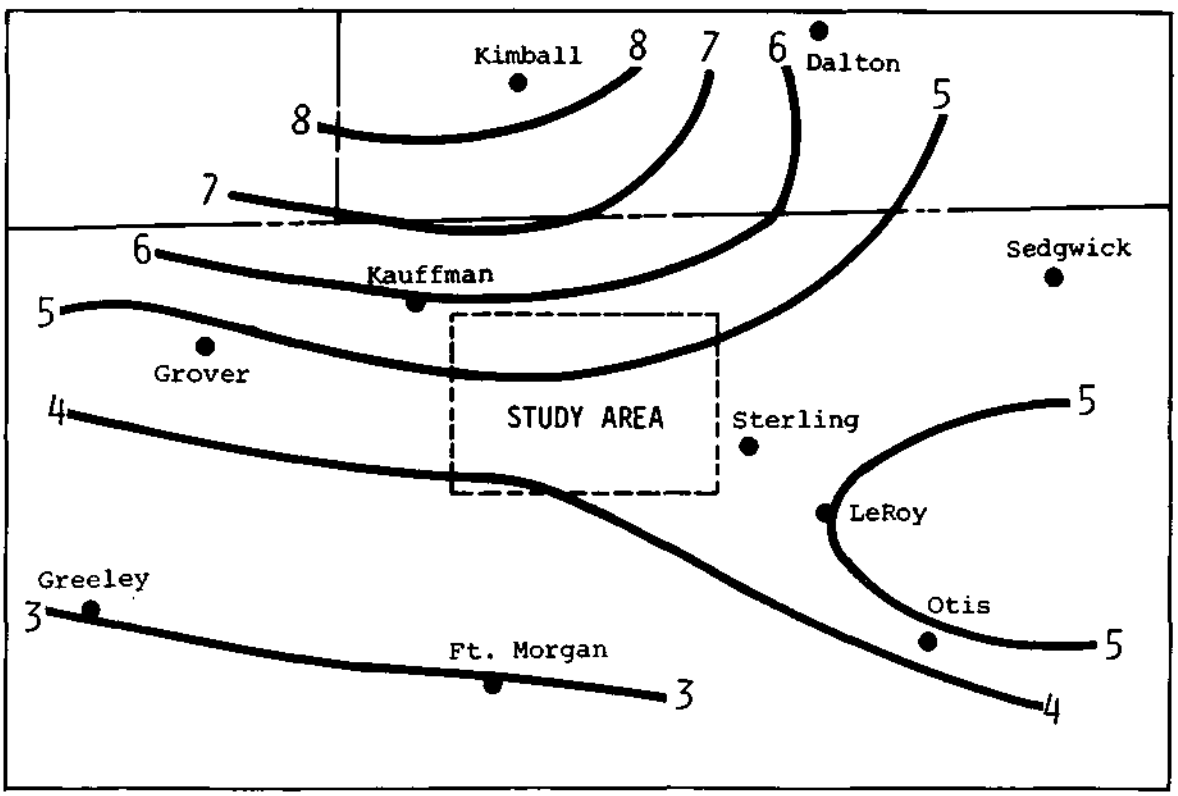


Figure 3. Number of hail days in an average 20-year period. Point values shown at stations near hail study area



Average number of hail days in 15 May-31 July period



Number of hail days in 15 May-31 July period expected (at a point) to be equalled or exceeded at least once in 10 years

Figure 4. Areal patterns of hail days in 15 May-31 July period

can expect at least once in 10 years three or more hail days during that 11-week period, whereas points in the northern part of the proposed study area will have 5 or more hail days at least once in a 10-year period.

The average hail-day pattern for this 11-week period is also shown in the upper map of Fig. 4. Comparison of these two maps reveals that, in general, the 10-year frequency values of these various stations are about twice as great as the average expected, and the patterns are alike.

Point-Area Relations. Fig. 5 shows two curves, each based on a different set of average hail day values, developed to illustrate variations in average hail-day frequencies with variations in size of sampling area. The 13-year average annual hail crop damage days in the three counties studied (Logan, Morgan, and Weld) are plotted by county area and represent the three lowest points (dots) on Fig. 5. The average obtained by combining the hail damage days of these three counties (which form a 7,113 mi^2 area) is the upper dot. A line was fitted through three of these dots to estimate the area-frequency relationship in damage days for these regions. A highly reliable statistical approach was not sought because of the paucity of data, but an effort was made to obtain an estimate of frequency of hail damage days in the study area. For instance, at 600 mi^2 (the size of the proposed hail study area) this curve indicates that the average number of hail damage days per year will be five in the study area.

Areas and their related hail-day frequencies also were created by sequentially combining the 15 May-31 July hail-day data of the eight Weather Bureau stations nearest the proposed hail study area. These eight stations are those on Fig. 4 with values on each of the monthly maps. These stations were combined on the basis of distance from the center of the study area. The area they formed (encompassed) was 4,500 mi^2, and in this analysis each station was considered to represent 500 mi^2 (4,500 ÷ 8). For instance, Kauffman and Sterling were the two nearest stations, and the average from their combined hail-day data was used to represent the 1,120 mi^2 area frequency shown as the lowest circle on Fig. 5. A curve was fit to the resulting 7 data circles to get a hail-day relationship for all hail days in the 15 May-31 July period. This set of data suggests that, on the average, the proposed hail study area (600 mi^2) would experience three to four hail days per year. These

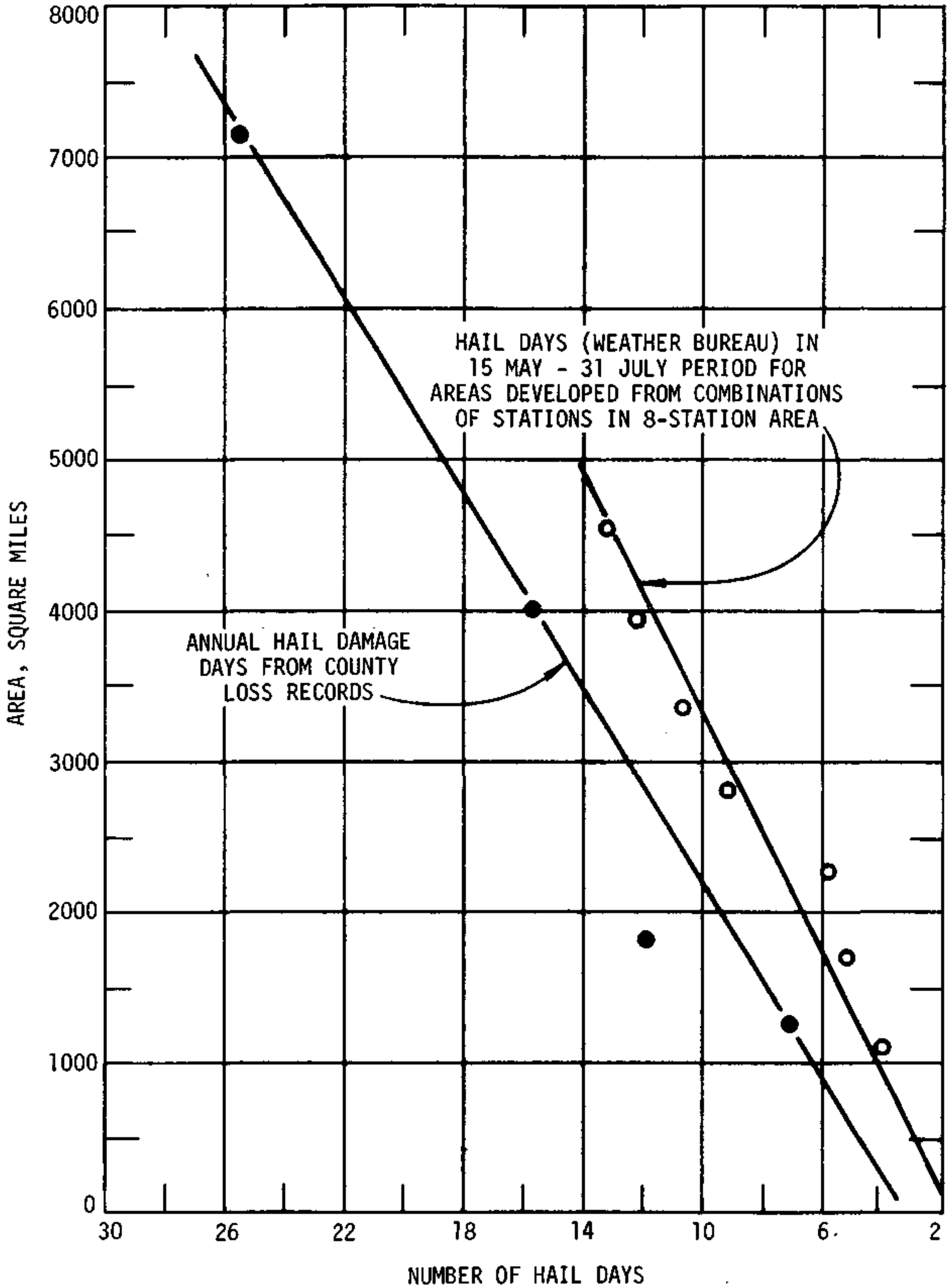


Figure 5. Areal frequency relations for average numbers of hail-damage days (insurance data) and average numbers of hail days (Weather Bureau data) in northeastern Colorado

