CHIAA Research Report No. 30

SUMMARY OF 1965 HAIL RESEARCH IN ILLINOIS

by

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Prepared for

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INTRODUCTION

Hail research conducted in 1965 included four studies, three of which are described in this report. The fourth is a detailed analysis of the hailstorms in Illinois on June 19-20, 1964, discussed in a separate publication (1).

The first study involved the determination of the hail risk to corn and soybeans. The research was begun in 1964 (2) and completed in 1965. Basically it concerns the development of an accurate areal portrayal of the hail risk to these crops by combining climatological hail data with crop-insurance data. The results obtained in 1965 indicate 1) the areal variation in crop risk from hail, and 2) the point and areal differences in degree of risk between corn and soybeans.

The second study concerned variations in hail intensity as related to area, time, and causes. Three types of climatological hail data, each containing different indirect measures of intensity were used. The major purposes of this hail-intensity investigation were 1) to determine which hail parameters indicative of intensity were causes of crop damage; 2) to compare the climatological areal variations in intensity with those derived from the Illinois insurance data; and 3) to compare the climatological temporal variations in hail intensity with those derived from the Illinois insurance data.

The third study pursued in 1965 was a continuation of the investigations of individual

Illinois hailstorms (3, 4, 5, 6). During the spring of 1965, 19 different hailstorms occurring on four different dates were observed on State Water Survey raingage networks in central and southern Illinois. Recording raingages in two southern Illinois networks comprising 93 recording and stick raingages were adapted to record the time of hail. These data plus network observer reports of hail time, size, and frequency were coupled with the rainfall data to enable cartographic portrayals of 13 hailstorms. A series of six hailstorms in a 7.5-hour period on April 8, 1965, passed across the Survey's 20-gage network located in the 13-square-mile area of Champaign-Urbana, and the hail-rain data from the raingages plus observer data allowed reconstruction of the six hailstorms during their passage over the network.

The fourth hail study dealt with the very damaging hailstorm in northern and central Illinois on June 19-20, 1964. The losses in the 24-hour storm period to insurance companies in the Association exceeded $4 million, the greatest 1-day loss on record for Illinois. Studied primarily were the radar-echo hailstorm patterns, the hailstorm patterns, the associated synoptic weather conditions, and the detailed areal portrayal of the loss patterns. The study was sufficiently extensive to warrant presentation in a separate report (1).

HAIL RISK TO CROPS

Introduction

Over the past two years the author, with the assistance of staff members of the Association and affiliated insurance companies, has worked towards the proper use of the climatological hail-days data to develop regional patterns of hail risk in Illinois. The desired goal was to obtain the best possible description of the hail risk to the two major Illinois crops, corn and soybeans.. These hail risk descriptions or patterns could then be used to develop new and presumably better regional rate structures in Illinois.

Obviously the summer or crop-season average hail-day patterns derived from U.S. Weather Bureau data were not entirely adequate portrayals of the areal variation in the hail risk to crops. Crop susceptibility td damage was also known to vary seasonally and regionally, but as mentioned in Research Report No. 23, it was extremely difficult to obtain an objective numerical expression of these area and time variations in damage susceptibility (2).

Hail risk to a crop at any point is a function of 1) the average number of hail occurrences during the crop's growing season, 2) the intensity of this hail, and 3) the susceptibility of the crop to damage. If the crop varies in susceptibility to damage with time (during the growing season), then the hail intensity values and average hail occurrences should be computed for each significantly different period of crop-damage susceptibility. The sum of these temporal values are then an expression of the total risk at any location.

The analysis accomplished in 1964 on this hail-risk problem revealed that average point values and subsequently statewide average patterns of hail days could be derived from the point hail data for semi-monthly periods, or any combinations thereof. Thus temporal and areal variations (or patterns) of one desired item for risk determination (hail days) were available (2). However, seasonal and regional expressions of hail intensities were not available, but necessary for an objective calculation of hail risk.

Analytical Approach

Several approaches to determining the seasonal variations of hail intensity and crop susceptibility at a point were analyzed and presented in Research Report 23, but the general subjectivity of these approaches raised many questions about the correct weighting of the risk in different periods of the crop season. This problem was resolved by determining a "seasonal intensity (SI) index" using the Illinois CHIAA data on loss cost and storm days for the 1957-1964 period. For each of the hailstorm days in this period a loss cost was calculated. The SI index for any period, such as a month, is the median value of all the storm loss cost values in a given month. In other words, this SI index could also be called a susceptibility-to-damage index because it integrates into one value, for any given time period, the intensity of the storms and the damagability of the crops in that period of time.

Since the eight years of CHIAA storm-day loss cost data were considered insufficie?? to allow calculation of valid regional SI indices, expressions of regional variations in hail intensity and damage susceptibility to crops had to be obtained by a different method. A "regional intensity (RI) index" was determined for each of the nine large crop-report-?? ing districts of Illinois using 17-year insurance records. In each district the loss costs of all townships were used to compile an area average loss cost, which then became the RI index for the district. Thus, an expression of hail intensity was made available for each district.

Determination of SI Indices

The listings of hailstorm-day loss costs (liability divided by losses) from the 1957-1964 Illinois data were provided by the CHIAA for both corn losses and soybean losses. For each crop, the data were divided into semi-monthly and monthly periods, and means and medians were determined for each period. The results are shown in Tables 1 and 2 and Figures 1 and 2.

Inspection of the corn loss cost values for the semi-monthly periods reveals that the maximum loss, or intensity-susceptibility, period occurred with storms in the July 1 - August 15 period when the storm loss values for the three 2-week periods were $. 001. The soybean loss cost values in Table 1 indicate that the second half of September is the 2-week period of maximum intensity-susceptibility (loss). Interestingly, a secondary peak occurs in the second half of June and another minor one in the first two weeks of August.

Table 2 also shows the monthly median and mean values for storm loss costs. Means are presented to illustrate the skewness of the storm data and the reason why median values were used. A few excessively damaging storms in a month, such as in June, during this 8-year period resulted in a great distortion of the June mean monthly loss cost value. Since the value of the monthly expression of loss depends on its validity in comparison with the other monthly values, this skewness obtainable from the mean values indicates the desirability of using median values.

The corn monthly median storm-day values indicate a peak of storm loss costs in July with a value of $. 001. Losses per storm in June and August are equal for corn, and as shown in Figure 2,. the monthly-values are normally distributed around the peak in July.

The median monthly storm-day loss costs for soybeans indicate a peak in July of $.0009 and a relatively high value in June. Except for those in May and July, the soybean monthly loss costs are greater than those for corn.

The median monthly loss costs shown in Table 2 were selected for use as the SI indices since in one number they integrated the temporal differences in hail intensity and in crop susceptibility. The decimals were dropped so that the May corn SI index became 1, the June index 3, the July index 10, etc.

Determination of RI indices

Since loss cost data integrated as one value any regional differences that exist in hail intensity and in damage susceptibility, regional intensity indices also were developed from CHIAA loss cost data. For each crop reporting district in Illinois, all the township loss costs derived from 1948-1964 data were averaged to obtain a regional loss cost value. These values for the nine districts are shown in Table 3. To obtain an RI index, the loss cost values were rounded to the nearest tenth of a dollar and the resulting RI indices used in the final determination of the crop risk values are presented in Table 3.

TABLE 3
REGIONAL AVERAGE LOSS COSTS AND RI INDICES

	Districts								
	NW	NE	W	C	E	WSW	ESE	SW	SE
Average Loss Cost, $	0.73	0.77	0.46	0.50	0.39	0.57	0.25	0.68	0.60
RI Index	0.7	0.8	0.5	0.5	0.4	0.6	0.3	0.7	0.6

TABLE 1

SEMI-MONTHLY MEDIAN STORM LOSS COSTS IN ILLINOIS BASED ON AVERAGE DAILY LOSS COSTS (PERCENT POLICIES) FOR 1957-1964 PERIOD

	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	Aug. 1-15	Aug. 16-31	Sept. 1-15	Sept. 16-30	Oct. 1-15	Oct. 16-31
Corn											
Number of Storm Days	24	42	55	66	72	64	40	19	14	0	0
Median Loss Cost, $	.0001	.0003	.0002	.00.10	.0010	.0010	. 00.01	.0001	.0001	0	0

TABLE 2

MEAN AND MEDIAN MONTHLY STORM LOSS COSTS IN ILLINOIS BASED ON AVERAGE DAILY LOSS COSTS (PERCENT POLICIES) FOR 1957-1964 PERIOD

	May	June	July	August	September	October
Corn						
Number of Storm Days	26	97	138	104	33	0
Median Loss,Cost, ,$	.0001	.0003	.0010	.0003	.0001	0
Mean Loss Cost, $	.00004	.0023	.0013	.0005	.0003	0
Soybeans						
Number of Storm Days	37	141	139	98	63	33
Median Loss Cost, $	. 0001	. 00.07	. 0009	• 0004	. 0003	. 0002
Mean Loss Cost, $	.0005	.0046	.0020	.0008	.0019	.0014

