PRECIPITATION IN A 550 SQUARE MILE AREA OF SOUTHERN ILLINOIS

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Since October 1957 the Illinois State Water Survey has operated a dense raingage network in southern Illinois, one of four networks within the state, to obtain accurate and detailed precipitation data for use in water resources research programs. This southern network, called the Little Egypt Raingage Network, provides a precipitation sampling area of 550 square miles in which there is one gage in each 11 square miles.

Precipitation data from this densely gaged network have provided information pertinent to three interrelated types of study in Southern Illinois. For climatological studies concerning the long-term averages and extremes of weather, information was obtained on the spatial variability of monthly, seasonal, and annual precipitation.

Knowledge of general meteorological interest concerning the physical atmosphere was obtained also, particularly data on time of precipitation formation, location of precipitation initiation, and duration of precipitation periods. Of primary interest to the Water Survey was the hydrometeorological information directly applicable to engineering problems in water resources, and particularly the information on characteristics of excessively heavy rainstorms in southern Illinois.

Selected findings for these types of studies from the network precipitation data for the 1958-1962 period are presented. Although a five-year period may not be adequate to provide a representative measure of some of the precipitation characteristics discussed, it can provide useful approximations, and this study gives a measure of what a five-year sample of precipitation can yield.

Network Area Description

The distribution of the 49 network raingages is portrayed in Figure 1. Every effort was made to place the raingages in a strict geometric pattern with a distance of 3.2 miles between gages. Great attention was given to the selection of sites with equivalent exposures. The network contains 25 standard 8-inch weighing-bucket recording raingages, which are serviced by a trained technician, and 24 standard 8-inch nonrecording (stick) raingages which are serviced by volunteer observers. The recording and nonrecording raingages generally were alternated for statistical purposes.

The network lies in the Mt. Vernon Hill Country Physiographic Section (Leighton et al. 1948), and the center of the network is located about 90 miles southeast of St. Louis (Fig.

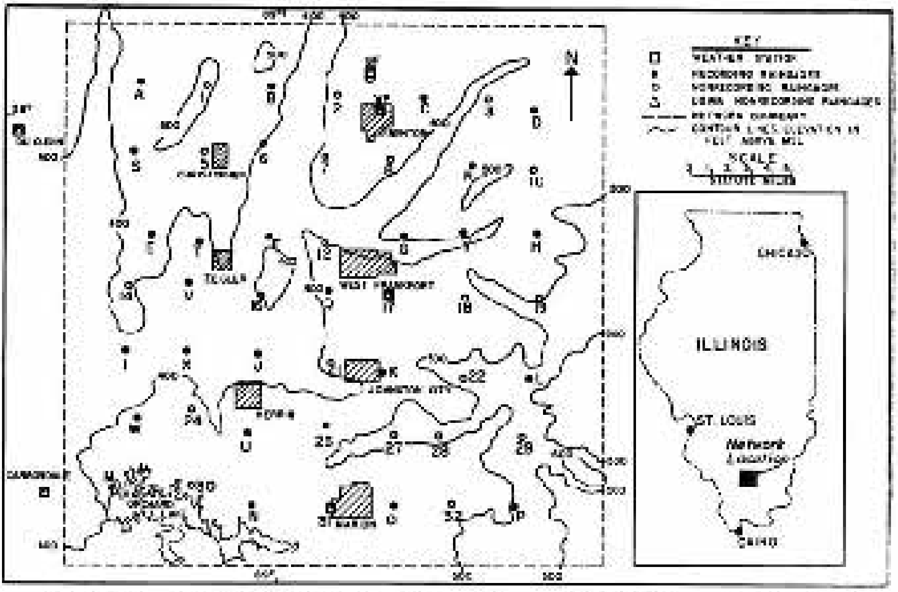


FIGURE 1.—The Little Egypt Raingage Network in Southern Illinois showing 49 gages within a square area of 550 square miles. Positions and types of raingages, elevation contour lines, and urban communities of the area are denoted.

1). The topography of the land is generally flat with a few low hills and ridges located in the eastern and northern parts of the network. The total relief is 250 feet, and elevations range from 350 feet (MSL) in the western part to 600 feet in the southeastern corner. Most of the area enclosed by the network boundary is a part of the drainage basin of the Big Muddy River.

The network is located in the center of the southern Illinois coal mining area which is referred to as Little Egypt (Price, 1958). A study of the land use in the network area revealed that 55 percent of the surface area is cropland, 18 percent woodland, 12 percent pasture land, 9 percent waste land, 4 percent urban areas, and 2 percent is bodies of water.

Analytical Methods

The basic analyses were based upon data for distinct periods of precipitation occurrence in the network. These periods of precipitation were delineated from a subjective definition. Any period of precipitation in the network which was separated in time from other precipitation by more than a six hour span of time without precipitation was identified as a precipitation period. Such a separation is believed to be adequate for separating most precipitation occurrences associated with different or separate meteorological conditions. For simplicity, all such precipitation periods were labeled as "storms" and are so referred to hereafter in this report. Obviously, more than one storm

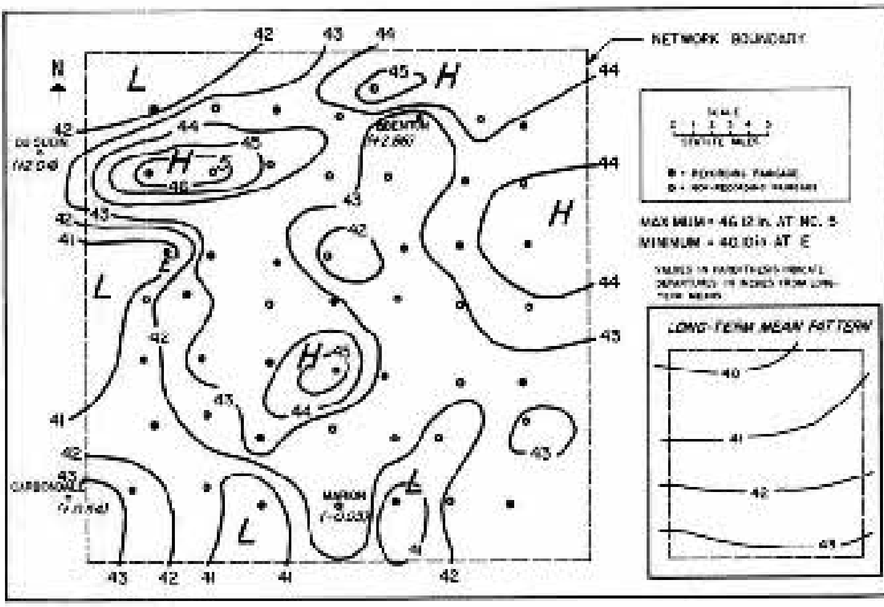


FIGURE 2.—Isohyetal pattern based on network average annual precipitation values (in inches) during 1958-1962 indicates the great areal variation detectable from dense network data. Note that average five-year pattern reverses the north-to-south increase seen in the long-term mean precipitation pattern.

would and did occur in a single calendar day, and many storms contained two or more "bursts" of heavy rain separated by short intervening periods of either lower rainfall rates or no rain.