hail days include damaging and non-damaging hailfalls, but the lack of adequate areal sampling of regional hail days is revealed by the placement of this curve to the right of the damage-day curve on Fig. 5. Theoretically, if the Weather Bureau 8-station data curve measured all hail days, it would be to the left of the damage-day (only) curve. Actually, the difference in the curves gives some estimate of the problem of using Weather Bureau data from scattered points throughout the region to establish areal frequencies of hail.

4. Temporal Variations

Point-Area Frequencies. The frequencies of hail days at each of the eight stations nearest the proposed study area for the 15 May-31 July study period are tabulated in Table 2. For instance, at Fort Morgan there were five years with no hail days, seven years with one hail day, five years with two hail days, and five years with three hail days within the 22 years of quality hail records. Inspection of the station statistics for this 11-week period reveals that the mode, or most frequent occurrence of any one number of hail days at four of these stations, was two and at the other four stations the mode was one hail day within the 11-week period. More than 50% of the years had two or fewer days with hail at all stations except Kimball.

The modes for the March-August period (Table 3) are not greatly different from those of the 15 May-31 July period, indicating that a large number of the hail days per year occur in this 11-week period. Kimball experienced much greater number of years with high hail-day frequencies ($\geq$ 7 days) in March-August than any of the other seven stations around the study area.

Fig. 6 presents point and area frequency curves for hail days at both the higher and lower ends of the distribution. Interpretation of the results on the high frequency graph indicate that the Sterling and Sedgwick stations would expect two or more hail days in this 11-week period at least once in five years, whereas the low frequency curves for these stations indicate that once in five years these two stations would each expect one or fewer hail days.

Inspection of the high frequency curves also reveal the variation between points or stations, and these differences represent the range of extremes found in the frequency curves for the eight stations nearest the

Table 2. Frequency of Years with Given Numbers of Hail Days in 15 May-31 July Period in 8-Station Area

	Number of years with a given number of hail days												
Station	0 Days	1	2	3	4	5	6	7	8	9	10	>10	Total Years
Ft. Morgan	5	7	5	5	0	0	0	0	0	0	0	0	22
Grover	5	7	9	6	5	3	0	0	0	0	0	0	35
Kauffman	2	5	6	5	2	2	2	1	1	0	0	0	26
LeRoy	9	9	28	18	1	0	2	1	1	0	0	0	69
Otis	4	5	10	5	3	1	0	0	0	0	0	0	28
Sedgwick	7	14	8	8	2	1	1	0	0	0	0	0	41
Sterling	6	15	5	2	0	0	1	0	1	0	0	0	30
Kimball	2	6	2	1	1	3	1	2	2	1	1	2(1)	24

1 year = 14 days, and the other year = 15 days

Table 3. Frequency of Years with Given Numbers of Hail Days in March-August Period in 8-Station Area

Station	0 Days	1	2	3	4	5	6	7	8	9	10	11	12	≥13	Total
Ft. Morgan	3	5	9	2	1	2	0	0	0	0	0	0			22
Grover	3	5	8	8	8	0	3	0	0	0	0	0	0	0	35
Kauffman	2	3	6	2	3	4	2	2	1	1	0	0	0	0	26
LeRoy	4	9	19	12	15	4	3	0	1	2	0	0	0	0	69
Otis	2	5	5	6	5	2	1	1	0	1	0	0	0	0	28
Sedgwick	3	14	10	7	4	1	1	1	0	0	0	0	0	0	41
Sterling	5	9	7	5	1	1	1	0	0	0	0	1	0	0	30
Kimball	2	6	1	1	0	0	0	5	0	2	3	1	1	2(1)	24

1 year = 15 days, and the other year = 17 days

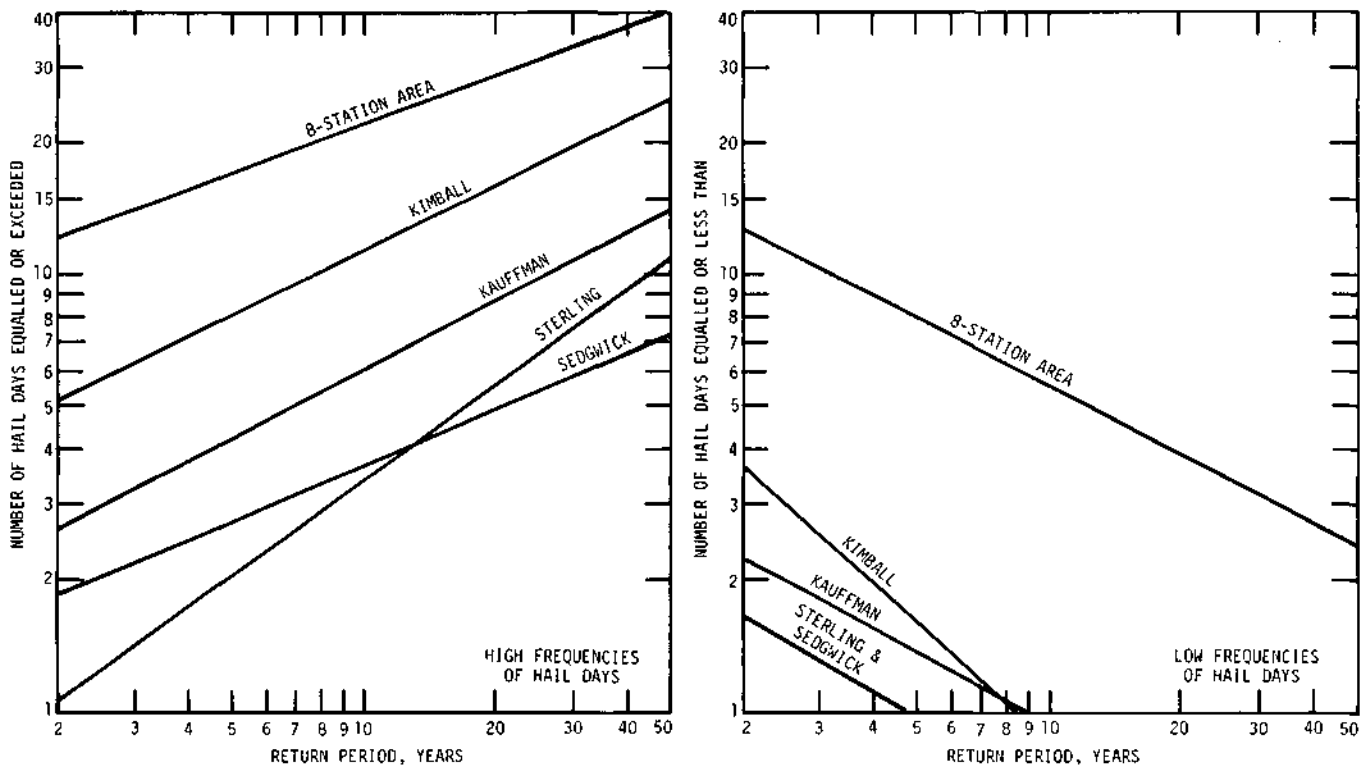


Figure 6. Point and area frequency curves for hail days (U.S.W.B. data) in 15 May-31 July period

study area. For instance, the once in 5-year value at Sterling (for the 15 May-31 July period) is two or more days, that for Kauffman is 4 or more days, that for Kimball is 8 or more days, and that for the 8-station (4,500 mi^2) area is 17 or more hail days. In comparison, 5-year point values at most Illinois stations (summer season) are 2 days and that for a 3,000 mi^2 area is 5 hail days (Changnon and Schickedanz, 1969).