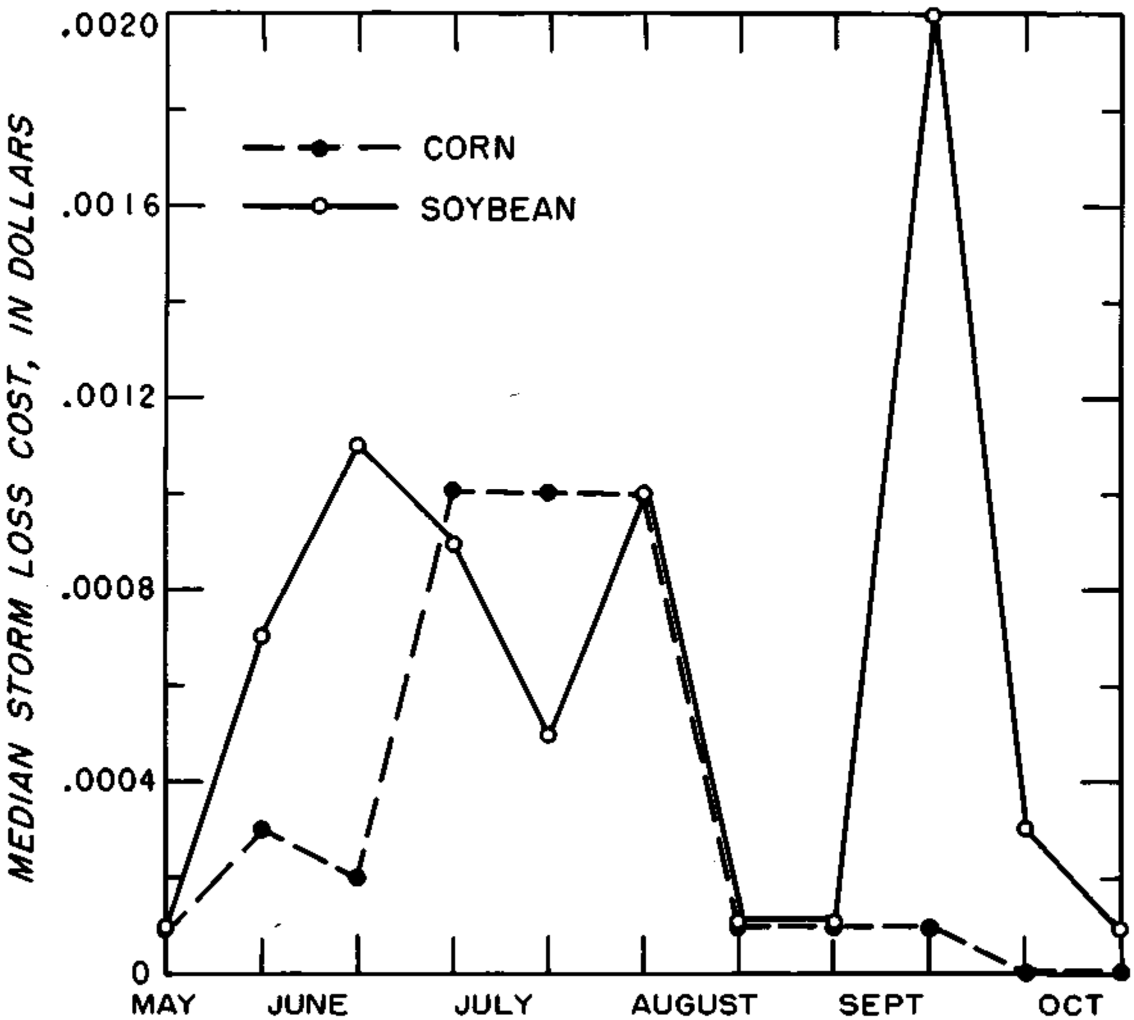

Fig. I. SEMI-MONTHLY LOSS COSTS FOR CORN AND SOYBEANS

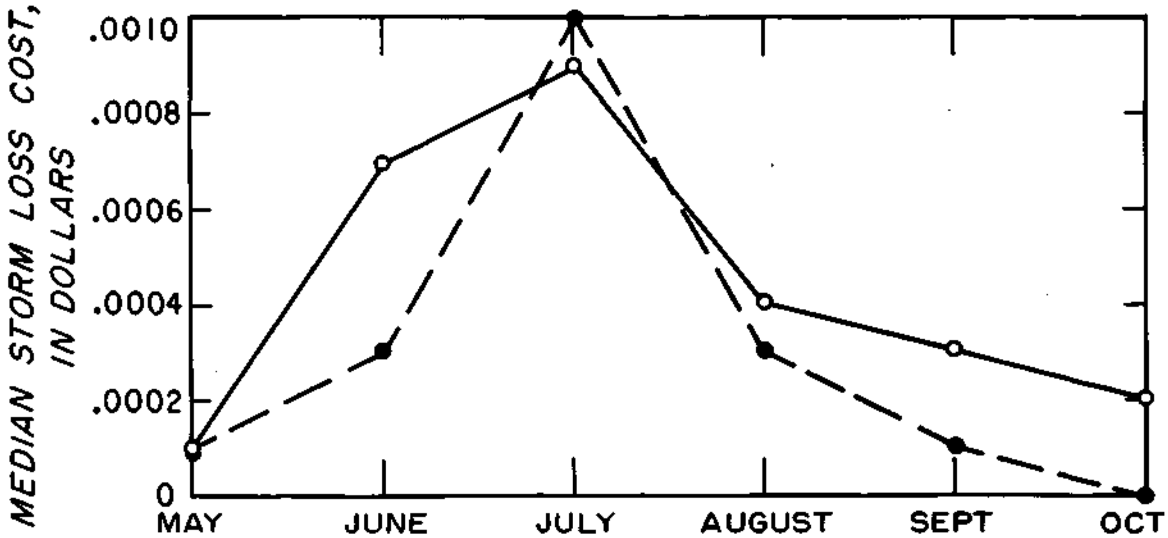

Fig. 2. MONTHLY LOSS COSTS FOR CORN AND SOYBEANS

Location of the nine districts is shown in Figure 6. These values revealed the existence of significant areal variations in hail intensity and damage susceptibility. Highest risk areas are the NW, NE, SW, WSW, and SE districts.

Method of Calculation of Hail Risk

The actual method of using the hail-day (frequency) data and the two intensity indices to determine areal patterns of the hail risk for each crop is illustrated here by the data from two different locations. At each station with accurate hail-day averages, the average monthly values were multiplied initially by the statewide monthly SI indices as shown in Table 4. The resulting products were summed to produce subtotals. These subtotals were 94 at Carlinville and 78 at Sycamore.

TABLE 4

EXAMPLES OF CALCULATIONS OF HAIL RISK TO CORN
AT CARLINVILLE AND SYCAMORE

	CARLINVILLE			SYCAMORE		
Month	Average number of hail days	SI index	Product	Average number of hail days	SI index	Product
May	12	1	12	9	1	9
June	8	3	24	9	3	27
July	4	10	40	3	10	30
Aug.	5	3	15	3	3	9
Sept.	3	1	3	3	1	3
		Subtotal	94			78
Regional Intensity (RI) index			0.6			0.8
Final Hail Risk Value (subtotal x RI)			56.4			62.4

The subtotals at all 89 locations with accurate hail records were then multiplied by the RI index derived for their appropriate area. The RI index for northeastern Illinois was larger than for west-southwestern Illinois, so that a final hail risk value for corn at Sycamore (62.4) was larger than that at Carlinville (56.4).

Actual corn hail risk values ran from a low of 22 in southeastern Illinois to a high of 86 in northwestern Illinois. The resulting indices were linearly scaled downwards to reduce the magnitude of the numbers. A risk value of 25 was equated to 1, and all other risk values were scaled to this base level so that a risk value of 75 was equal to 3, or was three times as great as the very low values. The resulting corn hail risk map is shown in Figure. 3. The pattern of hail risk for corn indicates that major areas of low risk occur in the east-southeast, extreme south, and generally along the upper portions of the Illinois River Valley. Areas with double the risk (2. 0) include most of northern Illinois, an east-west belt in south-central Illinois, and other scattered small regions in the state.

The bean hail risk values were computed in an identical fashion using SI indices (Table 2) derived from soybean data. The computed risk values in Illinois ranged from a low of 32 to a high of 121. These also were scaled downwards so that values of 35 or lower were equal to 1, making a bean risk value of 70 equal to 2. The resulting pattern of hail risk to soybeans is portrayed in Figure 4.

Hail risk to soybeans is lowest in east-southeastern Illinois and generally low across most of central Illinois. Areas of higher risk are found in south-central and northern Illinois.

Relationship of Corn and Bean Risks

At each of the 89 hail-data stations the unadjusted risk values for soybeans were