For each storm, an isohyetal map of the network was prepared and the mean amount of precipitation over the network was calculated by averaging all gaged amounts. In addition, the average duration of the storm at any point in the network was calculated, and the time and location of the beginning and ending of the storm and the precipitation type were listed.

CLIMATOLOGICAL FINDINGS

Annual Precipitation. Figure 2 shows the average annual precipitation pattern in the network; the annual mean for the five-year period was 42.93 inches. The greatest average annual point value was 46.12 inches at gage 5, and the lowest value was 40.10 inches at gage E. Thus, a spatial variation of more than 6 inches, or 12 percent, occurred across a five-mile distance. Changnon (1962) noted similar short-distance variations in average annual precipitation values for ten-year periods in dense raingage networks in central Illinois. In general, precipitation was least in the southern part and greatest in the northern and eastern parts.

Also shown in Figure 2 is a small-scale inset map of the network area which portrays the pattern of precipitation for the area based on long-term annual normals of the U. S. Weather Bureau (1956). The mean pattern has a south-to-north decrease which is the reverse of the 1958-62 average pattern. Comparison of the pattern on this inset map with the 1958-62 pattern furnishes some measure of the great amount of areal variation in average annual amounts which are detected by a dense network of raingages.

Four Weather Bureau stations in the immediate vicinity of the network had long-term normal values and the departures of the 1958-62 annual average amounts from these normals are shown in parenthesis for these four stations (Fig. 2). The 1958-62 annual averages at DuQuoin and Benton were 2 to 3 inches in excess of their long-term normals, whereas those at Marion and Carbondale were near normal. The precipitation during the 1958-62 period in the network area can be classified as near to slightly above normal.

Comparison of the five-year average annual values shown on Figure 2 with surface elevation (Fig. 1) revealed a lack of correlation. This comparison was made to discern whether or not locations in the network with higher elevations experienced higher precipitation amounts. Such a relationship has been found in the Shawnee Hill area located south of the network (Roberts et al., 1957). The possible relationship of precipitation and elevation was in-

TABLE 1.—Average Annual Precipitation Values for Fifty-foot Intervals of Elevation in the Little Egypt Network

Elevation interval, feet above MSL	Number of raingages	Average value rainfall (in.) per interval
351-400	12	43.01
401-450	18	42.77
451-500	10	43.23
501-550	6	42.30
551-600	3	42.58

vestigated by sorting the 1958-62 values of all 49 raingages according to the raingage elevations. As shown in Table 1, there was no discernible relationship since the raingages located in the two highest 50-foot elevation intervals produced relatively low average annual values, and the highest interval value came from raingages located in the middle elevation range.

The relationship of the average annual precipitation pattern with other data which might explain the distribution was further investigated. A count was made of the number of times each raingage received the maximum amount of precipitation in a storm. These data showed very little correlation with the amount of precipitation. For instance, gage P (Fig. 1) received the greatest number of storm-maximum amounts, a total of 36, and yet gage P had a relatively low average annual value. A similar inverse relationship occurred at gage A which had the second greatest number of storm-maximum values, 30, but a low annual precipitation value.

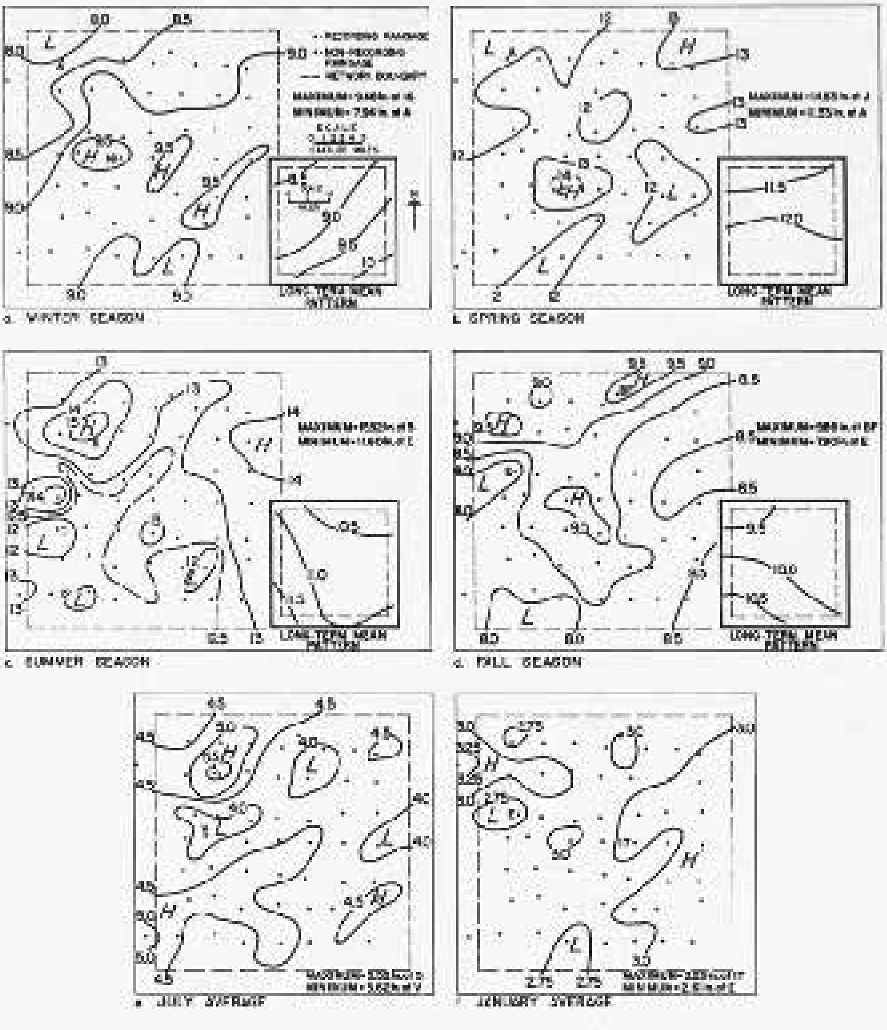


FIGURE 3.—Seasonal and selected monthly isohyetal patterns for the Little Egypt Network based on average precipitation values (in inches) for the study period. The greater warmer weather variability is clearly portrayed in these patterns.