Temporal Change. Records from five stations in the northeastern Colorado area with long records of quality hail data were used to portray the temporal variations in hail days for the May-August period. Stations chosen for this analysis were the two first-order stations, Cheyenne and Denver (both with records available for the 1901-1969 (Table 1) period); for the only substation, LeRoy, with quality hail data for 1901-1969; and for two other substations, Kauffman and Dalton, with continuous quality records of hail from 1936 through 1969. Inspection of Fig. 1 shows the locations of these stations and that the Kauffman and LeRoy stations are those closest to the proposed study area.

A harmonic analysis was performed on the data from 1936 through 1969 for the five stations to determine if significant cycles were present. It was found that the time series for Dalton and Denver were random series during this period. Cheyenne and Kauffman had long-term significant cycles with 34 year periods. The time series for LeRoy has significant cycles with 17 year periods. The harmonic analysis also indicates that Cheyenne, Kauffman, and LeRoy are at the low point of their cycles and thus the 5 year period from 1971-1976 might very well be in a period of upward trend in the number of hail days per year.

In an effort to reveal the general trends and fluctuations in these long time series, the data were plotted in 5-year running totals (Fig. 7). Comparison of the Cheyenne and Denver curves does not reveal a high degree of similarity. In general, the Cheyenne curve shows 5-year peaks centered around 1910, 1930, and 1950, suggesting a 20-year cycle, and it also exhibits extreme temporal variability with values ranging from a 5-year high of 60 hail days to a low of 22. The Denver curve reveals a high in the 1905-1909 period, a general period of low hail frequency during the 1911-1940 period, and a 15-20 year period of relatively high hail frequencies since 1945. The range of the

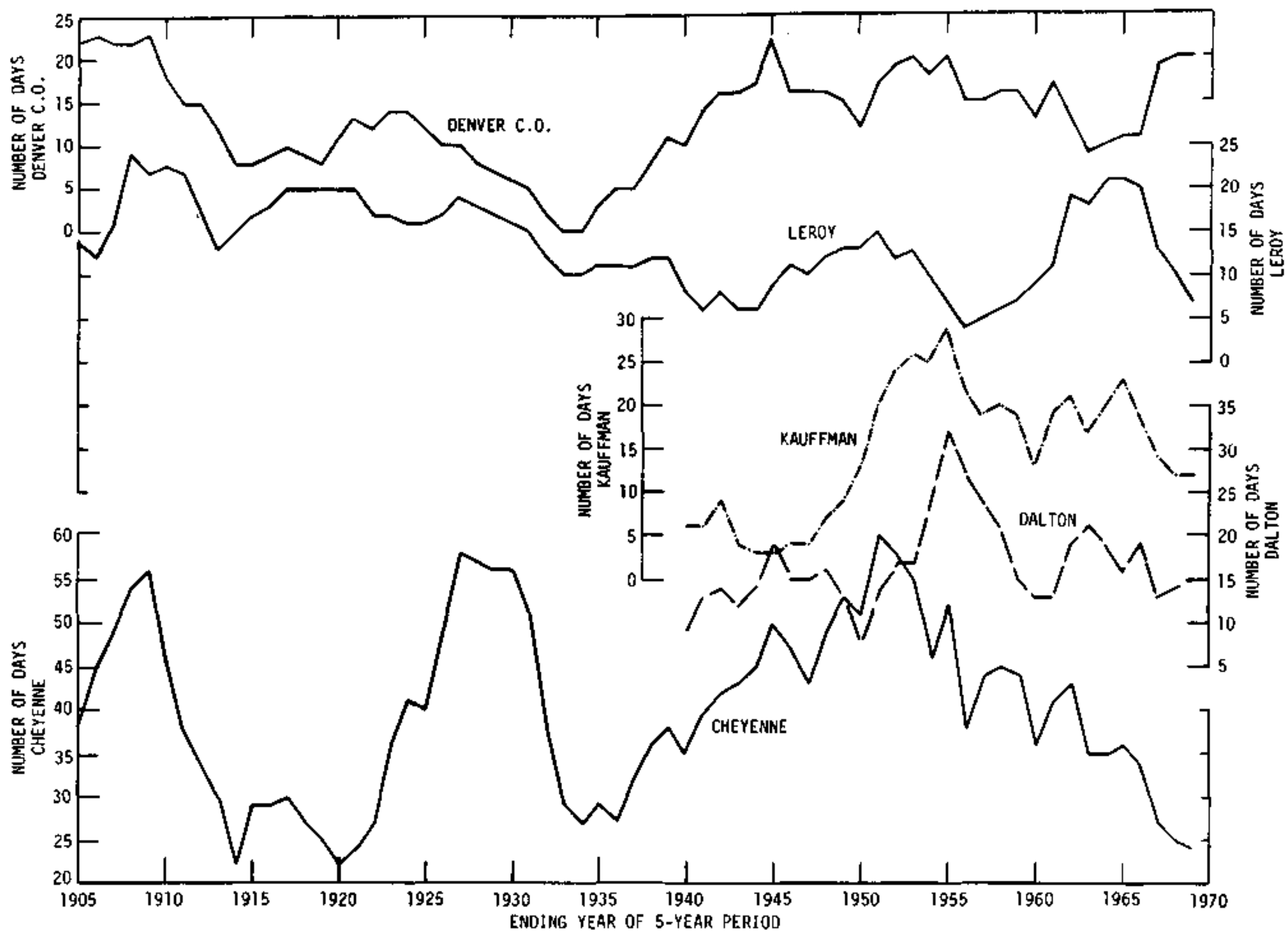


Figure 7. 5-year moving totals of hail days occurring in the May-August period at five selected stations

5-year values at Denver are much lower, from a high of 23 hail days to a low of 0 hail days in the 5-year periods ending in 1933 and in 1934.

In many respects, the curve for the LeRoy substation closely resembles the Denver curve through 1935, but thereafter it has a shape that does not agree with Denver or Cheyenne. Inspection of the Kauffman and Dalton curves reveal that they are rather similar. High frequencies are reached in 5-year periods ending in 1955 and in 1965-1966, and low values occur during the early 1910's and for the 5-year period ending in 1960. However, the shapes of their hail-day curves do not agree with any of the others plotted on Fig. 7. This lack of agreement between stations in the same general geographical area is indicative of the lack of areal spread of hailstorms on most days and may be indicative of differences in their hail climates. Certainly, the considerable differences in the curves for Denver and Cheyenne, which are both largely derived from local mountain-bred hailstorms, reveals that the conditions conducive to such storms are not prevalent at both locations in any given year or in long series of years.

Another means of examining the temporal variations in hail days and the areal spread of hailstorms on any given day in the 15 May-31 August period is furnished by Table 4. The statistics on the total number hail days are based on a combination of data from the 7-stations nearest to the proposed hail study area. For instance, the 1946 data for the 15 May-31 July period revealed that there were a) 4 total hail days in the 4,500 mi^2 area, as defined by these 8 stations, b) three of these hail days were days with hail occurring at only one station, and c) on the fourth day, hail was reported at 2 stations among the 8. There were 315 hail days in the 8-station area within the 24-year period represented in Table 4, and 80% of these days were single station occurrences of hail. Comparable statistics for a 3,000 mi^2 area in Illinois revealed that only 60% of the summer hail days were represented by hailfalls at a single station. Lack of widespread hailfalls within this 4,500 mi^2 area of Colorado-Nebraska is further revealed by the fact that on only 5 days did 4 of the 8-stations report hail.