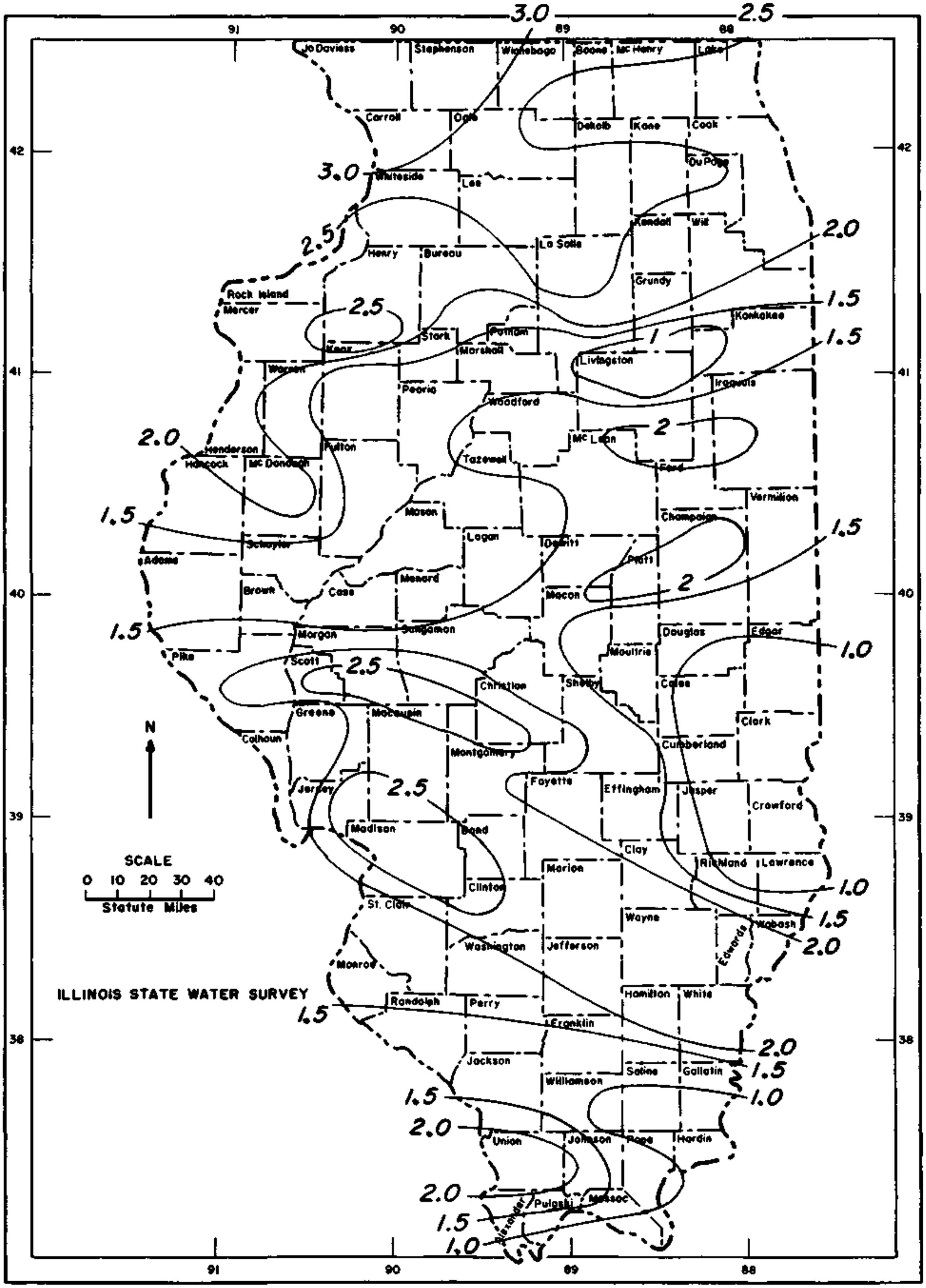

Fig. 3. HAIL RISK TO CORN

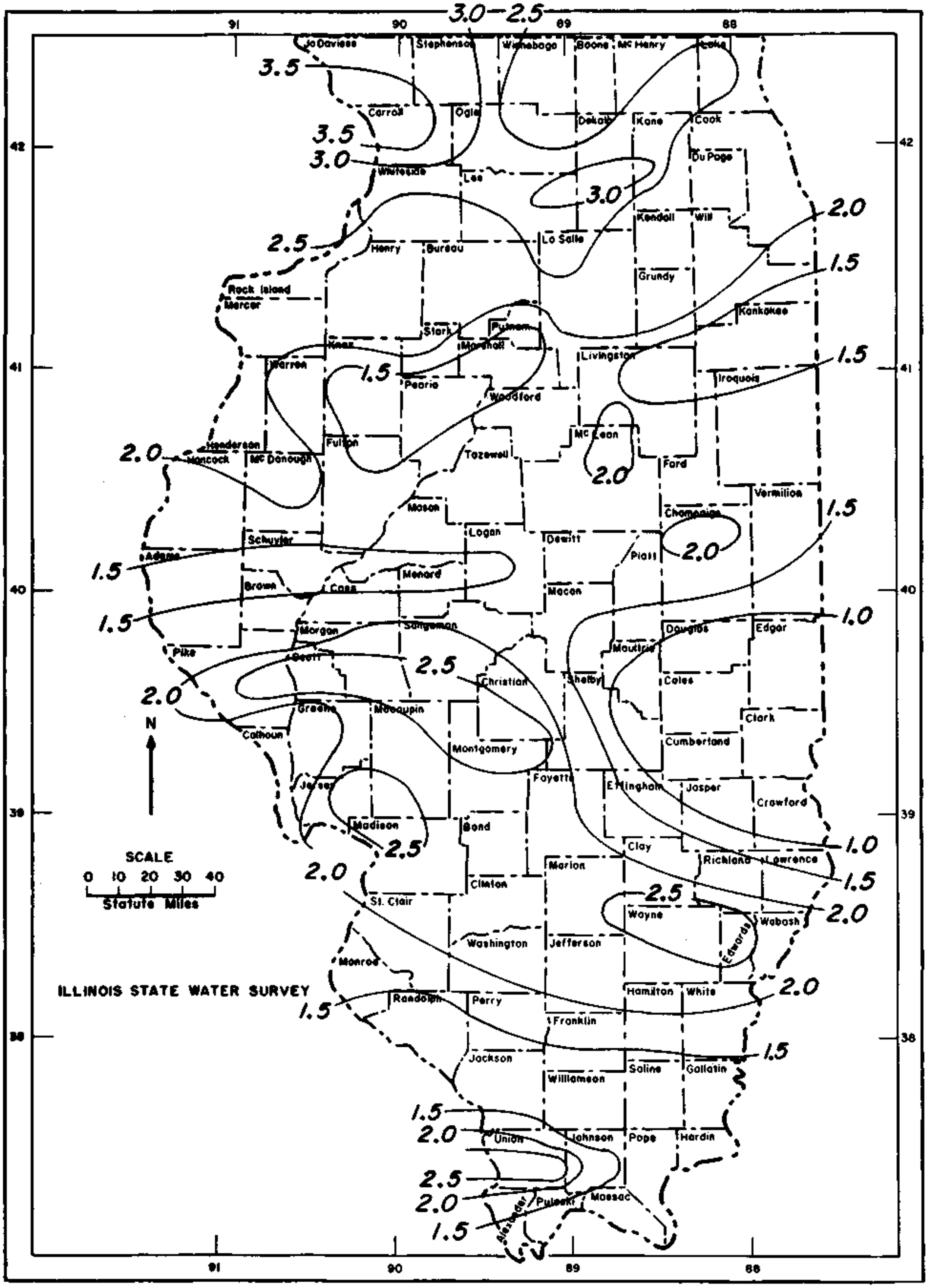

Fig. 4. HAIL RISK TO SOYBEANS

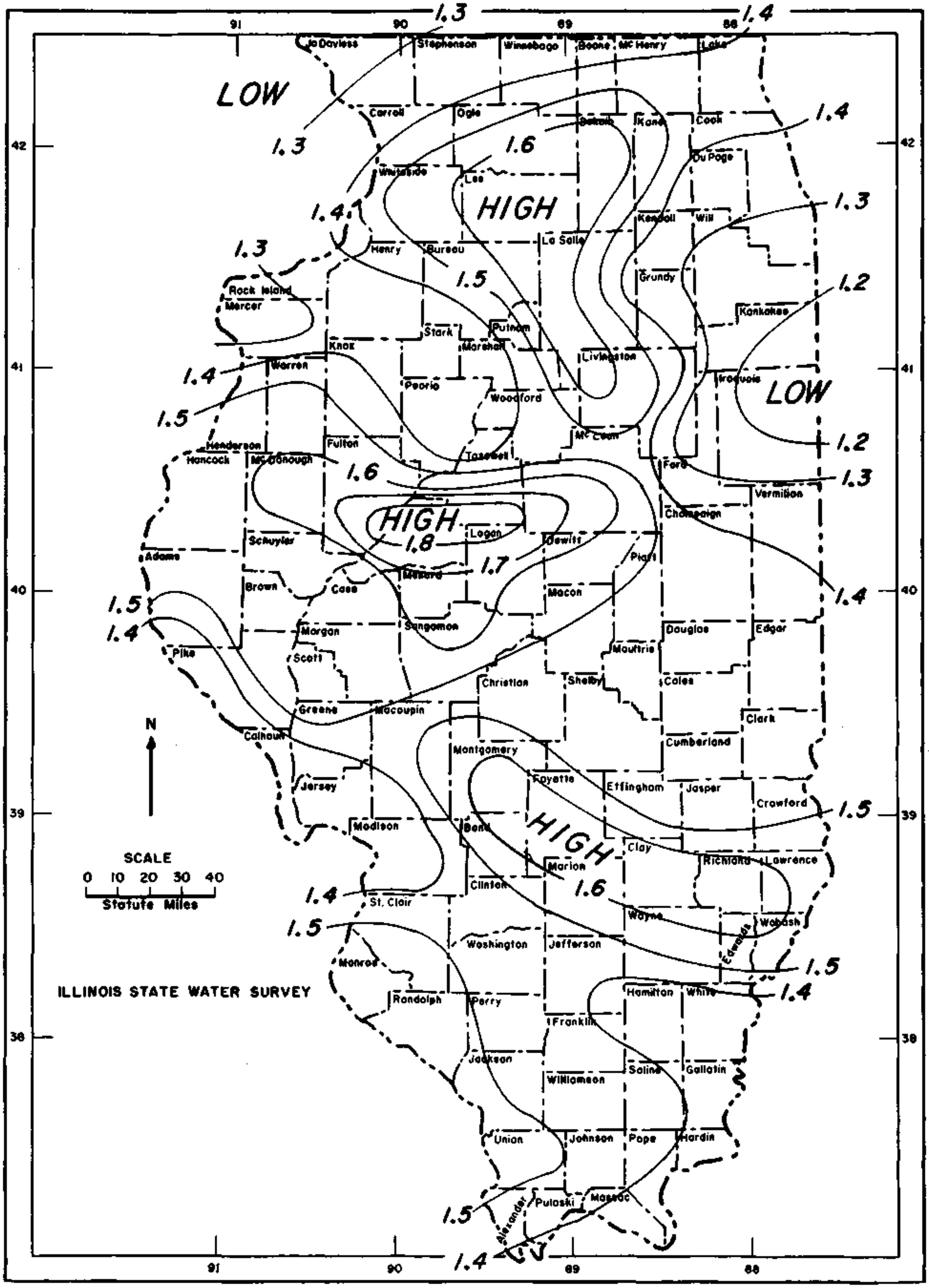

Fig. 5. RATIO OF SOYBEAN RISK TO CORN RISK

divided by those for corn to obtain a ratio which would be a measure of the surcharge difference between corn and soybeans.

The ratios obtained by dividing the soybean risk by corn risk for the 89 stations were plotted and a ratio map constructed as shown in Figure 5. The soybean risks are greater than the corn risks throughout Illinois, and the ratio varies from a low of 1.2 in extreme eastern Illinois to a high of 1.8 in central Illinois. In most areas the bean risk is from 40 to 60 percent greater than the corn risk, and the statewide average is 50 percent.

HAIL INTENSITY STUDIES

Introduction

The desire to have other objective measures of the intensity of hail'also led to three climatological studies involving various expressions of hail characteristics. These studies were pursued to gain general basic hail knowledge and to obtain data to evaluate- the hail-risk intensity indices derived from the loss cost data for the state.

Three different types of historical hail data were available to furnish various expressions of intensity. One of these was a detailed record of hailstone sizes which occurred during a 20-year period at Urbana. Hail intensity as related to crop losses is usually a combination of factors including stone size, number of stones per unit area, and associated wind speed at a given point (3). Normally, one can expect that a large number of big stones falling with high winds would be the worst possible condition for damage, both to crops and property. However, damage to crops may not be too great when big stones occur because an excessive number of large (greater than 2-inch diameter) stones per unit area is seldom observed in Illinois hailstorms. Thus, the occurrence of large stones does not necessarily serve as an accurate measure of hail intensity as related to crop losses.

A second measure of hail intensity was obtained using field reports of 1100 cooperative observers who participated in a 5-year program of hailstorm studies in Illinois (7). In a 22, 000-square-mile area of central Illinois located east of the Illinois River, these observers, who were all farmers, reported detailed information on the incidence of hail and its various characteristics including the time of occurrence, st?? size, and stone frequency on the ground. These observers also reported the occurrence??

of damaging winds and the occurrence of crop and property damages. . Although no measure of the wind speed or exact amount of crop damage was provided, the hailstone characteristics and wind occurrences could be compared for all incidences of no crop damage, for all incidences of little damage, and for all occurrences of much crop damage. Thus, storm characteristics or intensity factors that related to crop losses could be evaluated in general loss terms.

The third source of data was records of the U. S. Weather Bureau. During a 21-year period, 1928-1948, cooperative weather observers located throughout Illinois were asked to classify all hail occurrences as having a "light, moderate, or heavy intensity". Instructions issued for use of these definitions were vague, but generally implied the degree of damage (8). Although subjective and thus prone to interpretive errors between different observers, it seems reasonable to conclude that the classifications of light and heavy intensities were quite likely comparable. That is, the heavy intensity hailstorm defined by most observers was likely to be a serious damage-producing local hailstorm, whereas the light intensity definition used by most observers was likely applied to storms that did no measurable damage. Thus, these subjective measures probably were a relatively good measure of hail intensity. In analyzing these data, further elimination of errors was hopefully attained by grouping the station data by areas, and this was done according to the nine crop-growing regions of the state. Thus, if some observers tended to be biased, the sample size and the grouping of data from eight or more stations in each area to arrive at regional values should help cancel inherent subjective errors.

In summary, these three forms of historical hail records in Illinois are not direct measurements of hail intensity, but they provide different and interesting measures of certain aspects of intensity. The Urbana 20-year record of hail sizes with 99 hailstorms provides an excellent point sample of the stone size spectrum and its differences with time and between months. The cooperative farmers' reports of hail from central Illinois provide a source of information on those conditions (stone size, frequency, duration, and wind) which combine to produce damage to crops. The Weather Bureau records of three levels of intensity primarily provide measures of regional intensity differences in Illinois. Although none of these measures of intensity were directly applicable to the hail-frequency-intensity problem,they have provided useful support information for its use, as well as new and interesting information on the characteristics of Illinois hailstorms.