The number of times each recording raingage received a 30-minute to 24-hour rainfall value equal to or in excess of the two-year frequency value was also compared with average annual precipitation at the 24 recording raingages. The areal pattern of these excessive rainfall occurrences is shown in Figure 10, and is discussed more fully under Hydrometeorological Findings, page 183. A correlation coefficient of +0.65 was obtained for the average annual amounts and the total number of excessive rainstorms. This coefficient indicated that the storms with excessive rainfall values, which occurred primarily in the warm seasons, explained about 40 percent of the areal variation found in the average annual precipitation in the network.

Seasonal Precipitation. Maps of the average seasonal precipitation for the 1958-62 period are presented in Figure 3. For each season a small inset map has been included to show the mean seasonal precipitation pattern based on long-term normals for stations in the network area.

The winter season precipitation pattern (Fig. 3a) has a relatively flat gradient with a general increase from the northwest to the southeast which is similar to the long-term mean precipitation pattern. The magnitude of the five-year average values is also approximately equivalent to those based on long-term means for the area. The spring pattern (Fig. 3b) has considerably more areal variations than does the winter pattern. The average spring values varied from a low of 11.5 inches at gage A to a high of 14.8 inches at gage J, a 3.3-inch difference. Most of the network had five-year average values equal to or greater than the long-term mean values indicated for spring.

The precipitation pattern of the summer season (Fig. 3c) has greater areal variability than that of the other three seasons. Precipitation in summer was greatest in the northwestern parts where gage 5 had an average of 15.5 inches. Precipitation was least in the southwest where gage I had 11.6 inches, making a maximum difference of nearly 4.0 inches. The low averages in the southwest are in direct contrast with the long-term pattern. The entire raingage network had average summer values in excess of the long-term mean values.

The fall season pattern (Fig. 3d) also exhibited considerable areal variability within the network. As in the summer season, the highest averages occurred in the northern parts which again is in direct contrast to the pattern based on long-term means. The 9.5-inch averages for 1958-62 were the only near-normal values in the network, and all other fall values in the network were below the long-term means.

Thus, in relation to the magnitude of precipitation, the five-year precipitation values for the spring and summer seasons were greater than long-term mean values. Those in the winter season were near normal, and those in the fall season were generally below normal. The winter precipitation pattern for the 1958-62 period was quite similar to the long-term mean pattern for winter. However, the five-year precipitation patterns for the spring, summer, and fall seasons exhibited considerably more areal variability than did the long-term mean patterns for these seasons.

Monthly Precipitation. The precipitation patterns for two months are shown in Figure 3 to illustrate the areal variability in monthly patterns based on five-year averages. Considerable point-to-point variation is shown in the July pattern (Fig. 3e) which has a maximum difference of nearly two inches between gages

TABLE 2. Precipitation Conditions in Little Egypt Raingage Network.

	Winter	Spring	Summer	Fall	Annual
Average number of days with precipitation in network	32	41	45	32	150
Average number of storms with network mean rainfall of					
trace or more	23	37	50	30	140
0.25 inch or more	11	16	14	8	49
0.50 inch or more	6	9	7	5	27
1.0 inch or more	2	3	3	3	11
Average number of storms with					
thunderstorms	3	18	35	12	68
hail	1−	6	2	1−	9
excessive rainfall values	1−	4−	8	2	14
Average duration at a point, hours, for					
all storms	11.6	6.4	2.6	5.2	5.5
storms with network means of 0.5 inch or more	18.3	11.9	7.2	12.6	12.8
Percent of total time with rain	12	11	6	7	9

V and 5 which are six miles apart. The January average pattern (Fig. 3f) exhibits much less areal variability of precipitation, but moderate variations in short distances are shown in the area near gage E.

Frequencies of Storms, Days with Rain, and Associated Weather Conditions. Among the climatological data derived from the network precipitation records were various network frequencies for calendar days with precipitation, for storms with varying network mean precipitation amounts, and for different weather conditions associated with the storms. Averages for much of this data are summarized in Table 2. In general, there were fewer storms than days with precipitation because some storm periods overlapped into two or three days. However, in the summer season there were more storms than days with rain because many summer storms were short and occasionally two occurred on the same calendar day.

During the 1958-62 period a total of 702 storms occurred, which is an average of 140 per year. Storms occurred most frequently in the summer and least frequently in winter. Nearly 50 percent of the total storms in winter and in spring had network mean precipitation values of 0.25 inch or more, but only 25 percent of the total storms in summer and fall were of this magnitude. Many storms in summer and fall had low mean rainfall values, but some of them produced moderately large amounts at a few raingages within the network.

In each season the average number of storms which produced mean network values of 0.5 inch or more was about 50 percent of the number of 0.25-inch or greater storms. Thus, the 0.5-inch or greater storms represented about 25 percent of the total winter and spring storms, but only 15 percent of the total number of summer and fall storms. Interestingly, there was very little seasonal difference in the average number of storms which produced 1.0-inch or greater network mean values.

Nearly 50 percent of the average annual number of storms in the Little Egypt Network were associated with thunderstorms. Thunderstorms occurred with 70 percent of all summer storms and with 12 percent of the winter storms. On the average, nine storms per year produced hail within the network and most of these occurred in the spring. Almost 16 percent of all spring storms were associated with hail.