The data in Table 4 also can be used to inspect for temporal changes in hail days on a regional basis. This can be achieved for the total days and for the frequency of single station or any other combination of stations with hail. The period from 1956-1965 was one of exceptionally high hail-day frequencies in the area. This is revealed by the total hail days for each

Table 4. Number of Hail Days Defined by Different Numbers of Stations in the 8-Station Area During the 15 May-31 July Period

	Number of Stations Reporting Hail on a Hail Day					
Year	1	2	3	4	≥5	Total Days
1946	3	1				4
1947	5					5
1948	9	1				10
1949	12	1	1			14
1950	12	0				12
1951	17	1				18
1952	8	2				10
1953	11	1				12
1954	6	2				8
1955	10			1		11
1956	11	2	1			14
1957	6	5	1			12
1958	12	4		1		17
1959	15	1	1			17
1960	9	2	1	1		13
1961	19	5				24
1962	20	4	4	1		29
1963	11	4				15
1964	7	4				11
1965	18	3	1			22
1966	3		1	1		5
1967	14		2			16
1968	5					5
1969	8	3				11
Totals	252	46	12	5	0	315

year in this 10-year period, and also by the number of days with two or more stations reporting hail.

Occurrences by Date s. The dates of hail, as reported by the 8 stations surrounding the hail study area, were used to develop a regional frequency of hail days according to their occurrence on each calendar date. The results are depicted on Fig. 8 along with a map of the 8 stations used to develop the statistics. These calendar-day data are based on frequencies during the 194-6-1969 period. For instance, during this 24-year period hail occurred seven times on May 15 (at one or more of the 8 stations) and June 16, and these are the two highest frequencies for any dates. Thus, in almost one-third of the years, hail occurred somewhere in this 8-station area on May 15 and June 16. Inspection of the dashed curve on Fig. 8 indicates other dates in May, June, and July which have experienced hail on 6 different years during the 24-year period.

The date values were combined into 3-day totals to remove some of the date-to-date variability reflected in the dashed line. The curve for the 3-day totals reveals the pronounced peak in hail day occurrences in mid-May with other peaks in the second and fourth weeks of June and in mid-July. The curve for the 3-day totals also reveals the fact that most of the hail days in this general area occur between 14 May and 20 July. Occurrence of hail days before and after this period is markedly less.

5. Summary and Conclusions

Statistics considered useful for the design, planning and operations of the National Hail Research Experiment have been presented in this section.

It is obvious from many presentations of the data that there is a lack of widespread hailstorms on any given date in the general area (Table 4 and Fig. 7). Chances for hail being reasonably widespread within a sizeable area (3,000 mi^2 or larger) are much lower in Colorado than in Illinois.

Importantly, the proposed hail study area appears to be in a climatic transition zone. Point averages in the southern portions of the study area are 50% lower than those in the northern portions (a distance of 20 miles). Furthermore, temporal distributions of hail days at LeRoy and Kauffman (at the southeast and northwest corners of the hail study area) reveal distinctly

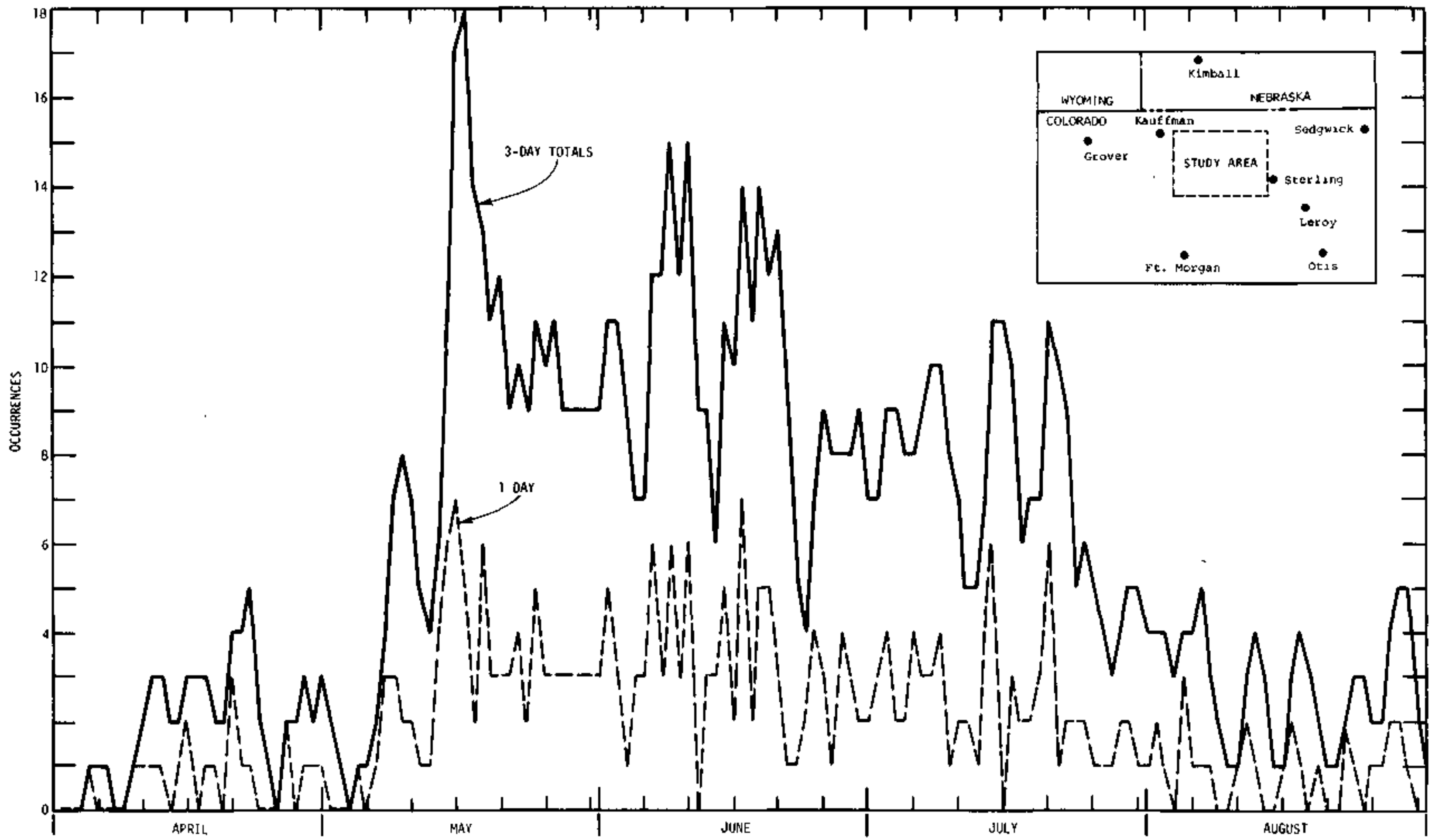


Figure 8. Daily frequencies of hail in 8-station area

different variations in their time distributions. Thus, there is evidence that the proposed hail study area is positioned in a zone of sharply changing hail climate.

Examination of temporal data for time trends and possible cycles in hail days reveal extreme difference between points. Cycles exist at Cheyenne, Kauffman, and LeRoy. There are sizeable temporal fluctuations in point hail-day frequencies for 5-year periods. For instance, Kauffman (located adjacent to the study area) had a range of 3 to 28 hail days (May-August) for 5-year periods during the 1936-1969 period. These results suggest that a 5-year field program in this area may experience a widely varying number of hail days. Harmonic analysis indicates that Cheyenne, Kauffman, and LeRoy are at low points of their cycles and thus the 5-year period from 1971-1976 might very well be in a period of upward trend in the number of hail days per year. Careful attention must be paid to the trends of hail days as revealed by long-term records of hail insurance and for existing stations such as Kauffman and LeRoy.

The Cheyenne maximum in the monthly average hail patterns indicates a general shift in orientation of its major axis from E-W in May and June to WNW-ESE in July. This suggests either a shift in storm motions or in storm development.

The calendar-day analysis of the hail days revealed that the 14 May-21 July period is truly the maximum of hail day activity in the proposed study area. Furthermore, there are apparent "singularities" in the dates that experience hail. Prime dates for hail activity include May 15, 16, 18; June 6, 8, 10, and 16; and July 14 and 20.

CLIMATOLOGY OF RADAR-HAIL ECHOES

1. Introduction

During the early 1960's a hail research project sponsored by Colorado State University was centered in northeastern Colorado. The summer operation of a 3-cm radar located near the southwest corner of the proposed study area (Fig. 1) was a part of this project. The resulting radar data for the 15 May-31 July period in 4—years (1961-1964) were analyzed and presented in reports in great detail. Certain hail-echo data from these studies have been used in this particular climatic study to analyze characteristics for hail-producing echoes that occurred in any portion of the proposed hail study area. The purpose of this study was to describe these hail-echo characteristics including their frequency, location of formation, motion, duration, and mergers with other echoes. Such climatic information should prove useful in the design of the field operations including placement of the radars and other planning for airborne and surface studies of the storms.