<u>Urbana Hailstone Sizes and Diurnal Distribution</u>

In the 1946-1965 period detailed records of hail occurrences at Urbana were maintained. These records for each hailstorm included the stone sizes, time of occurrence and duration, and the maximum wind gust at the approximate time of hail-fall. In this 20-year period there were 99 hailstorms, although in five instances two or more hailstorms occurred on one day, resulting in hail on 91 calendar days. This is an average of more than 4 hail days per year which is above the 3+ annual average number for Urbana (9). For convenience, the stone sizes were grouped into three classes with class 1 representing stones less than 1/2 inch in diameter, class 2 those of 1/2 inch to 1 inch, and class 3 those greater than 1 inch in diameter.

The data for the various months is shown in Table 5. Because of infrequency of hail, the July (2 storms) and August (8 storms) data were grouped, as were the September (6 storms) and October (2 storms) data. These were reasonable seasonal groupings and allowed the determination of more reliable averages for these periods.

TABLE 5

HAILSTORM FREQUENCY, STONE SIZE FREQUENCIES, AND ASSOCIATED AVERAGE WIND GUSTS AT URBANA, 1946-1965

	Mar	Apr	May	Jun	Jul - Aug	Sep - Oct	All Other Months	Totals
Total Storms	19	20	11	17	10	8	14	99
Maximum Stone Sizes								
Class 1	15	14	11	14	7	6	12	79
Class 2	3	4	0	3	2	1	2	15
Class 3	1	2	0	0	1	1	0	5
Average Peak Gust, mph	24-	29	25	22-	25	31+	25-	

When the frequency of the larger (class 2 and 3) sizes are expressed as a percent of the total monthly hailstorms, we find that for the months in the crop season (May - October), June had 18 percent, July - August had 30 percent, and September - October had 25 percent. Of the 99 hailstorms in the 20 - year period only 20, or 20 percent of the total, produced stones measuring 0. 5 inch or larger in diameter. Further, stones measuring over 1. 0 inch in diameter occurred in only 5 storms or in only 5 percent of the hailstorms. This vividly illustrates the relative infrequency of large stones at a point. In the crop season eight storms produced 1/2 inch or larger stones and non?? of these occurred in May, and the only two storms with 1-inch or larger stones occurred in the later part of the growing season.

The wind data presented in Table 5 indicate that late summer and fall hailstorms were associated with higher gusts on the average than those in the other times of the year. Thus, the July-October hailstorms should have a better chance for crop damage potential than those in May and June. The relatively higher percentages of larger stones in the July-October hailstorms and the higher wind speeds with these storms suggest that hailstorms at Urbana, at least in this 20-year period, were likely more intense in the July-October period than were hailstorms in any other period of the year

TABLE 6

DIURNAL DISTRIBUTION OF HAILSTORMS AT URBANA

Number of Storms per Period

Time, CST	Spring-Early Summer (March-June)	Late Summer-Fall (July-October)	Winter (Nov. -Feb.)	Totals
0000-0300	6	3	1	10
0301-0600	8	0	1	9
1601-0900	7	1	2	10
0901-1200	8	1	1	10
1201-1500	12	5	1	18
1501-1800	13	2	2	17
1801-2100	7	5	5	17
2101-2400	6	1	1	8

The times of occurrence of the 99 Urbana hailstorms are also interesting measures of the diurnal distribution of hail. The occurrences by 3-hour intervals are shown in Table 6 for three 4-month periods and the total period.

The occurrences of winter hailstorms and those in March were quite evenly distributed throughout the day. Since these were largely all frontal storms, convective activity from daytime heating was not a major factor in storm development. The late spring, summer, and fall hailstorms were most frequent in the afternoon hours and thus reflect the influence of diurnal heating. However, the late summer and fall hailstorms showed a tendency for a secondary maximum of occurrence in the early evening hours, suggesting that more prolonged convective activity is required to obtain the development of hail at this time of the year.

Hail Observer Data

Over a 5-year period, 1958-1962, 1100 volunteer hail observers in central Illinois reported the occurrence of hail at their farms (7). During this time, 738 detailed hail reports were obtained. Data reported included the date and time of occurrence, duration of hailfall, maximum and average stone sizes, stone frequency per square foot, incidence of damaging winds, and the occurrence of crop damage. Crop damage was reported as none, little, or much damage, and generally referred to damage to corn and soybeans.

The hail reports were sorted into three classes: no crop damage (644 reports), little crop damage (65 reports), and much damage (29 reports). The various hail parameters for each class were analyzed and compared with the averages and medians for the other classes. Some of the 738 reports did not contain complete hail data, so certain findings here do not represent all 738 reports.

In Table 7, the number of reports per month are shown. As would be expected, very few crop damage reports occurred in April and October. June led in the number of damage reports and numbers in May, July, and September were nearly equal. Forty-three percent of all the crop-damage reports occurred in June. Comparison of the number of reports per month revealed that 21 percent of all the June hailstorms produced crop damage (little or much), whereas in July and August 33 percent were damaging and in September 50 percent were damaging. Thus, hailstorms that occur in late summer appeared to be more capable of producing crop damage than those th?? occur earlier in the crop season.

TABLE 7

NUMBER OF HAIL REPORTS PER MONTH

	Apr	May	June	Jul	Aug	Sept	Oct	Total
Total Reports	217	233	192	45	15	26	10	738
No Damage	212	217	152	30	10	13	10	644
Little Damage	2	13	30	6	4	10	0	65
Much Damage	3	3	10	9	1	3	0	29
Total with Damage	5	16	40	15	5	13	0	94
Damage Total as Percent of Total Reports	2	7	21	33	33	50	0	13

Hailstone Size Relations

Table 8 shows the monthly numbers of reports sorted according to five different maximum stone sizes. About 14 percent of all 738 hail incidences produced stones of 1-inch or more in diameter. The 20-year Urbana record revealed that only 5 percent of the hail occurrences at a point had 1-inch or larger stones.

The. 1/4 inch and 1-inch stones were most frequent in April whereas the 1/2-inch diameter stones were more frequent in May, and both the 3/4-inch and the larger than 1-inch stones occurred most often in June.

Incidences of large stones, those of 3/4-inch diameter or greater, show an interesting progression with time. These large stone occurrences represent 22 percent of the April incidences, 30 percent of the May reports, 39 percent of those in June, 42 percent of those in July, 53 percent of those in August, and 46 percent of the September total.

TABLE 8

NUMBER OF REPORTS OF HAIL SORTED ACCORDING TO MAXIMUM HAILSTONE DIAMETERS

Maximum Stone Diameter (inches)	Apr.	May	Jun	Jul	Aug	Sept	Oct	Total
1/4	104	82	53	15	3	7	6	270
1/2	65	82	65	11	4	7	3	237
3/4	19	42	43	9	5	6	1	125
1	19	16	17	6	3	4	0	65
>1	10	11	14	4	0	2	0	41
Total	217	233	192	45	15	26	10	738

The temporal increase in crop damage frequency revealed by the percentage values in Table 7 agrees with this temporal increase in large stone occurrences. Although the sample is small, it would appear that, on the average, late summer hailstorms tend to produce larger stones than those in spring and early summer.

Table 9 shows the monthly distribution of the maximum stone sizes that were reported with storms producing crop damages (little and/or much) and with storms producing no damage. In most months, the percentage of reports listing relatively large stones (3/4-inch or more) associated with damages was somewhat higher than the percentage listing large stones with no damages. However, the difference between these percentages was not significant in most months, even in June, July, and September which are three of the four months of maximum crop damage. In July, for instance, maximum hailstones of 1-inch diameter or greater were listed with 27 percent of the damage cases and with 21 percent of the no-damage cases.

TABLE 9

NUMBER OF MONTHLY OCCURRENCES OF MAXIMUM OBSERVED HAILSTONES IN FIVE SIZE CLASSES, EXPRESSED AS A PERCENT OF MONTHLY TOTAL REPORTS OF NO CROP DAMAGE AND OF CROP DAMAGE

Maximum Stone Diameter (inches)	April		May		June		July		Aug.		Sept	
	ND*	D**	ND	D	ND	D	ND	D	ND	D	ND	D
1/4	48	20	35	31	30	20	33	33	30	0	23	30
1/2	30	20	35	31	34	32	23	27	30	20	23	30
3/4	9	20	18	13	20	32	23	13	30	40	23	22
1	9	20	6	25	9	8	11	20	10	40	23	7
>1	4	20	6	0	7	8	10	7	0	0	8	7

* ND= No damage

** D= Damage to crops (little and/or much)

Table 10 summarizes the maximum stone size data for all 738 reports according to the three crop damage categories. These data reveal the existence of a relationship between stone sizes and the degree of crop damage. Stones 1 inch or larger were associated with 35 percent of all much-damage cases, but with only 15 percent of the little-damage cases and only 11 percent of the no-damage reports. However, 41 percent of the much crop damage reports occurred with stones of 1/2-inch or smaller diameters.

TABLE 10

FREQUENCY OF POINT REPORTS OF MAXIMUM STONE SIZE FOR DIFFERENT SIZE CLASSES, EXPRESSED AS A PERCENT OF ALL REPORTS

	Maximum Stone Diameter, Inches				
	1/4	1/2	3/4	1	>1
Much Damage	24	17	24	21	14
Little Damage	25	35	25	12	3
No Damage	40	32	17	8	3

Areal Frequency of Hailstones

The number of stones per square foot for the 644 no-crop-damage reports were compared with the number for the 94 crop damage reports (little and much). The average number of stones associated with different maximum stone sizes is shown in Table 11. For all stones, regardless of size, the frequency of stones per square foot for no-crop-damage was no different than that frequency for crop damages. From the data in Table 11 it appears that the occurrence of crop damage is not a function of the number of stones that occurred. This was especially emphasized by the fact that the crop damage cases associated with the smaller stone sizes (1/4-and 1/2-inch diameter) had areal stone values that were lower than those averages associated with the larger stones.

TABLE 11

AVERAGE NUMBER OF STONES PER UNIT AREA
ACCORDING TO VARIOUS STONE SIZES

Number of Stones per Square Foot
for Maximum Stone Diameters, Inches

	1/4	1/2	3/4	1	>1	All Stones
No Damage	23	29	30	33	26	27
Little and Much Crop Damage	27	23	22	42	30	27

Wind with Hail

Table 12 shows the reported occurrences of damaging winds with cases of differeht degrees of crop damage and cases of no damage, expressed as a percent of all the hail reports. All 29 reports of much crop damage from hail also listed damaging winds. Almost all reports (95 percent) of the little crop damage incidences also were associated with damaging winds, and interestingly there was a slightly higher percentage of winds occurring with the smaller stone sizes. Only a small percentage of the 644 no damage reports listed damaging winds. Although no wind speeds are listed, these data definitely indicate that heavy crop damage is almost always associated with high winds capable of producing damage. Apparently, small or large stones that fall without simultaneous damaging winds will seldom produce crop damage.