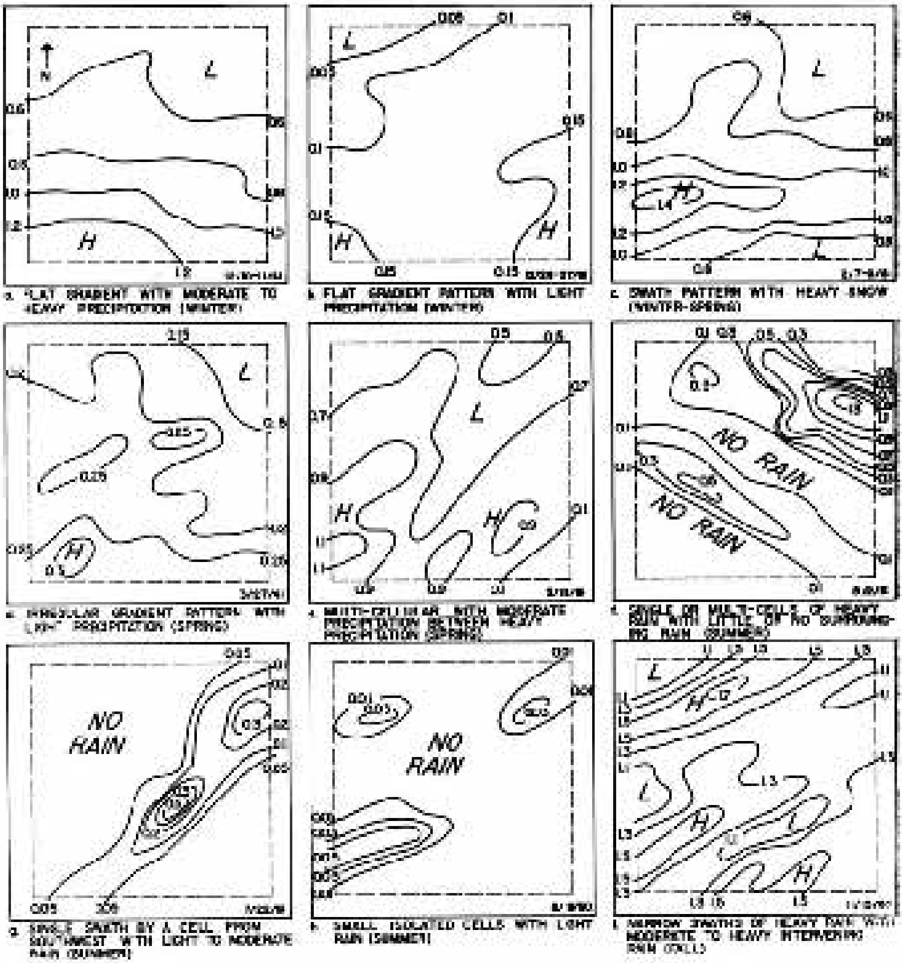


FIGURE 4.—Typical patterns of storm precipitation (in inches) found for each season from network data.

Meteorological Findings

Some findings derived from the data collected in the Little Egypt Raingage Network were more directly related to meteorology than to climatology or hydrometeorology. These findings concerned characteristics of the storm periods and the time and space variations in the incidence of precipitation.

Storm Patterns. Certain types of network isohyetal patterns, in regard to shape, configuration, and quantity of precipitation, were found to be prevalent in certain seasons and to occur repeatedly. Each season had one or more typical patterns of precipitation, which are illustrated in Figure 4. As expected, the most prevalent winter storm patterns (Fig. 4a and 4b) had flat gradients with no great variations in amounts with distance. Usually these patterns were oriented so that the heavier storm precipitation occurred in the southern parts of the network. Heavy snow storms frequently produced a swath-like pattern illustrated by the storm map for February 7-8, 1961 (Fig. 4c),

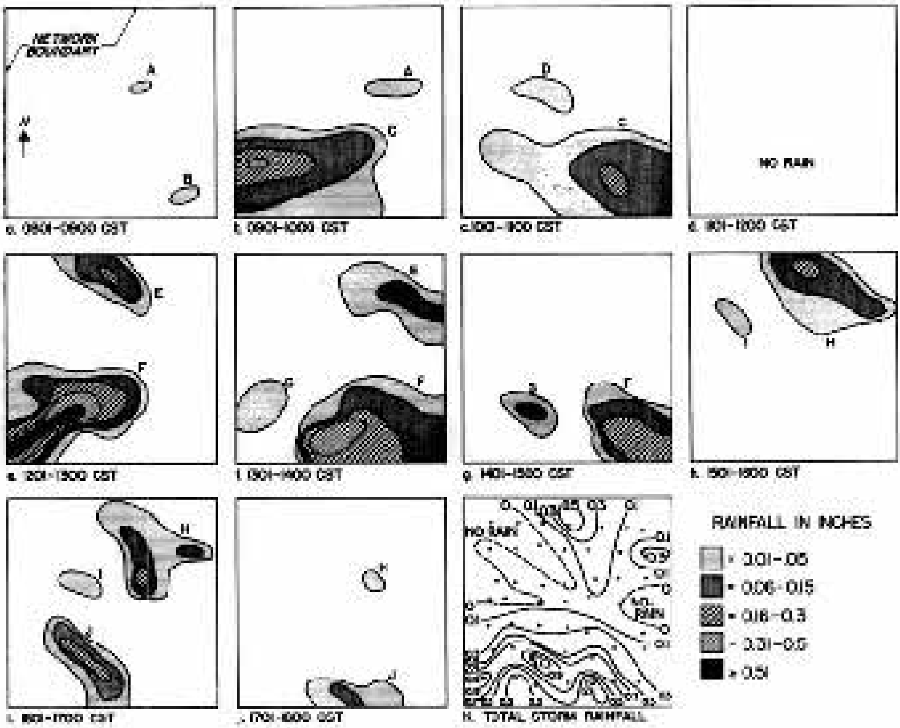


Figure 5.—Maps of the hourly rainfall sequence and total rainfall for the storm of August 21, 1958, illustrating several characteristics of a typical summer storm in the network area.

which produced snow varying from 2 inches in the northern parts to more than 7 inches in the center of the swath.

A typical spring storm pattern associated with light precipitation is shown in Figure 4d. Figure 4e portrays another typical spring storm isohyetal pattern which is characterized by broad swaths of moderate to heavy precipitation which are enveloped by light to moderately heavy precipitation.

Figure 4f shows one of three frequent summer storm patterns. This pattern is often multi-cellular, but the surrounding or intervening areas have little or no measurable rain. Another typical summer storm pattern is caused by a single rain cell which moves across the network from the southwest leaving a narrow swath of light to moderate rainfall (Fig. 4g), and a third (Fig. 4h) is characterized by one or more isolated small cells of light rainfall.

A pattern frequently found in fall season storms of heavy precipitation is shown in Figure 4i. This particular pattern is somewhat similar to the multi-cellular spring storm pattern (Fig. 4e), except that it has narrower swaths of heavy precipitation suggesting the passage of small rainshowers through an area of continuous rain.

Sequence maps in Figure 5 show the rainfall patterns for each hour during the storm of August 21, 1958. The total storm rainfall map (Fig. 5k) has an isohyetal pattern which is representative of one of the typical summer storm patterns (Fig. 4f). An hourly rainfall analysis revealed that this storm was composed of a series of 10 separate cells which either developed in the network or moved across the network.