2. Data

Selected information were obtained from a series of reports that presented in great detail data on hail echoes in northeastern Colorado during the 1961-1964 period (Schleusener et al, 1962; Schleusener et al, 1963; Marwitz et al, 1965). In these reports, maps for each 2-week period in the 15 May to 31 July period were prepared for each year to depict the tracks of the echo centroids of all known hail-producing echoes in the region. For instance, there were 4 maps (1 for each year) for the 15-31 May period, and each showed the hail-producing echoes throughout the northeastern Colorado region. These echo centroid tracks were plotted from the echo origin through its dissipation, and also indicated were the starting and ending times plus mergers with other echoes.

Transparent maps with the outline of the proposed hail study area were overlayed in these published echo track maps to define and delineate those echoes that crossed any portion of the proposed 600-mi^2 study area. Statistics derived from the 113 echoes found on these echo maps were those used in this radar climatic study.

3. Results

Frequency. The frequencies of hail-producing echoes in the proposed study area for each 2-week period in each year are shown in Table 5. Inspection of the yearly values for each 2-week period reveals considerable year-to-year variability and thus great scatter around the 4-year averages. It is significant that each 2-week period had at least 1 echo. The averages reveal that hail echoes were most frequent in the late July and late May periods and least frequent in the late June period. The total average number of echoes for the 11-week period is 28, although the 4-year sample indicates a range from 16 (1964) to 43 (1962).

The frequency of days with hail-producing echoes in the proposed study area appears in Table 6. These values exhibit less year-to-year variability than do the number of echoes (Table 5). In general, the days also indicate reasonable continuity in a given year. That is, if the frequency was high in the May period, it was relatively high in the succeeding four 2-week periods, and visa versa. The values for 1963 are the only exception to this relationship. The annual totals of hail-echo are listed along with those from the two other hail data sources. In general, these show a very good correspondence, although the number of crop-loss days in the 3-county area in 1962 greatly exceeds the number of days with hail-producing echoes (that occurred in the study area) and the number of days with hail from the records of the eight Weather Bureau stations in the immediate area. It should be remembered that the number of hail-producing echoes that "occurred" in the study area were not necessarily hail producers in the study area. The hail they produced could have occurred anywhere in northeastern Colorado.

Echo Tracks. Fig. 9 depicts the composite of radar-echo tracks for the five 2-week periods for which data were available from the 1961-1964 period. A regional reference map is shown in the upper left of Fig. 9, and the centroid tracks of the 25 hail echoes that occurred during 15-31 May where the proposed study area exists are shown in the upper right map. Locations of echo formations were generally to the immediate west or to the far southwest of the study area and the echoes exhibited a variety of tracks. Hail echoes were somewhat less frequent in the 1-15 June period, and they indicated a distinct tendency for formation to the west of the study area. General examination of the centroid tracks shown in the 5 maps of Fig. 9 reveals the extreme variability in directions of motions for the hail-producing echoes.

The origins of the echoes, as defined by published material, are the small closed circles, and the dissipation or echo termination points are represented by the arrow heads. If two echoes merged, the track of the echo that had the longest life prior to the merger was depicted. Echo mergers are shown where they occurred by the joining of two lines. Several of these can be seen in the map for the 16-31 July period.

Table 5. Frequency of Hail-Producing Echoes in Proposed Study Area During Each 2-Week Period and Year

	May 15-31	June 1-15	June 16-30	July 1-15	July 16-31	Total
1961	4	5	6	7	5	27
1962	10	8	8	6	11	43
1963	8	2	1	5	12	28
1964	3	3	2	5	2	15
Average	6.2	4.5	4.3	5.8	7.5	28.3

Table 6. Frequency of Days with Hail-Producing Echoes in Proposed Study Area During Each 2-Week Period and Year

	May 15-31	June 1-15	June 16-30	July 1-15	July 16-31	Total	No. hail days in USWB area (8-stations)[(1)]	No. crop-loss days in 3-county area[(2)]
1961	4	4	5	4	4	21	24	24
1962	7	4	4	5	8	28	29	47
1963	5	2	1	3	8	19	15	13
1964	2	3	2	4	2	13	12	10
Average	4.5	3.3	3.0	4.0	5.5	20.3	20.0	23.5

(1) Based on 15 May-31 July period

(2) Based on total season, April-September

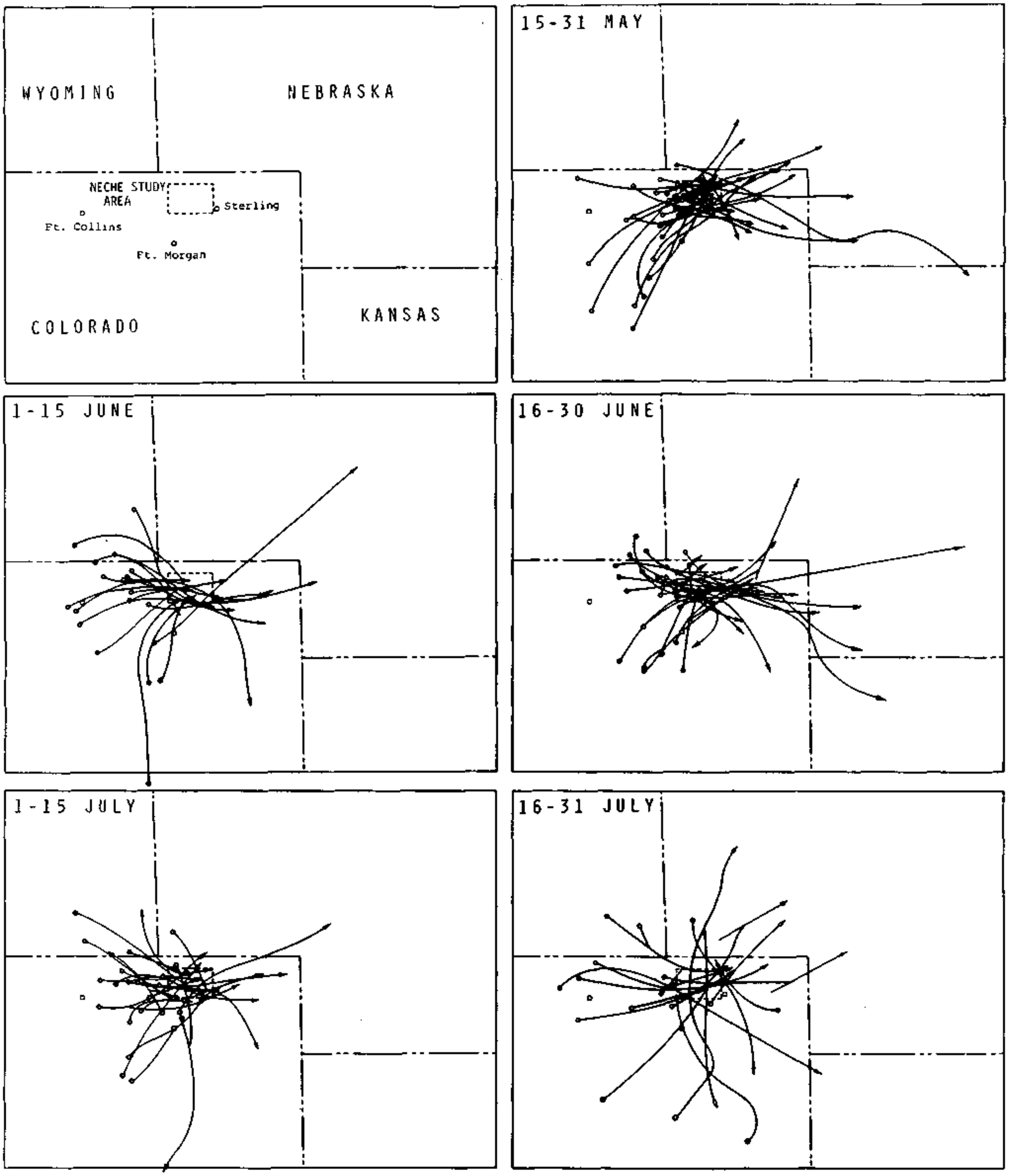


Figure 9. Tracks of centroids of all hail-producing echoes in 1961-1964 that occurred inside the region designated as the study area

Motion. The directions of motion of the 113 hail-producing echoes were summarized according to the average direction of each through the study area. The results were tabulated by 20-degree sectors (Table 7), and the resulting motion "roses" for the 2-week periods are shown in Fig. 10. In the May 15-31 period, a distinct preference for motions from the SW and WSW are shown, and in the two periods of June there is a definite tendency to westerly motion. The strong westerly component is still prevalent in July 1-15, although there is an increasing tendency for echoes to move through the region from the WNW. The strong preference for echo motions from WNW is clearly obvious during the July 16-31 period. This period also had more hail-producing echoes than any other 2-week period. The motion rose for all 113 hail-producing echoes also is shown in the lower right hand corner of Fig. 10. This presentation reveals that the prevailing echo motion through the proposed study area was westerly, the 20-degree sector centered at 270 degrees with nearly equal frequencies of motions from the WNW and WSW. The occasional north or south moving echo is another factor to be considered, and is one that would tend to recommend a square-shaped study area rather than a E-W oriented rectangular study area.