The directions of the damaging winds associated with the hail occurrences are shown in Table 13. No significant differences in directional frequencies appear between the classes of no damage, little damage, and much damage. A preponderance of the damaging winds blew from the south, southwest, and west.

TABLE 12

OCCURRENCE OF DAMAGING WINDS WITH HAIL

Percent of Hail Occurrences with Damaging Winds

	Stones of 1/2" Diameter or Less	Stones of 3/4" Diameter or larger	Total Reports
Much Crop Damage	100	100	100
Little Crop Damage	97	92	95
No Damage	12	14	13

TABLE 13

DIRECTIONS OF DAMAGING WINDS WITH HAILFALLS

Percent of Total
Occurrences in Each Direction

	N	NE	E	SE	S	SW	W	NW
Much Crop Damage	10	0	0	0	38	17	25	10
Little Crop Damage	5	0	2	8	16	29	23	17
No Damage	5	2	0	4	35	23	20	11

Duration of Hailfall

The final parameter available for investigation from these data was the duration of hailfall. Table 14 shows the average and median durations of hailfalls for the various damage classes. These data reveal that duration increased with the amount of damage. This indicates that longer hail durations are associated with more chance for damage, and suggest the occurrence of a greater frequency of stones, or as Schleusener suggests, a greater volume of ice per unit area (10). The data on the areal frequency of stones in Table 11 do not support this conclusion, although it is possible that the areal frequency counts of stones associated with the longer duration hailfalls are somewhat incorrect because of additional time for melting during the storm.

TABLE 14

DURATION OF HAILFALL AT A POINT

Duration in Minutes

	No Crop Damage	Little Crop Damage	Much Crop Damage
Average	6.5	8.7	12.5
Median	5	5	10

Conclusion

In general, it appears that the one factor that consistently produces crop-hail damage, regardless of stone size, stone frequency, or storm duration, is the associated occurrence of high-speed damaging winds. Thus, the impact energy of the stones, regardless of their size or unit frequency, is greater in high winds, which agrees with findings on crop damages is Colorado (10). There is some degree of association between larger stones and heavy crop damage, but damage does occur frequently with relatively small stones. The frequency of stones per unit area *sho??*

no correlation with the occurrence of crop damage, although the degree of damage does relate with the duration of hailfall. The percentage of hailstorms producing crop damage increased from month-to-month during the crop growing season, suggesting that late summer and early fall hailstorms on the average are more capable of damage than those prior to July in central Illinois.

U. S. Weather Bureau Hail Intensity Reports

During the 1928-1942 and 1946-1948 periods, U. S. Weather Bureau cooperative weather observers were asked to report the intensity of all hailfalls as "light, moderate, or heavy". These reports are subjective in definition (8), but the length of reporting period and the large number of station reports over the state permit some reasonable accuracy in determining the regional variations in hail intensity.

Data from 50 stations in Illinois (Fig. 6) with excellent hail records for these 18 years were used in this analysis. To overcome observer bias, the data from the stations were grouped according to the nine crop-reporting districts in Illinois (Fig. 6). The number of stations with data in each district is shown in Table 15 along with the total number of hail reports. The number of reports in the three intensity categories are expressed as a percent of the total hail reports for each district.

TABLE 15

NUMBER OF STATIONS AND NUMBER OF HAIL REPORTS PER STATE DISTRICT

District	Number of Stations	Total Reports Per District	Average Reports Per Station	Percent of District Total: Light Intensity	Moderate Intensity	Heavy Intensity
NW	11	286	26	75	16	9
NE	7	191	27	78	17	5
W	10	207	21-	78	15	7
C	4	98	24+	72	18	10
E	5	97	19+	57	32	11
WSW	7	197	28	83	9	8
ESE	5	86	17	78	14	7
SW	5	25	25	69	24	7
SE	5	53	11-	90	4	6

Although the number of reports per district varies considerably, there is much less regional variation when these reports are expressed as the average number per ' station. Prior hail research has shown that the areas with the highest average frequencies of severe hailstorms, as based on long-term climatological records, occur in the two northern, the western, and in the WSW districts (11). Three of these districts have the highest average number of reports per station shown in Table 15, revealing the representativeness of the 18-year period under study. Further, the E, ESE, and SE districts have been shown to be the areas of lowest frequency of severe hailstorms in Illinois over a 50-year period, and the 18-year

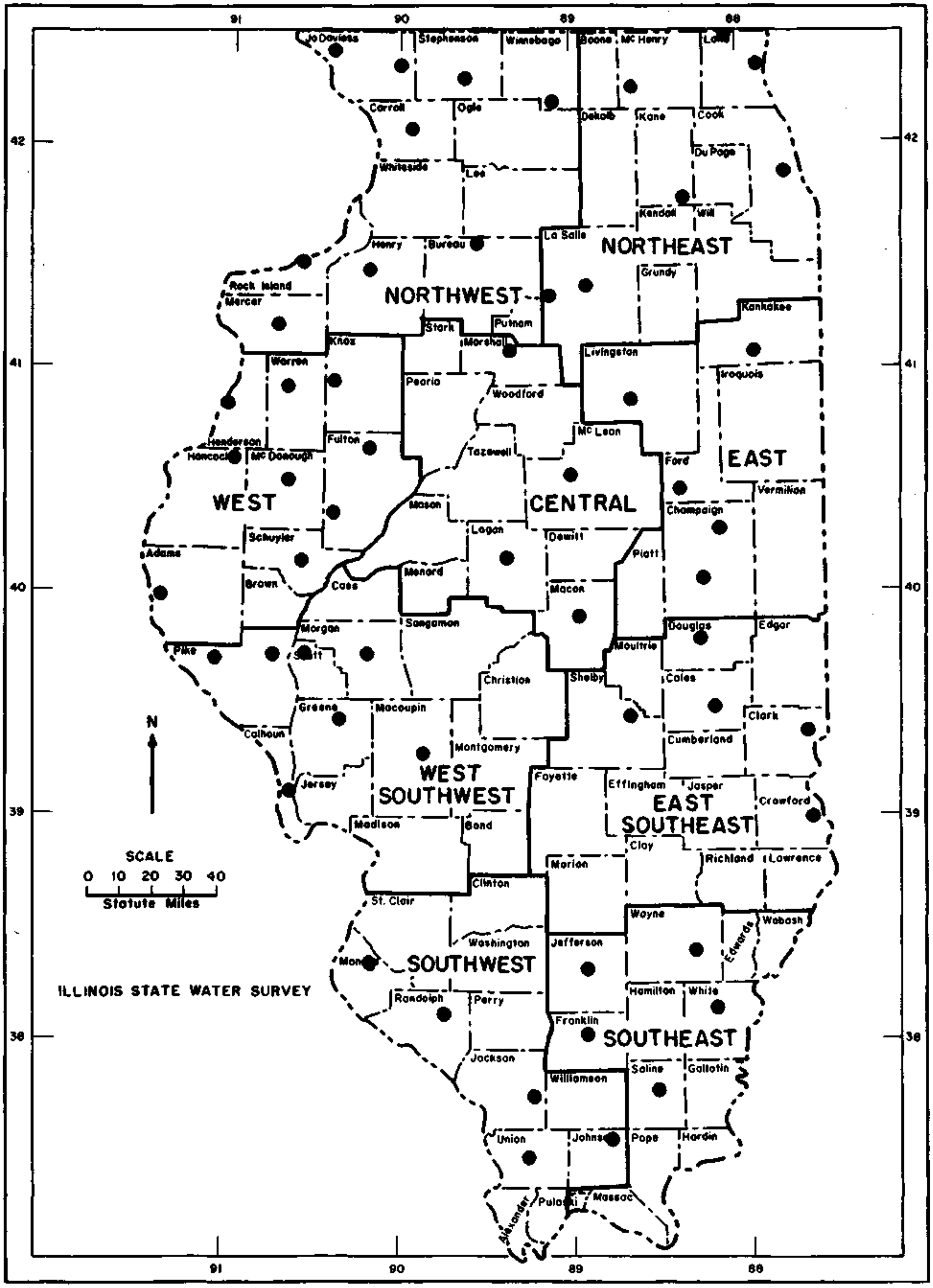

Fig. 6. STATIONS AND DISTRICTS USED IN REGIONAL HAIL INTENSITY ANALYSIS

sample of intensity data also agrees with this earlier finding.

Not many great regional differences in intensity percentages appear in Table 15. The east district does appear to have had significantly more moderate hail intensity occurrences than any other district, and the southeast district has significantly fewer moderate intensity hailstorms than the other districts. Based on the combination of the moderate and heavy intensity classes, the percentage of all hailstorms in the east, central, and southwest districts that were intense hailstorms was greater than in other areas of Illinois. However, these districts do not rank high in average number of hailstorms. Both the NE and the WSW districts, which rank high in the average number of hail occurrences per station, have low frequencies of intense hailstorms. Only the northwest area has a relatively high point average of hailstorms as well as a relatively high frequency of intense occurrences.

Table 16 shows the number of moderate to heavy reports per district in each month, expressed as a percent of the monthly total hail occurrences.

Consideration of the monthly averages reveals that the percentage of more intense hail occurrences decreases steadily from March through June, but the June value is nearly doubled in July and the percentage remains high in August and maximizes in September. The intensity-frequency peak in September agrees with the Urbana stone size-wind gust finding and with findings from the 1958-1962 damaging hailstorms in central Illinois. That is, hailstorms in September more frequently have greater intensity or damage capability than those in any other month of the year. The somewhat higher intensity percentages in March and April relate solely to the intensity reflected in damage to property rather than crops.

TABLE 16

PERCENT OF REGIONAL MONTHLY HAIL INCIDENCES REPORTED AS MODERATE OR HEAVY INTENSITY

District	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
NW	20	21	15	36	25	18	36	21
NE	13	17	25	18	21	10	50	20
W	11	16	27	18	16	15	30	28
C	33	18	13	0	32	58	100	0
E	27	32	21	25	62	82	100	20
WSW	25	16	5	10	39	10	22	0
ESE	16	20	5	22	46	0	0	0
SW	59	26	22	8	20	9	14	17
SE	7	10	13	2	2	0	0	0
Average	23	20	16	15	29	23	39	12

The regional percentages in Table 16 show a relatively high incidence of intense hailstorms in eastern and central Illinois during the July - September period. All hailstorms reported in these two districts in September were classed as having moderate or heavy intensity.

Another means of studying the frequency of intense hailstorms in the crop season is afforded in Table 17. The moderate and heavy intensity combination of percentages reveals that 60 percent of.the June-September hailstorms in eastern Illinois were classified as relatively intense, whereas only 2 percent were so classed in the southeastern area. The results for this combination of the two heavier intensities suggest that a greater proportion of the storms in northwestern, central, and eastern Illinois are intense than those elsewhere in the state.