The sequence of hourly maps for Figure 5 is a good illustration of the characteristics of summer rainshowers and thundershowers that constitute a typical summer storm in the network area. The cells which occurred before 12 PM were air mass showers, whereas those in the afternoon were associated with a cold front passage. Cursory examination reveals that some large cells (C, F, H, and J) produced rain over areas ranging from 150 to 300 square miles. However, many of the smaller cells (A, B, D, and I) produced rain over areas of only 5 to 25 square miles. During the ten-hour period of this storm the 10 rain cells assumed a wide variety of sizes, shapes, speeds and directions of movement, and rainfall intensities. This type of storm analysis was made for other summer storms, and results showed that many such summer storms were a composite of four or more rain cells.

Network Initiation of Storms. Two analyses of the initiation of storms in the network were made utilizing the 1958-62 data from the 24 recording raingages. One dealt with the areal variations in the initiations, and the other concerned temporal variations.

Data for storms starting in the central part of the network, obtained from the 10 interior gages, were compared with records of storm-starts at the 14 gages on the network perimeter. By such a separation, initiation data for developed precipitation systems which moved into the net-

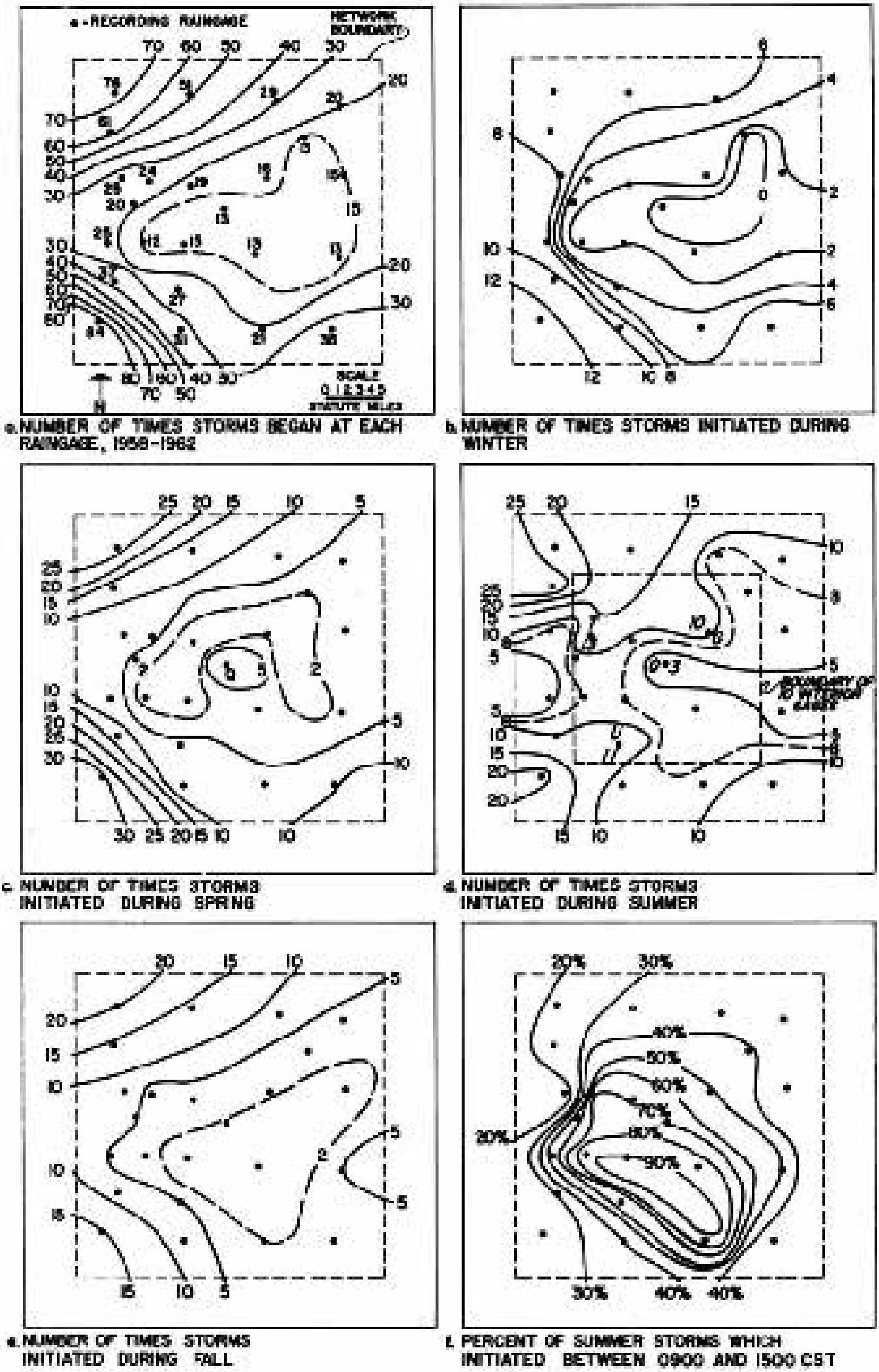


FIGURE 6.—Maps showing the annual and seasonal distributions of storm initiations in network. Note the high percentage of storms moving into the area from westerly directions.

work could be compared with data for precipitation developing within the confines of the network.

Annual and seasonal areal variations in the initiation of storms are displayed in Figure 6. Most major precipitation systems in Illinois have been shown to move from westerly directions, and a preponderance of movements are from either the southwest or northwest (Changnon and Huff, 1961). The areal distribution shown for all storms in the 1958-62 period (Fig. 6a) reveals the great frequency of storm initiations recorded at the three northwesternmost and three southwesternmost raingages. The number of initiations at these six gages accounted for 50 percent of the total storms in the network. Initiations were least frequent in the 225-square-mile central area (see boundary indicated on Fig. 6d), where the initiations totaled 172 or 24 percent of the total storms. This total represents an annual average of 34 localized developments in the central area.

Seasonal variations in the areal distribution of initiations are shown in Figure 6b-e. The patterns for winter and spring indicate a principal maxima of initiations in the southern and southwestern parts of the network. Apparently rain-producing systems in these two seasons in southern Illinois moved most frequently from the south-southwest. The number of storm initiations in the interior of the network was very small in both of these seasons.

In the summer season also (Fig. 6d), most of the initiations were in the northwest and southwest corners of the network. Considerable variation exists in summer between the number of initiations at nearby raingages as revealed by the pattern along the western network boundary. One-third of the 249 summer storms initiated at the 10 interior gages (Fig. 6d), but less than 20 percent of the total storms in the other three seasons started there. Frequency pattern within this interior reveals a marked tendency for occurrences in the northern, western, and southwestern parts (gages T, G, and U). In the five-year period analyzed, a total of 85 summer storms, an annual average of 17, developed within the 225-square-mile area.