Echo Durations. The echo duration data were sorted and classed according to 1-hour periods with those with durations greater than 4 hours sorted into one class. One echo lasted 7 hours. Echo durations in the first three 2-week periods show a distinct tendency to persist for more than four hours, whereas those in the two periods in July indicate a preference for durations between 2 and 3 hours.

Echo Formation Locations. The data in Table 7 indicate that 21 of the 113 echoes that affected the proposed study area actually developed where the proposed study area is to be located. These localized developments were largely within July, and interestingly, these really accounted for the differences found between the total numbers of echoes for the five 2-week periods. For instance, inspection of the values of echo development for the "Out of Area" class reveals relatively small differences between the 2-week period values, and hence, the majority of the differences between these periods is due to the "In Area" values.

Table 7. Selected Statistics for all Hail-Producing Echoes that Occurred Somewhere in the Hail Study Area during the 15 May-31 July Period of 1961-1964.

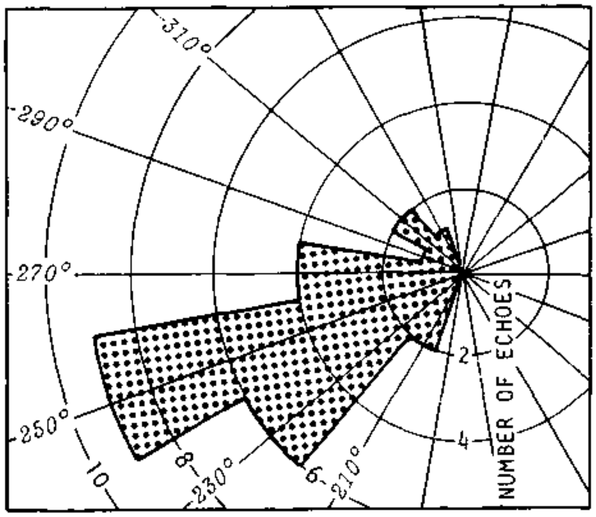
Number of Hail Echo Tracks that Occurred in the Study Area (1961-1964)

Period	Duration (hrs) <1	1-2	2-3	3-4	>4	Total
5/15-31	2	3	3	5	12	25
6/ 1-15	0	4	0	4	10	18
6/16-30	0	3	2	5	7	17
7/ 1-15	0	3	10	4	6	23
7/16-31						14931330
Totals	3	17	24	21	48	113

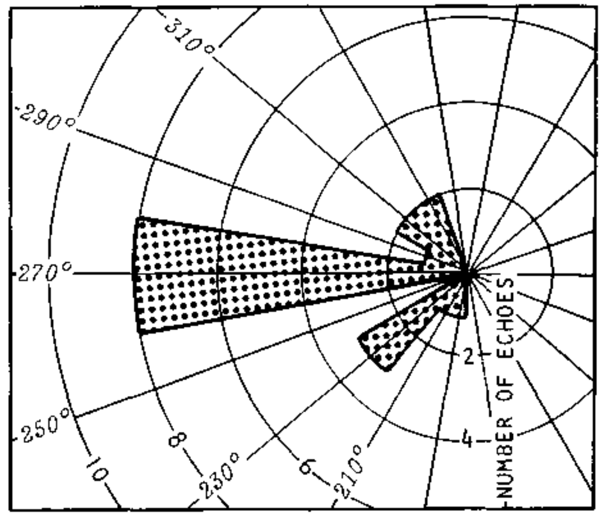
Period	Echo Development Locations: In Area	Out of Area	Echo Mergers Locations (with respect to the study area): In Area	Up-Wind	Down-Wind	Not Merged
5/15-31	6	19	1	7	2	15
6/ 1-15	0	18	6	0	4	8
6/16-30	1	16	5	4	3	5
7/ 1-15	5	18	5	4	4	10
7/16-31	9	21	9	2	3	16
Totals	21	92	26	17	16	54

Direction Across Study Area

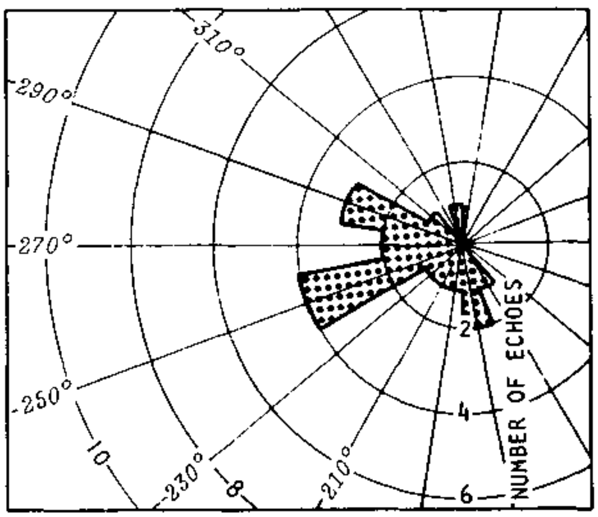
Period	180-200°	201-220°	221-240°	241-260°	261-280°	281-300°	301-320°	321-340°	341-360°	Other
5/15-31	0	2	6	9	4	1	2	1	0	0
6 / 1-15	1	1	3	0	8	1	2	2	0	0
6/16-30	1	1	1	4	2	3	1	0	1	3
7 / 1-15	0	3	1	3	7	5	2	1	1	0
7/16-30									13625102010	0
Totals	3	10	17	18	26	20	9	4	3	3



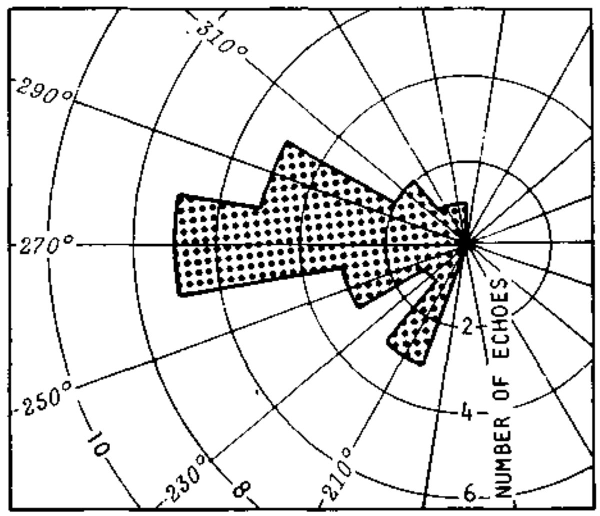
MAY 15-31 (25 echoes)



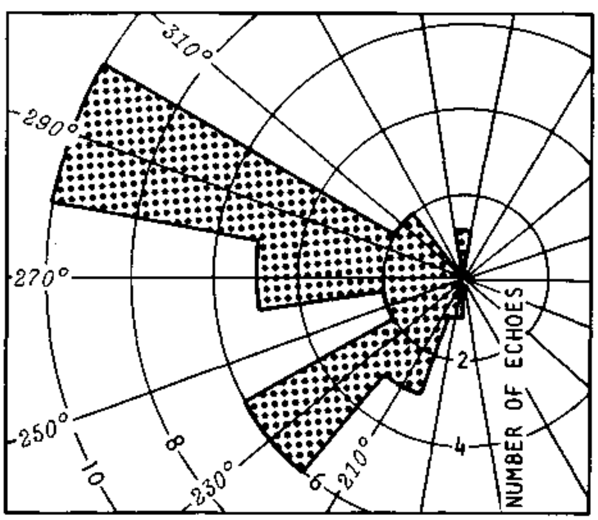
JUNE 1-15 (18 echoes)