TABLE 17

FREQUENCY OF DIFFERENT HAIL INTENSITIES IN THE JUNE-SEPTEMBER PERIOD EXPRESSED AS A PERCENT OF TOTAL HAIL REPORTS

Intensity Classes	NW	NE	W	C	E	WSW	ESE	SW	SE
Light	69	79	78	62	40	82	60	88	98
Moderate	14	15	13	19	46	2	15	9	2
Heavy	17	6	9	19	14	16	5	3	0
Moderate + Heavy	31	21	22	38	60	18	20	12	2

If regional intensity comparisions are based solely on the heavy intensity frequencies in Table 17, then the areas of more frequent intense hailstorms are central, northwestern, west-southwestern, and eastern Illinois. Thus, hailstorms in central Illinois are going to reach heavy intensity in the crop season three times more often than those in northeastern Illinois and six times more frequently than those in southwestern Illinois. If these frequency values can be considered to represent actual regional differences in hail intensity, then the percentages for heavy intensity, or for any of the intensity levels, could be used as numbers to express regional differences.

Comparison of Results from Climatological Intensity Studies with the CHIAA Intensity Indices

The seasonal intensity indices derived from the CHIAA data for soybeans and corn show maximization in July (Tables 1 and 2). The Urbana hailstone-wind data and the 1958-1962 central Illinois observer records do not indicate that hailstorms are at their greatest intensities in July, but rather in early fall. The July peaks in the insurance intensity indices obviously are determined more by the susceptibility of the crops to damage in July than by any great increase in intensity in hailstorms at this time. The climatological hail intensity findings indicate that, except for May and June storms, the July hailstorms are slightly less intense than those in the succeeding months.

Monthly ratios of hail intensity based on the various climatological parameters are presented in Table 18 along with those intensity indices derived from the CHIAA storm loss data. The U. S. Weather Bureau index was derived from the average monthly values of intensities shown in Table 16. These percentages of all storms per month classed as moderate or heavy intensity were compared by assigning the lowest value,' which was 12 percent in October, the value of 1. The monthly number of central Illinois hail reports of light and much damage (Table 7) were expressed as a percent of normal, and the resulting values were compared after assigning the lowest value, 7 percent in May, the value of 1. An intensity index was derived from the monthly Urbana stone size-wind gust data by expressing the number of hail reports with stones larger than 1/2-inch as a percent of all monthly reports, and then multiplying this value by the average monthly gust speed (Table 5). All three forms of climatological data produce their highest indices of intensity in Septembe??

and the next highest in July and August.

TABLE 18

VARIOUS INTENSITY INDICES FOR MONTHS IN THE CROP SEASON

	May	June	July	Aug.	Sept.	Oct.
CHIAA Corn Intensity Index	1	3	10	3	1	0
CHIAA Soybean Intensity Index	1	7	9	4	3	2
U. S. Weather Bureau Data Index	1.3	1.2	2.4	1.9	3.2	1
Central Illinois 5-year Data Index	1	3	4.7	4.7	7	0
Urbana Hail-Wind Data Index	1.2	4.0	7.5	7.5	7.8	7.8

The CHIAA loss cost data were used to derive regional loss-intensity (RI) values which were used in the derivation of the final risk values for Illinois. These values are listed in Table 19 for the nine crop districts. The regional loss costs were normalized to a base of 1 by assigning the lowest cost value, $0. 3 in the ESE district, the value of 1. Similarly, the heavy intensity district percentages (Table 17) from the Weather Bureau data were made comparable by assigning the smallest number above zero, which was 3 percent in the SW district, the value of 1.

TABLE 19

VARIOUS REGIONAL INTENSITY VALUES

	NW	NE	W	C	E	WSW	ESE	SW	SE
CHIAA Loss-Cost Indices	2.3	2.7	1.6	1.6	1.3	2.0	1.0	2.3	2.0
Rank	2-3	1	6-7	6-7	8	4-5	9	2-3	4-5
Climogological Indices	5.7	2.0	3.0	6.3	4.7	5.3	1.7	1.0	0
Rank	2	6	5	1	4	3	7	8	9

Comparison of the values and their ranks shows a general lack of agreement. The loss cost values indicate the maximum loss from hail intensity differences as well as crop susceptibility differences occurs in the NW, NE, WSW, SW, and SE districts. The climate indices indicate that greatest frequency of intense hailstorms occurs in the C, NW, WSW, and E districts.

Both intensity expressions agree by indicating high regional values in the NW and WSW and generally low intensities of hail in the W and ESE. In all the other five districts the results do not agree. The disagreement in these two expressions of regional intensity differences in hailfalls probably is a result of the fact that the CHIAA loss cost values are strongly affected by regional differences in the target, that is, the susceptibility of the crops to damage. However, the statewide pattern of intensity variations shown by the climate data appears to be quite reasonable in light of past hail research in Illinois (11).

1965 HAILSTORMS ON DENSE RAINGAGE NETWORKS

Introduction

The State Water Survey operates four dense raingage networks in Illinois. On four different dates in the spring of 1965, hailstorms passed over portions of three of these networks, and certain interesting data concerning the surface features of these hailstorms were obtained.

These networks are composed of recording and nonrecording (stick) raingages. Observers who make daily measurements of rainfall at the stick gages also are asked to report the time of occurrence, duration, and the size of hail. Evaporation funnels in theiweighing-bucket recording raingages were removed so that the occurrence of hail was registered as the stones struck the bucket inside the gage. No stone size, classification, or frequency data are obtained, but the occurrence and exact time of the hailfall is registered. The resulting data from the dense networks furnished interesting details on the hail paths, storm movement, and the related rainfall amounts. Similar prior investigations have been made of other hailstorms on these networks (3, 4, 5, 12).

Hailstorms on March 28, 1965

On the afternoon and evening of March 28, 1965, seven separate hailstorms passed across portions of the Shawnee raingage network, which is located in the hill region of southern Illinois. Four of these storms occurred with afternnon thunderstorms associated with an east-west stationary front located just north of the storm zone, and three occurred during the night. These later storms were associated with the passage of the old stationary front which had become a cold front with southward movement. The winds at 500 mb in the storm area were from the WSW at 70mph.

In Figure 7 the paths of two afternoon hailstorms are portrayed. Isochrones (time lines) portray the time of occurrence of hail and its forward advance. Storms labeled 1 and 2 were apparently associated with one large thunderstorm which moved from the southwest to northeast. The associated isohyetal (rain) pattern and hail areas suggest that the thunderstorm had two hail cells with one dissipating (storm 1) and the other cell developing as the storm moved across the network (storm 2). In both instances the area of hailfall was centered where rainfall was greatest. Storm labeled number 1 (Fig. 7) was advancing at 20 mph, whereas hail cell number 2 was moving forward at 55 mph. The average duration of hail at a point was 1 minute or less, and the duration for rain was only 5 minutes. Sizeable deflections on the chart records at gages 62, 59, 60, 56, and 0 (near Marion) indicated that storm number 2 was producing moderately large hail at these points. The stick gage observer at gage number 32 (east of Marion) recorded hail of 3/4-inch diameter. This larger hail cell (storm 2) produced hail over 180 square miles.

Two other afternoon hailstorms occurred in the area as shown in Figure 8.