Figure 6e shows the pattern of initiations for the fall season with a principal maximum in the northwestern corner of the network and a secondary maximum in the southwest corner. In the fall and summer precipitation-producing systems in southern Illinois apparently moved from the northwest more frequently than from the southwest which reverses the tendency for the winter and spring seasons.

The diurnal variations in the number of initiations by season and for all 702 storms are shown in Figure 7. Winter storm initiations in the network were most frequent between 3 and 4 AM with a secondary maximum from 5 to 6 PM. The spring season diurnal distribution has four peaks in the frequencies with little agreement with the winter distribution.

The summer season diurnal distribution of initiations has a pronounced maximum occurring between 12 and 3 PM. As indicated previously, many of the 172 storms which initiated within the network interior area occurred in the sum-

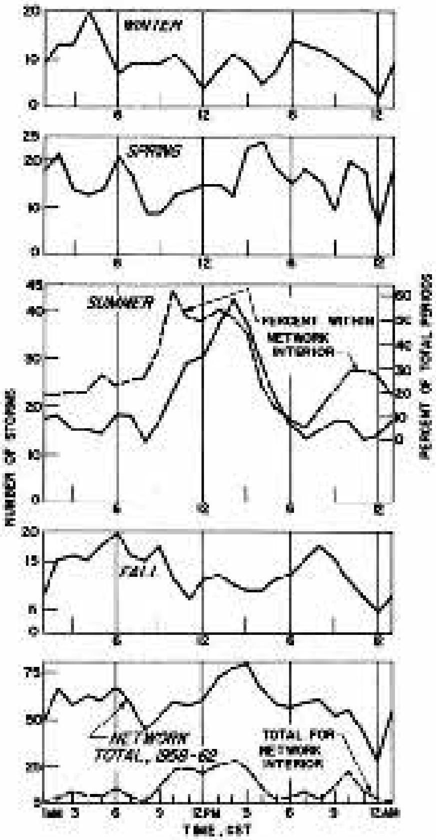


FIGURE 7.—Diurnal graphs showing the total hourly number of storm initiations in each season and for the five year period. The values shown for each hour are two-hour moving totals. Network storms started most frequently in early afternoon, least frequently near midnight.

mer. From 9 AM to 2 PM the formations of storms in this interior accounted for more than 50 percent of all the network storm initiations for the summer, and therefore largely account for the mid-day peak found in the summer hourly frequencies (Fig. 7). Formations in these hours suggest that most of these storms were localized air mass showers that often depend on mid-day heating for their development. Chiang (1962) has shown that in summer months warm, moist tropical air masses are present more than 50 percent of the time in southern Illinois. The areal significance of storm developments in the mid-day hours is further revealed by the isopercentile pattern on Figure 6f which is based on the number of storm initiations in the six-hour period ending at 3 PM. The fall diurnal distribution (Fig. 7) is somewhat similar to the winter distribution with maxima occurring in the early morning and early evening.

The diurnal distribution of initiations for all 702 storms in the five-year period of record, also in Figure 7, shows the maximum number between 2 and 3 PM and the minimum between 11 PM and 12 AM. Also shown in this figure is the diurnal distribution of initiations for all storms within the network interior, which again reveals the strong preference for development of these storms in the hours between 9 AM and 3 PM.

Duration of Storms. For each of the 702 storms that occurred in the network during 1958-62, an average duration of precipitation at any location within the network was obtained by averaging the precipitation duration values for all the recording raingages which had measurable precipitation. The average point duration values calculated from all the storms in each season and year are listed in Table 2. The mean duration of storms in the winter was more than four times as great as the mean duration of storms in summer.

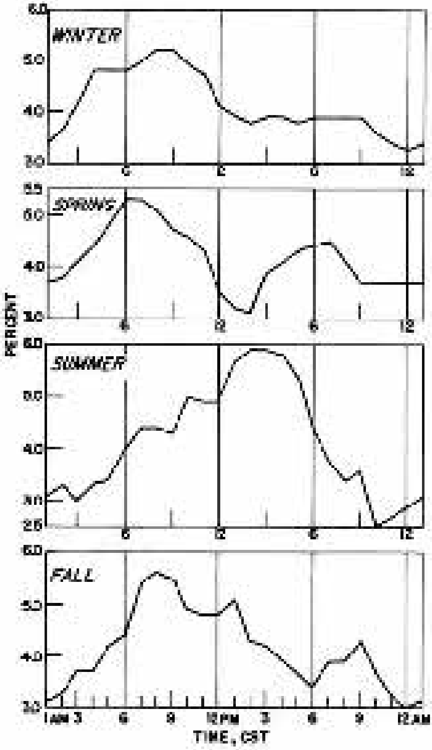


Figure 8.—Diurnal graphs showing the hourly frequencies of precipitation occurrence in the network in each season. The number of instances of precipitation per hour are expressed as a percent of the total hours of precipitation in each season. Precipitation was most frequent between 12 and 5 P.M. in summer, but between 4 and 10 A.M. in other seasons.

The average number of calendar days with measurable precipitation in the network is 150 per year (Table 2), or 40 percent of the total days, and long-term records reveal that at a point in the network area the average number of days with measurable rain is 115 (Anon., 1947), which is 32 percent of the total days in a year. However, the average annual number of hours with measurable precipitation at any point within the network is 769 hours which is about 9 percent of the total hours in a year.

Diurnal variations in the frequency of hours with precipitation are shown in Figure 8. In the winter, spring, and fall precipitation was most frequent between 4 and 10 AM; in summer it was most frequent from 12 to 5 PM. In winter, summer, and fall the hours when precipitation was least frequent were between 10 PM and 12 AM, whereas in spring precipitation was least frequent between 12 and 2 PM.

Hydrometeorological Findings

Of primary hydrometeorological interest in the the data from the Little Egypt Raingage Network were storms which produced heavy precipitation throughout or on small parts of the network. Storms which met one of two requirements pertaining to rainfall intensity were selected for analysis. The storms selected were (1) those with a network mean precipitation of 0.5 inch or more, or (2) those which produced rainfall amounts equal to or in excess of the amounts expected to occur at a point once every two years. Characteristics of storms with network mean precipitation values of 0.5 inch or greater were selected for one analysis because these storms produced nearly 70 percent of the total precipitation for the network. Information about storms producing excessive rainfall values is used in the design of hydrologic structures.