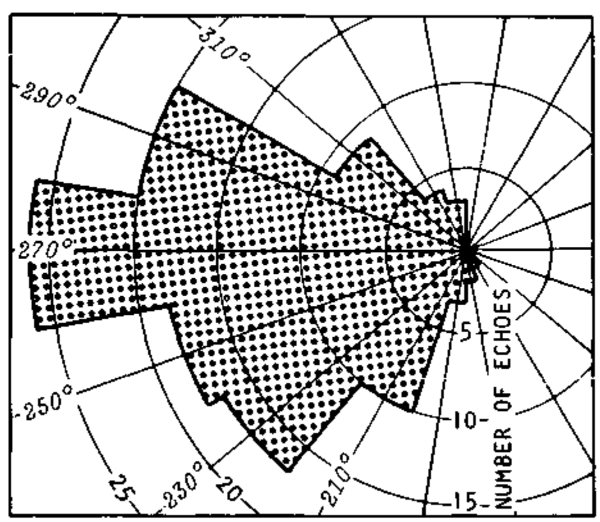
JUNE 16-31 (17 echoes)



JULY 1-15 (23 echoes)



JULY 16-31 (30 echoes)



MOTIONS OF 113 HAIL-PRODUCING ECHOES
(1961-64) THAT CROSSED ALL OR
PORTIONS OF NECHE STUDY AREA

Figure 10. Motions of hail-producing echoes that crossed all portions of Colorado hail study area in 1961-1964 period

Echo Merging. The merging of echoes, as defined by the data source publications, is relatively frequent in the study area and environs. Approximately 50% of the 113 echoes had a merger with another echo upwind, in the study area, or downwind of the study area. The four 2-week periods after 31 May revealed (Table 7) about the same frequency of echo mergers in the study area, between 5 and 9. Upwind mergers of hail-producing echoes were most prevalent in the May period, whereas downwind mergers were rather uniformly distributed throughout the five periods. Non-merging echoes were most prevalent in the May and two July periods.

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APPENDIX B

Table 1. Adjustment factors for crop susceptibility.

Month	Susceptibility Relative (SR)*	Susceptibility Index (SI)
April	1.	1.0000
May	68.	.0147
June	234.	.0043
July	121.	.0083
August	6.	.1667
September	1.	1.0000

* The susceptibility relative is obtained by dividing the monthly hail intensity index for each month by the monthly hail intensity index for the month of April.

The monthly intensity index is computed in the following manner: Loss cost is a number that represents the total storm-day losses divided by the liability for the area with loss, the ratio being multiplied by $100. The median storm-day loss cost value has been determined for various months in several states by Changnon and Stout (1967)."" To obtain the monthly hail-intensity indices the dollar designations were removed from the median values and they were multiplied by 10 .

** Changnon, S. A., and G. E. Stout, 1967: "Crop-Hail Intensities in Central and Northwest United States," J. of Appl. Meteor., 6:542-548.

Table 2. Adjustment factors for price changes.

Year	Price Relative (PR) (in %)	Price Index (PI)
1957	235	.00426
1958	250	.00400
1959	240	.00417
1960	239	.00418
1961	240	.00417
1962	244	.00410
1963	243	.00412
1964	237	.00422
1965	248	.00403
1966	267	.00375
1967	253	.00395
1968	261	.00383
1969	261	.00383

Table 3. Adjustment factors for liability.

Year	Liability Relative (LR) (in %)	Liability Index
Logan County		
1957	101.19	.010
1958	112.20	.009
1959	86.61	.012
1960	76.61+	.013
1961	76.19	.013
1962	35.57	.028
1963	24.40	.041
1964	24.11	.041
1965	23.21	.043
1966	56.40	.018
1967	110.12	.009
1968	86.67	.012
1969	86.67	.012
Morgan County		
1957	46.82	.021
1958	88.20	.011
1959	164.97	.006
1960	53.36	.019
1961	90.38	.011
1962	101.27	.010
1963	55.54	.018
1964	35.93	.028
1965	94.74	.011
1966	124.14	.008
1967	305.44	.003
1968	116.08	.009
1969	116.08	.009
Weld County		
1957	80.98	.012
1958	118.56	.008
1959	100.46	.010
1960	60.51	.017
1961	76.53	.013
1962	75.25	.013
1963	14.83	.067
1964	16.71	.060
1965	39.06	.026
1966	28.77	.035
1967	100.07	.010
1968	92.49	.011
1969	92.49	.011

Table 3. Adjustment factors for liability (cont.).

Year	Liability Relative (LR) (in %)	Liability Index
Tri-County		
1957	84.90	.012
1958	113.28	.009
1959	101.82	.010
1960	65.61	.015
1961	77.77	.013
1962	63.52	.016
1963	22.28	.045
1964	21.26	.047
1965	38.83	.026
1966	48.10	.021
1967	123.89	.008
1968	92.72	.011
1969	92.72	.011

Logan County - 364 mi^2 in crop land, 1827 mi^2 in county

Morgan County - 274 mi^2 in crop land, 1282 mi^2 in county

Weld County - 880 mi^2 in crop land, 4004 mi^2 in county

Tri-County - 1518 mi^2 in crop land, 7113 mi^2 in county

Table 4. Adjustment indices for dollar loss and acreage data.

a. Indices for Dollar Loss (ADL)

Year	May	June	July	August	September
Logan County					
1957	3.1	0.9	1.8	35.5	213.
1958 '	2.7	0.8	1.5	30.0	180.
1959	3.7	1.1	2.1	41.7	250.
1960	4.0	1.2	2.2	45.3	272.
1961	4.0	1.2	2.2	45.2	271.
1962	8.4	2.4	4.7	95.7	574.
1963	12.4	3.6	7.1	140.8	845.
1964	12.5	3.7	7.2	144.2	865.
1965	12.5	3.7	7.2	144.4	866.
1966	5.0	1.4	2.8	56.3	338.
1967	2.6	0.8	1.5	29.6	178.
1968	3.4	1.0	1.9	38.3	230.
1969	3.4	1.1	1.9	38.3	230.
Morgan County					
1957	6.7	1.9	3.7	74.6	447.3
1958	3.3	1.0	1.9	36.7	220.0
1959	1.8	0.5	1.0	20.9	125.1
1960	5.8	1.7	3.2	66.2	397.1
1961	3.4	1.0	1.9	38.2	229.4
1962	3.0	0.9	1.7	34.2	205.0
1963	5.4	1.6	3.1	61.8	370.8
1964	8.7	2.5	4.8	98.5	590.8
1965	3.3	1.0	1.7	36.9	221.7
1966	2.2	0.6	1.2	25.0	150.0
1967	0.9	0.3	0.5	9.9	59.3
1968	2.5	0.7	1.4	28.7	172.4
1969	2.5	0.7	1.4	28.7	172.4
Weld County					
1957	3.9	1.1	2.2	43.7	255.6
1958	2.5	0.7	1.4	26.7	160.0
1959	3.0	0.9	1.7	34.8	208.5
1960	5.2	1.5	2.8	59.2	355.3
1961	4.0	1.2	2.2	45.2	271.1
1962	4.0	1.2	2.2	45.1	266.5
1963	20.4	5.9	11.5	231.4	1380.2
1964	18.6	5.4	10.4	211.0	1266.0
1965	7.7	2.2	4.3	87.3	523.9
1966	9.6	2.8	5.4	108.5	656.3
1967	2.9	0.8	1.6	32.9	197.5
1968	3.0	0.9	1.7	34.5	210.7
1969	3.0	0.9	1.7	34.5	210.7

Table 4. Adjustment indices for dollar loss and acreage data (cont.).