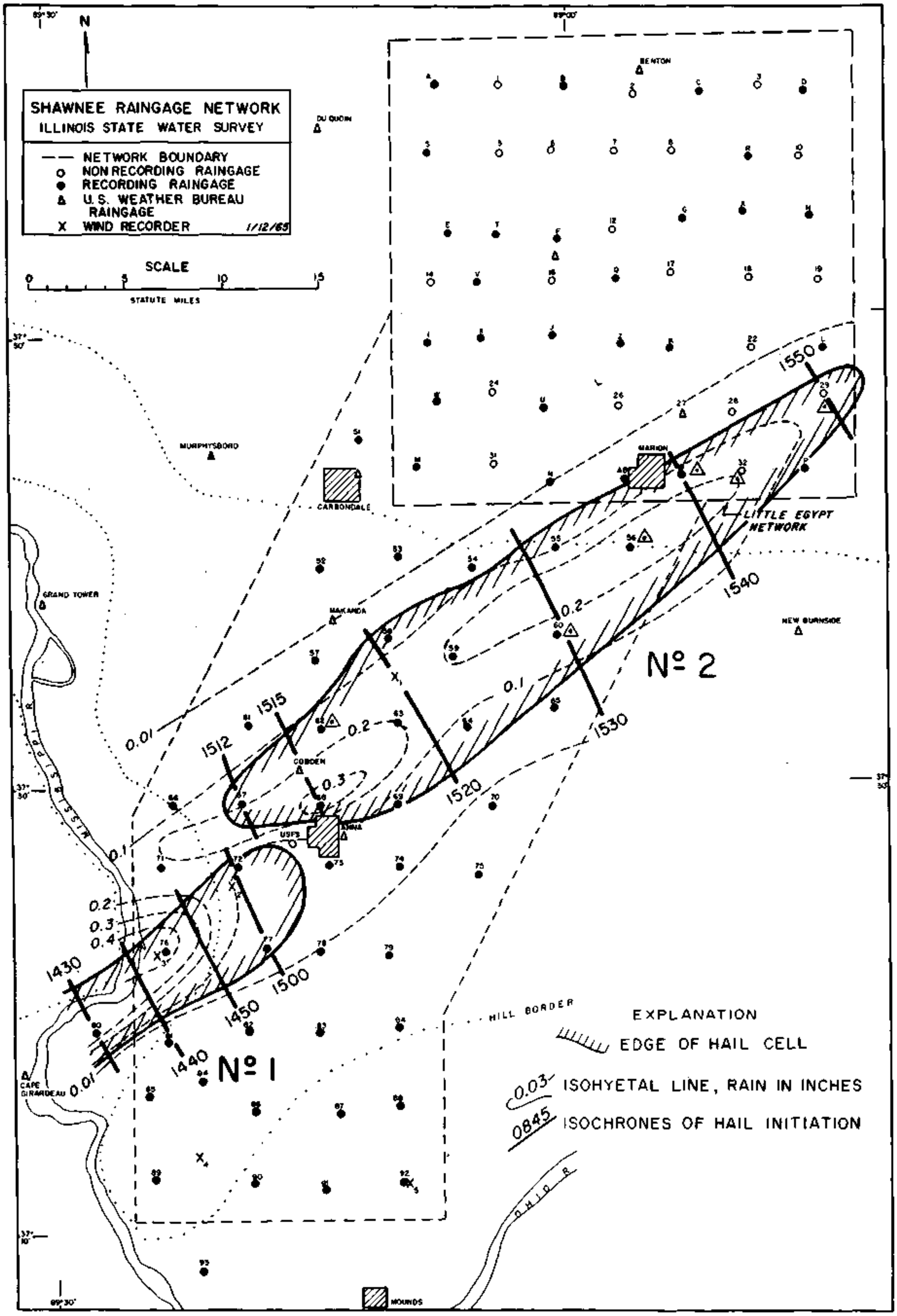

Fig.7. HAILSTORMS 1 & 2 ON MARCH 28, 1965

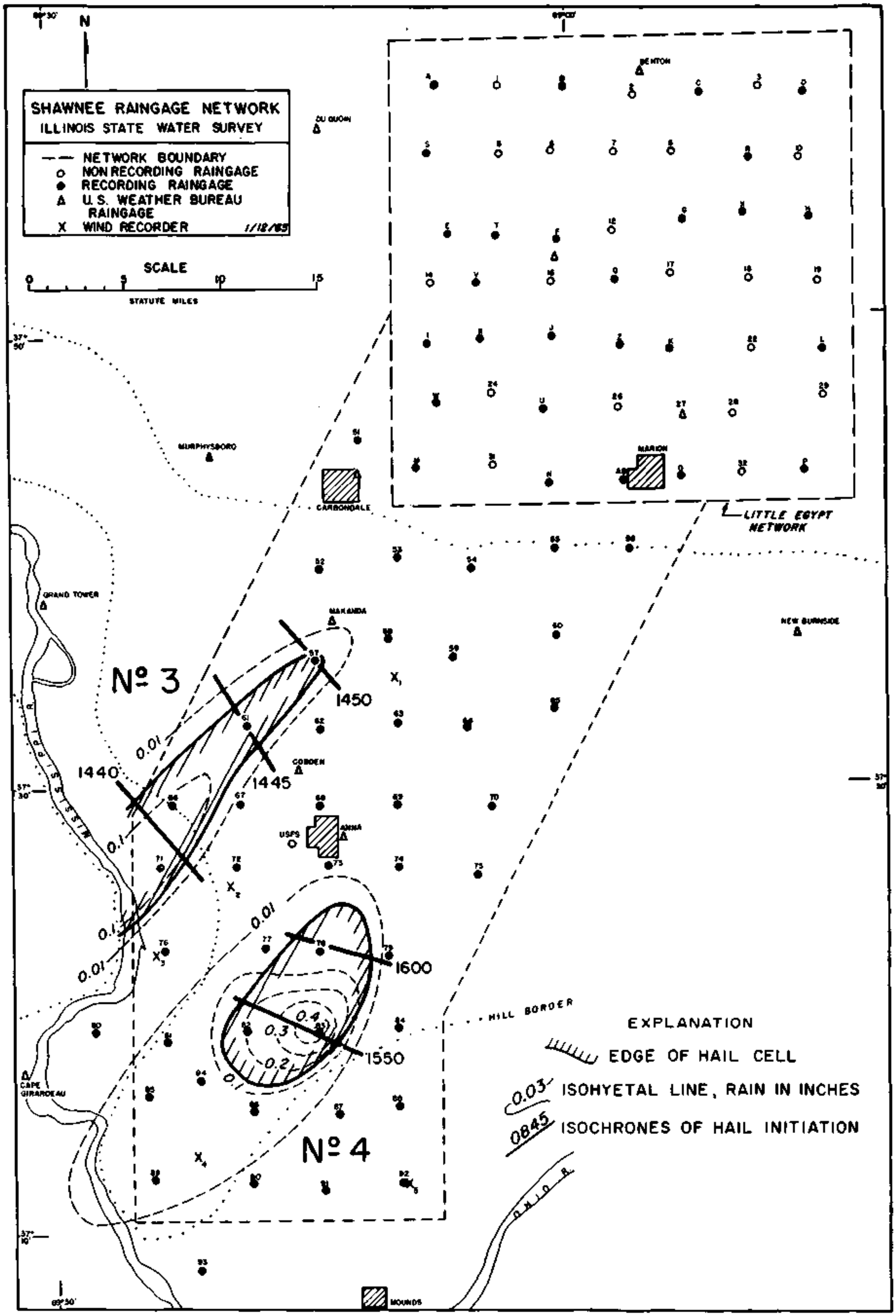

Fig. 8. HAILSTORMS 3 & 4 ON MARCH 28, 1965

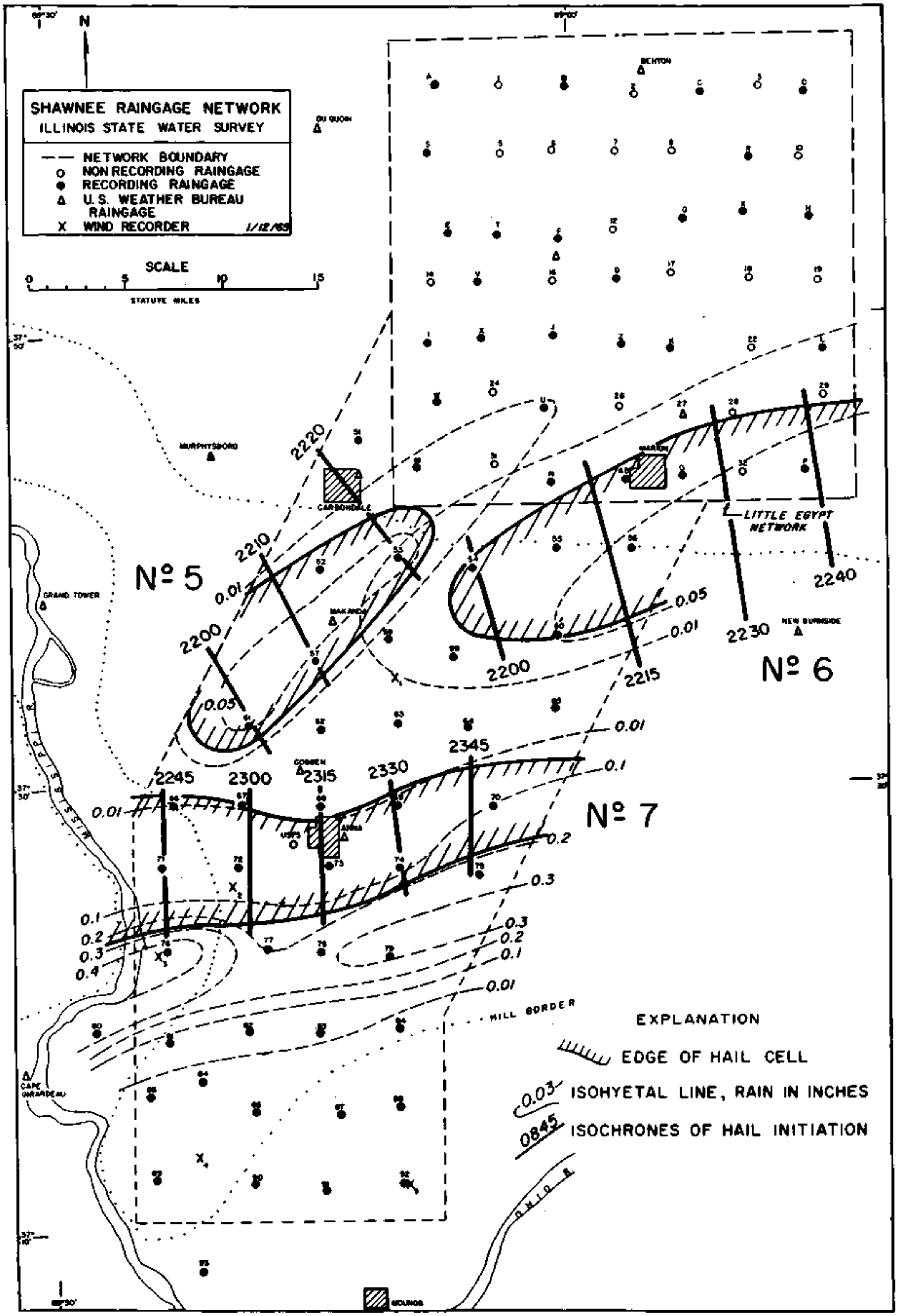

Fig. 9. HAILSTORMS 5,6 & 7 ON MARCH 28,1965

Storm 3 was entering the Shawnee network ahead and just a few miles north of storm number 1 (Fig. 7), This storm (storm 3) dissipated shortly after entering the network, as did number 1, and was associated with low rainfall amounts which fell in 3 minutes or less. The final afternoon hailstorm (storm 4) occurred as storm number 2 was dissipating. This storm produced small hail over a few square miles. However, the hail fell where the rain cell maximized with 0.45 inches of rain in 10 minutes.

Figure 9 depicts the patterns of three night hailstorms during the night of March 28. Storms 5 and 6 both developed at 2200 CST and moved to the northeast at speeds of 30 mph and 26 mph, respectively. The hailstones were small and the associated rain was light. The hail fell generally in the center of the rain patterns. The final hail cell (storm 7) moved across the network at a speed of 15 mph. The 4 - mile wide area of light hail fell along and to the left of the heavy rainfall associated with it.

The seven March 28 storms: 1) moved at widely differing speeds, 2) produced hail over widely different sized areas, and 3) were associated with a wide range of rainfall amounts. However, they had common characteristics in that most of the hail fell in the center of the rain pattern or cell, and the duration of associated rain was quite short. Heavy rainfall rates occurred, but the short durations produced small point amounts.

<u>Hailstorms on April 5-6, 1965</u>

During the night of April 5-6, 1965, six hail cells (storms) passed across the Little Egypt raingage network in southern Illinois. The initial hailstorm appeared on the network at 2350 CST on April 5, and the last storm on the network terminated at 0240 CST on April 6. The first four storms were associated with thunderstorms in a squall zone lying ahead of a cold frontlocated in southeastern Missouri, and the last two were associated with thunderstorms associated with the cold frontal passage.

The first three hail cells are shown in Figure 10a. Rainfall amounts with each cell were extremely light, less than 0. 04 inch, and the raingage traces suggest that all the precipitation may have been derived from the hail. Cells 1 and 2 apparently occurred in one large thunderstorm, and both cells moved to the northeast at speeds of 30 mph. Rain and hail in cell 3 apparently developed simultaneously at gage L and moved off the network.

Hail cell number 4 (Fig. 10b) moved from the west onto the network at a speed of 25 mph. Hail fell along the right flank of the heavy rain zone, and most of the recording raingages in the hail area indicated that the hail again constituted much of the measurable precipitation.