Storms with Network Means of 0.5-Inch or More. In the 1958-62 period, 136 of the 702 storms had a network mean precipitation value of 0.5 inch or greater. The average annual number of such moderately heavy storms was 27; highest number in one year was 33 in 1958 and lowest number was 21 in 1959. These moderately heavy storms represent only 19 percent of the total storms in the period; however, they were responsible for 68 percent of the network's total precipitation, and thus were selected for detailed study.

In Table 2, certain seasonal and annual statistics of these heavier precipitation periods are presented. The greatest number of these storms occurred in the spring which has an average of nearly 10 such storms per year; the fewest storms occurred in fall which has an average of five per year. Averaging the network mean precipitation values for these storms for each season showed the highest values (1.29 inches) in summer and the lowest (0.91 inch) in spring.

In all seasons except winter most of these heavier rainstorms were associated with thundershowers which occasionally were mixed with rainshowers. In the winter season more of these storms were with rain-rainshowers, or with rain mixed with snow, than with thundershowers. Only one of the winter storm periods was a snow storm, but three of the 48 spring storms were solely snow storms.

The number of bursts of precipitation, or sudden changes in precipitation rate, during the 136 heavier storms was determined on a seasonal and annual basis. For all 136 storms, a total of two bursts per storm was most frequent. On a seasonal basis, two bursts per storm were most frequent in summer and fall, whereas one burst was most common in spring and three bursts were characteristic of the winter storms.

Initiation data for these storms of 0.5 inch or greater were compared with those for the total 702 storms. The mapped frequency of initiations of the heavier rain periods had a pattern generally similar to that for all storms (Fig. 6a). These heavier network storms frequently were precipitation systems that moved into the network rather than systems that developed within the network area. However, one-third of all the heavier rainstorms in summer formed within the network, which is the same ratio obtained for all network summer storms.

The time of initiation of the heavier storms was also investigated and compared with the data for all network storms (Fig. 7). The 0.5-inch and greater storms initiated most frequently between 2 and 4 AM and between 6 and 8 PM, whereas the major initiation peak for all 702 storms was between 1 and 3 PM. The diurnal distributions of initiations of the heavier storms in the winter and spring seasons were similar to those obtained for all the storms (Fig. 7). In the fall the heavier storms initiated most frequently between 8 and 9 PM in contrast to the peak on initiations for all storms between 5 and 6 AM. In summer most of these heavy storms initiated between 7 and 9 PM.

TABLE 3.—Two-Year Frequency Amounts for Southern Illinois and Number of Network Storms which Produced Two-Year or Greater Frequency Amounts for Varying Durations.

Duration	Amounts to be equalled or exceeded at least once every two years, inches	Number of storms with at least one raingage amount equal to or greater than two-year value				
		Winter	Spring	Summer	Fall	Annual Average
30 min	1.1	1	16	31	9	11
1 hr	1.4	1	10	27	6	9
2 hrs	1.7	0	6	17	5	6–
3 hrs	1.9	0	6	16	4	5
6 hrs	2.2	1	6	15	5	5
12 hrs	2.8	0	3	11	4	4–
24 hrs	3.2	0	2	9	3	3
Average	–	1–	4–	8–	2	–

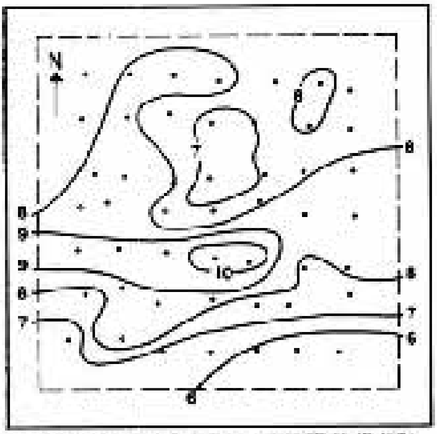
The average point duration of the 0.5-inch or greater storms was 12.3 hours, compared with 5.6 hours for all storms (Table 2). This tendency to have durations in excess of the average duration for all storms also prevailed in each of the four seasons.

Storms with 2-year Frequency Amounts. All storms with one or more gaged amounts equal to or in excess of the amounts expected to occur at a point in Southern Illinois at least once in a two-year period for any one of seven durations between 30 minutes and 24 hours were selected for analysis. During the 1958-62 period, 70 storms, or almost 10 percent of the total number, produced a two-year frequency amount for one or more of the seven possible durations. Table 2 shows the seasonal and annual average number of storms with two-year excessive rainfall values.

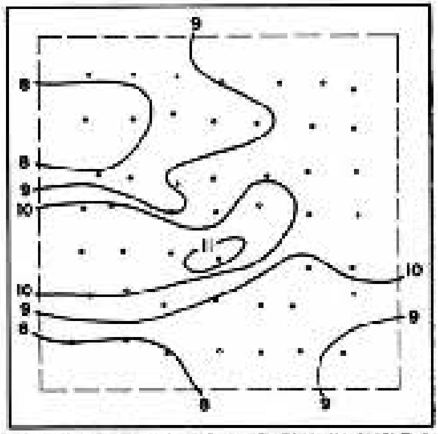
Huff and Neill (1959) have identified the two-year frequency amounts expected in Southern Illinois for each of the seven durations, and these are listed in Table 3. The number of network storms which produced two-year frequency amounts is also listed. Only 15 of the 70 storms had 24-hour amounts equalling or exceeding the two-year value of 3.2 inches for this duration. However, 57 of the 70 storms had 30-minute amounts of 1.1 inches or more. As shown in Table 3, the network annual averages diminish with increasing duration.

Data in Table 3 indicate that more than 50 percent of the storms with excessive rainfall amounts occurred in summer which has an average of eight such storms per year. Only two storms with two-year frequency amounts occurred in winter.