Year	May	June	July	August	September
Tri-County					
1957	3.7	1.1	2.1	41.9	251.3
1958	2.6	0.8	1.5	29.3	176.0
1959	3.0	0.9	1.7	34.1	204.3
1960	4.7	1.4	2.6	53.0	317.7
1961	4.0	1.1	2.2	44.8	269.0
1962	4.7	1.4	2.7	53.7	321.9
1963	13.6	3.9	7.6	154.2	924.9
1964	14.6	4.2	8.2	165.3	991.7
1965	7.6	2.2	4.3	157.9	519.9
1966	5.7	1.7	3.2	65.0	390.0
1967	2.4	0.7	1.3	26.7	160.0
1968	3.0	0.9	1.7	34.5	206.8
1969	3.0	0.9	1.7	34.5	206.8

b. Indices for Acres Damaged (AAL)

Year	May	June	July	August	September
Logan County					
1957	7.4	2.1	4.1	83.4	500.0
1958	6.6	1.9	3.7	75.0	450.0
1959	8.8	2.6	5.0	100.0	600.0
1960	9.6	2.8	5.4	108.4	650.0
1961	9.6	2.8	5.4	108.4	650.0
1962	20.6	6.0	11.6	233.4	1400.0
1963	30.1	8.8	17.0	341.7	2050.0
1964	30.1	8.8	16.9	341.7	2050.0
1965	31.6	9.2	17.8	358.4	2150.0
1966	13.2	3.8	7.4	150.0	900.0
1967	6.6	1.9	3.7	75.0	450.0
1968	8.8	2.6	5.0	100.0	600.0
1969	8.8	2.6	5.0	100.0	600.0
Morgan County					
1957	15.7	4.5	8.8	177.5	1050.0
1958	8.3	2.4	4.7	91.7	550.0
1959	4.4	1.3	2.5	50.0	300.0
1960	14.0	4.1	7.7	158.4	950.0
1961	8.1	2.3	4.5	91.7	550.0
1962	7.2	2.1	4.0	83.4	500.0
1963	13.2	3.9	7.4	150.0	900.0
1964	20.6	5.9	11.5	233.4	1400.0
1965	8.1	2.4	4.3	88.0	550.0
1966	5.9	1.7	3.3	66.7	400.0
1967	2.2	0.7	1.3	25.0	150.0
1968	6.6	1.8	3.6	72.0	430.0
1969	6.6	1.8	3.6	72.0	430.0

Table 4. Adjustment indices for dollar loss and acreage data (cont.).

Year	May	June	July	August	September
Weld County					
1957	9.0	2.6	5.1	102.5	600.0
1958	6.2	1.8	3.5	66.7	400.0
1959	7.3	2.1	4.1	83.4	500.0
1960	12.5	3.5	6.8	141.7	850.0
1961	9.6	2.8	5.4	108.4	650.0
1962	9.7	2.8	5.5	110.0	650.0
1963	49.5	14.4	27.8	561.8	3350.0
1964	44.1	12.8	24.7	500.1	3000.0
1965	19.1	5.5	10.6	216.7	1300.0
1966	25.7	7.4	14.3	291.7	1750.0
1967	7.3	2.1	4.1	83.4	500.0
1968	7.9	2.3	4.5	90.0	550.0
1969	7.9	2.3	4.5	90.0	550.0
Tri-County					
1957	8.7	2.5	4.9	98.4	590.0
1958	6.5	1.9	3.6	73.3	440.0
1959	7.2	2.1	4.0	81.7	490.0
1960	11.2	3.2	6.3	126.7	760.0
1961	9.5	2.8	5.3	107.5	645.0
1962	11.5	3.4	6.5	130.9	785.0
1963	33.0	9.6	18.5	374.2	2245.0
1964	34.5	10.0	19.4	391.7	2350.0
1965	19.0	5.5	10.7	215.0	1290.0
1966	15.3	4.4	8.6	173.4	1040.0
1967	6.0	1.7	3.3	67.5	405.0
1968	7.9	2.3	4.5	90.0	540.0
1969	7.9	2.3	4.5	90.0	540.0

Table 5. List of formulas for the computation of sample sizes for various tests and designs.

1. Hypothesis A Seeding does not affect the conditional distribution of hail damage, given that hail occurs

a) Random-historical design (sequential)

θ_1 = Location parameter of the historical log-normal distribution

σ = Shape parameter of the historical log-normal distribution

δ = Percentage difference it is desired to detect

D = $\log_e$ (1-6)

$\theta_o = \theta_1 + D$

s = $(\theta_o + \theta_1)/2$

Sample size (N_1) for hypothesis $H_1 = \theta \geq \theta_1$ (seeding produced no worthwhile effect)

$$N_1 = \frac{h_1 + \beta(h_o - h_1)}{(\theta - S)\pi} \qquad \textit{(1-tail test)} \qquad \text{EQ(1)}$$

Sample size (N) for hypothesis H $=\theta \leq \theta$ (seeding reduced the historical location parameter form θ_1 to θ_o)

$$N_o = \frac{h_1 + (1-\alpha)(h_o - h_1)}{(\theta - S)\pi} \qquad \textit{(1-tail test)} \qquad \text{EQ(2)}$$

where: $$h_o = \frac{\sigma^2}{(\theta_1 - \theta_o)} \cdot \log_e \frac{\beta}{1-\alpha}$$

$$h_1 = \frac{\sigma^2}{(\theta_1 - \theta_o)} \cdot \log_e \frac{1-\beta}{\alpha}$$

β = type II error

α = type I error

Π = is the randomization factor, ie, 50-50 would be 1/2

b) Random-historical (non-sequential)

$$N = \frac{(\mu_\alpha + \mu_\beta)^2 \sigma^2}{D^2 \pi} \qquad \textit{(1-tail test)} \qquad EQ(3)$$

where: μ_α = the normal deviate for a probability level

μ_β = the normal deviate for 3 probability level

D = the difference in log means it is desired to detect and is the same as in 1 a above

σ = shape parameter of the historical log-normal distribution

Π = is the randomization factor

For 2-tail test, 1/2 a is substituted for a

c) Random-experimental (log-normal test)

$$N = \frac{(\mu_\alpha + \mu_\beta)^2 \sigma^2}{D^2 \pi(1-\pi)} \qquad \textit{(1-tail test)} \qquad EQ(4)$$

where symbols are defined as in EQ 3

d) Random-experimental (Optimal-C(a))

$$N = \frac{\tau^2}{\Delta^2 \log_e^2 \theta \ \pi(1-\pi)} \qquad EQ(5)$$

where: 9 = is the multiplication factor, ie, 20% increase is 1.2, 20% decrease is .8

$\Delta^2 = \gamma$ = gamma shape parameter of the non-seeded distribution (used when predictor variables <u>are not</u> used)

Δ^2 = average of the squares of the values predicted by the multiple linear regression equation (see Appendix C) divided by the standard error of estimate squared (used when predictor variables are used)

$\tau 2$ = is the noncentrality parameter (see Neyman and Scott, 1967a) and is determined by pre-assigned values of a and β

Π = is the randomization factor

2. Hypothesis B Seeding does not affect the probability of hail in the target (experimental-random design, optimal C(a))

a)

$$N = \frac{\tau^2(P_o(1-P_o))}{\xi^2 \pi(1-\pi)} \qquad EQ(6)$$

where: P = is the probability of hail on days without seeding

P_1 = probability of hail on days with seeding

ξ = (P,-P) difference in probability it is desired to detect

π = is the randomization factor

T = same as in 1 d above

b) (Alternative formula)

$$N = \frac{\tau^2(1-P_o)}{\xi^2 \cdot P_o(\pi(1-\pi))} \qquad EQ(7)$$

where: $\xi = (\frac{P_1 - P_o}{P_o})$ percentage increase or decrease it is desired to detect, ie, 20% increase is .2

other symbols same as in EQ 6

3. Hypothesis C Seeding does not affect the hail damage averaged per experimental unit (experimental-random design, optimal C(a) test)

$$N = \frac{\tau^2(\Delta_1{}^2 + \Delta_2{}^2)}{\eta^2(\Delta_1\Delta_2)^2 \cdot \pi\ (1-\pi)} \qquad EQ(8)$$

where: Δ_2 = same as Δ in EQ 5

$\Delta_1 = [\frac{P_o}{1-P_o}]^{1/2}$ P_o same as in EQ 6 n = $\xi_1+\xi_2$- where ξ_1 is the percentage decrease in probability and ξ_2, is the percentage decrease in hail damage it is desired to detect

Π, T, same as in EQ 6

All tests under 2 and 3 are 1-tail or 2-tail tests depending on the choice of T.

APPENDIX C

(under separate cover)