Cell number 5 barely occurred on the network, but it was associated with a thunderstorm which moved from the northwest rather than from the WSW as had the prior hail cells in this series of storms. The last hail cell of the April 5-6 series (Fig. l0d) derived from a massive thunderstorm which also moved from the northwest. The cell 6 hail fell along the right flank of the center (heavy rain) of the storm, and the hail cell moved from the northwest at 30 mph. In the network, hail fell over 100 square miles, and the stick gage observers at gages 27 and 32

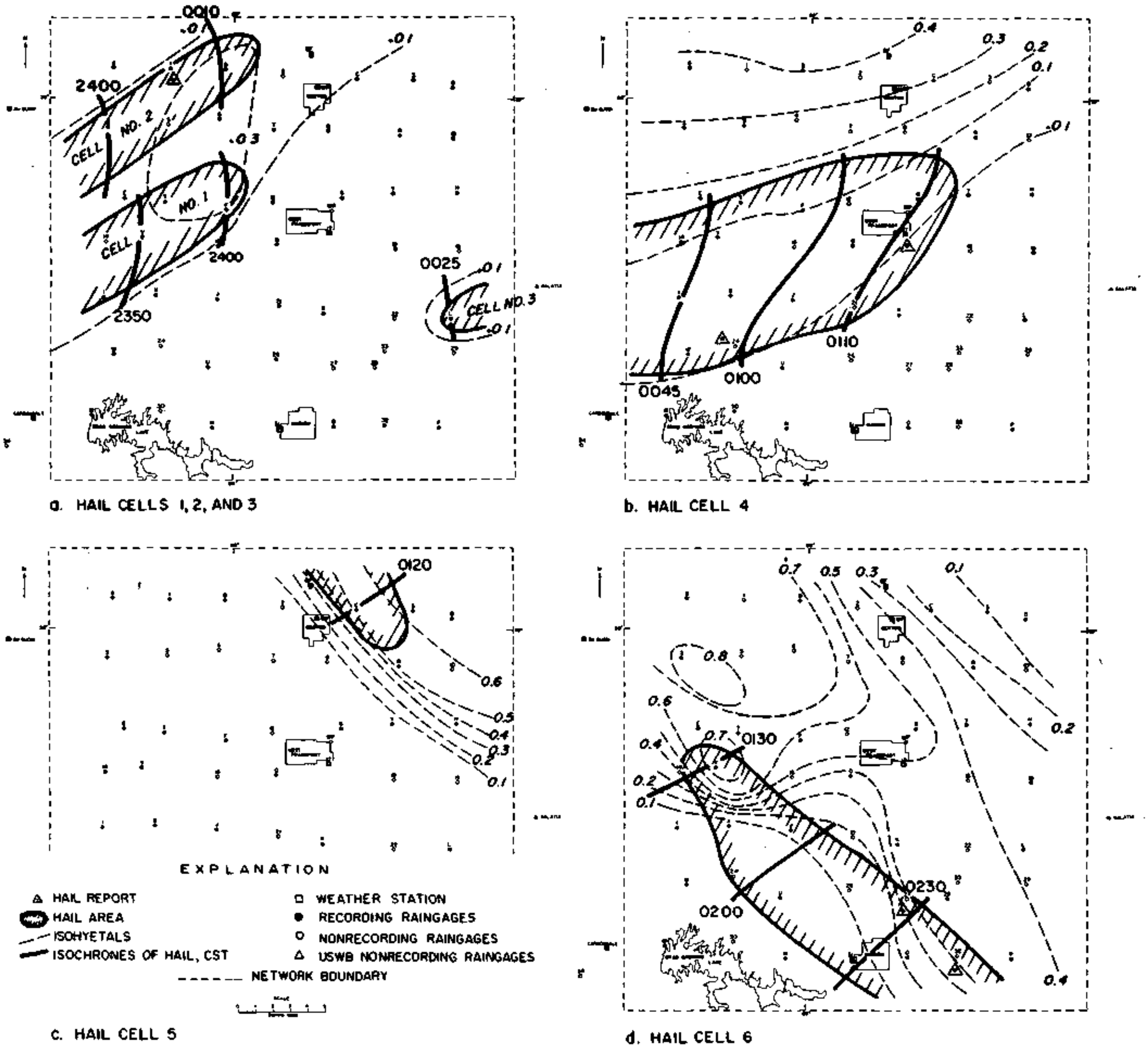

FIG. 10 HAILSTORMS ON APRIL 5-6, 1965

reported hailstones with diameters of less than 1/2-inch.

The three hail cells on April 5-6 associated with moderately heavy rain (numbers 4, 5, and 6) occurred along the right flank of the storm center, whereas those associated with light precipitation did not. In most areas of hail occurrence the amount of hail appeared to represent much of the precipitation recorded. Nevertheless, very little precipitation (less than 0. 05 inch) fell in most of the hail areas.

Hailstorms on April 8, 1965

In a 7. 5-hour period on April 8, 1965, a series of six hailstorms passed across the 13-square-mile Boneyard raingage network. This small, densely-gaged network is located in Chainpaign-Urbana, and many detailed reports of hail were gathered in the urban area. The network area was too small to obtain complete areal descriptions of any of the hail cells, but portions of their total hail patterns, the related rainfall patterns, and other hail characteristics provided a means for an interesting study of a case of multiple hail occurrences over a small area.

The hail-producing storms occurred along an east-west oriented warm front lying across central Illinois. An associated deep low moved into the storm area by late afternoon, and the last storms on the 8th occurred in the warm air sector of the low.

The first cell (Fig. 11) moved across the northeastern portion of the network from the northwest at a speed of 25 mph. Only small hail (less than 1/4-inch diameter) was produced, and rainfall was very light with durations of 5-10 minutes. Cell 2 occurred 20 minutes later, moving from the west at 20 mph. Hail was again small and rainfall amounts were low. Durations of hail and rain at a point were le?? than 5 minutes.

Cell 3 occurred three hours later (Fig. 11) and just barely reached the network area. Small hail and light rain were again produced, and the storm moved from the WSW at about 15 mph. Cell 4 was the first storm to produce moderately heavy rain and large hail. The rainfall core, as defined by the 0.2-inch line, is unusually narrow, about 1 mile wide. Stones measuring up to 1. 5 inches in diameter occurred in the heavy rainfall core with irregular shaped stones of 1-inch diameter throughout much of the hail area in the network. Durations of the hailfalls at a point varied from 2 to 4 minutes, and in many areas stones almost completely covered the ground. The storm moved from the west at 25 mph.

Ninety minutes later cell 5 moved across the network from the WNW at a speed of 15 mph. Spherical hail stones measured between 1/2-inch and 1-inch in diameter and point durations ranged from 2 to 5 minutes. In some areas hail nearly covered the ground, and as shown of Figure 11, the rain was moderately heavy. Radar indicated that the storm which produced hail listed as cell 5 had a tornado-hook echo pattern?? west of the network.

The final hail cell of April 8, cell 6, was the only one which had both edges defined as it passed across the network from the WNW. This narrow cell (1-mile wide) moved at 18 mph, and like the first two morning hail cells, was associated with very light rain and produced small hailstones.

Figure 11 also depicts the rainfall pattern based on the total rain from the six

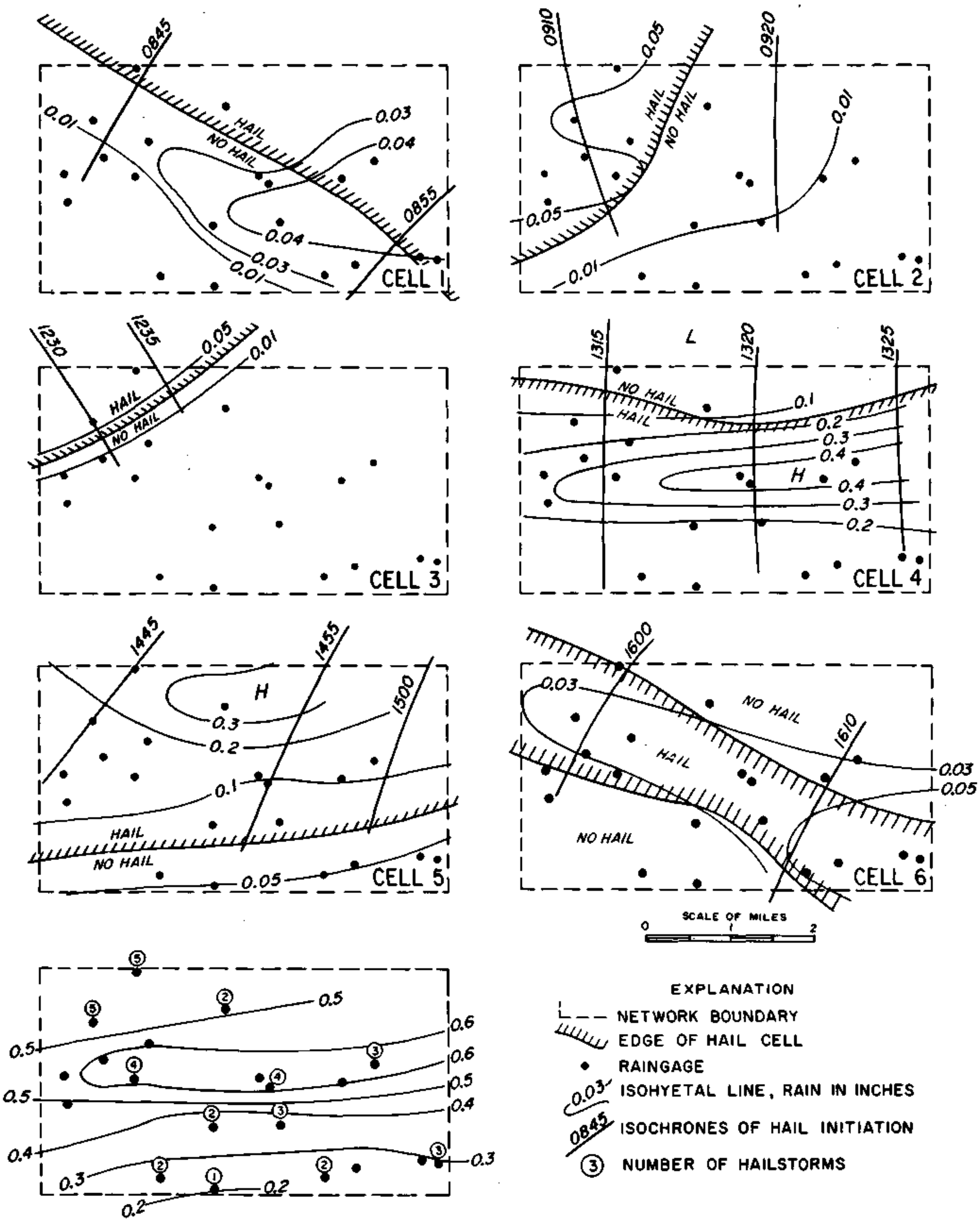

Fig. II. RAINFALL AND HAILSTORMS ON APRIL 8, 1965

hailstorms. Encircled numbers indicate the number of hail cells that occurred at various locations in the network area on April 8. Some locations in the northwest portion of this 13-square-mile area experienced five hailfalls in 7. 5 hours, whereas other points less than 2 miles away experienced only one hailfall.

Summary

A review of the characteristics displayed by these 19 spring season hail cells of 1965 reveals certain interesting facts.

1. There were two basically different types of hailstorms.
2. The first type produced very light rain, small stones, and hail over a small area.
3. The second type was associated with large thunderstorms which produced moderately heavy rainfall, moderate to large hailstones, and hail over large areas. These characteristics are similar with those found in most summer season hailstorms in Illinois.
4. On a given day and within a short period of time, both types of hailstorms occurred.
5. Within a period of only a few hours and in relatively small areas (13 to 1000 square miles), the hail cells moved at widely varying speeds and directions.
6. The hailfall in the first type of storm (small hail cells occurring with light precipitation) frequently represented much of the storm's precipitation, and frequently occurred in the center of the rainfall or storm core and over much of the storm area.

7. The hailfall with the second type of hail cell also frequently occurred in ?? area of light precipitation, but it was generally located on the right flank of the heavy precipitation area.

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