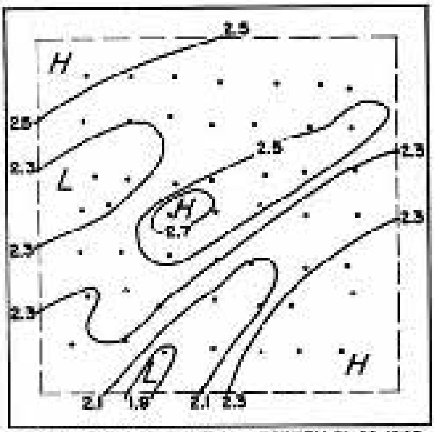
Examples of four storms which produced excessive rainfall amounts are shown in Figure 9. The most severe short duration rainstorm in the network during the 1958-62 period occurred during the night of August 16-17, 1959 (Huff and Changnon, 1961). Each network raingage (Fig. 9a) had amounts in excess of the two-year recurrence interval value for all durations from 30 min-



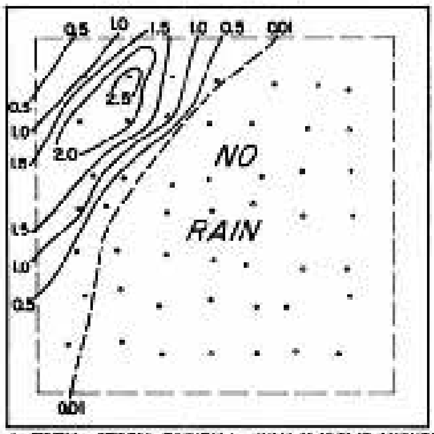
a. TOTAL STORM RAINFALL, AUGUST 16-17, 1959 (16 HOURS)



b. TOTAL RAINFALL FOR 4 STORMS IN MAY 5-8, 1961 (96 HOURS)



c. TOTAL STORM RAINFALL, JANUARY 21-22, 1962 (22 HOURS)

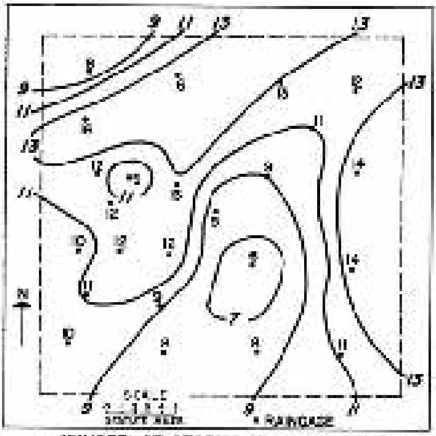


d. TOTAL STORM RAINFALL, JULY 11, 1961 (2.4 HOURS)

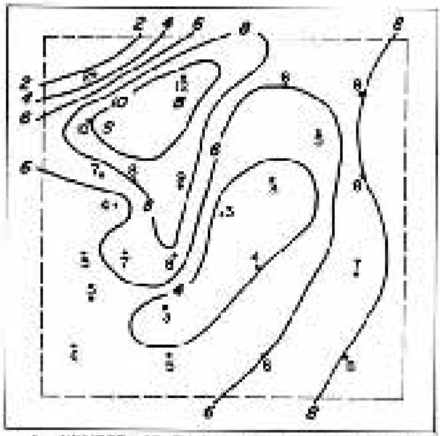
FIGURE 9.—Isohyetal patterns of selected storms which produced excessive point rainfall amounts in the network during the 1958-1962 period. Total rainfall throughout the network in the August 16-17, 1959 storm exceeded the once in 100-year recurrence interval for a 16-hour period.

utes to 24 hours. Four intense rainstorms occurred in a four-day period during May 1961, and the resulting four-day total precipitation pattern is presented in Figure 9b. Each of the four storms comprising this period had values in excess of certain two-year frequencies. Figure 9c depicts the isohyetal pattern for a winter storm which produced six-hour amounts in excess of the two-year frequency values for this duration.

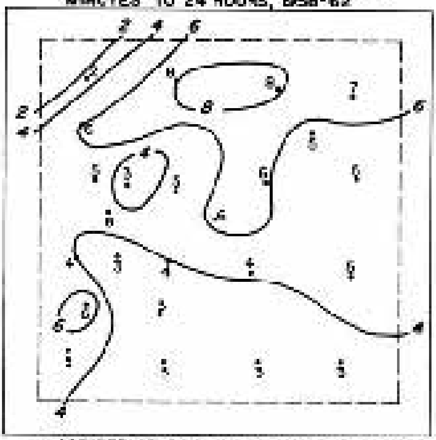
Using the network mean precipitation values for these 70 storms, an average value of 1.02 inches was



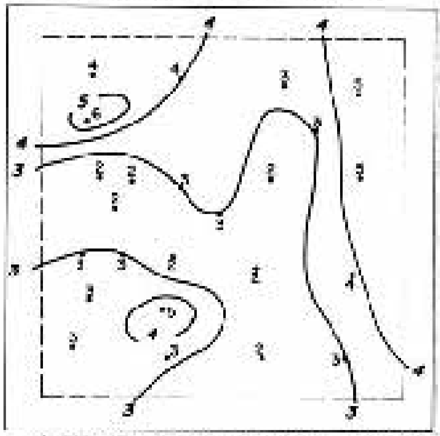
a. NUMBER OF STORMS THAT PRODUCED 2-YEAR OR GREATER RECURRENCE INTERVAL VALUES FOR ANY DURATION FROM 30-MINUTES TO 24 HOURS, 1958-62



b. NUMBER OF TIMES EACH GAGE RECORDED A 30-MINUTE AMOUNT ≥ 2-YEAR RECURRENCE INTERVAL VALUE (1.1 in.)



c. NUMBER OF TIMES EACH GAGE RECORDED A 6-HOUR AMOUNT ≥ 2-YEAR RECURRENCE INTERVAL VALUE (2.2 in.)



d. NUMBER OF TIMES EACH GAGE RECORDED A 24-HOUR AMOUNT ≥ 2-YEAR RECURRENCE INTERVAL VALUE (3.2 in.)

FIGURE 10.—Number of times that two-year or greater recurrence interval rainfall values occurred at each recording raingage in the network during the study period are shown for selected durations.

computed. However, many of the 70 storms produced little or no precipitation in large parts of the network area. Consequently, 26 of the 70 severe storms had network mean values lower than 0.5 inch, and 15 of these had network mean values lower than 0.3 inch. As an example, the storm on July 11, 1961 (Fig. 9d), had excessive values for the durations from 30 minutes through three hours, but the network mean rainfall was only 0.25 inch.

Three analyses of the area distribution of two-year frequency amounts within the network were performed. For each duration the point frequencies of two-year amounts were computed and areal variations of the point frequencies within the network were compared. Next, the point and network (area) frequencies of excessive amounts for each duration were compared to measure the point-areal relationship of excessive rainfall occurrences. Last, the relationship between the occurrence of frequency values at different numbers of network gages during a storm was ascertained.

The number of storms that produced two-year or greater frequency amounts for any duration from 30 minutes to 24 hours at each raingage is portrayed in Figure 10a. Considerable areal variation is apparent with the highest numbers of excessive storms recorded at the raingages in the northwestern and eastern areas where the average annual precipitation was found to be greatest (Fig. 2). Excessive storms were least frequent at raingages in the southern parts where the average annual precipitation was least.

In Figure 10b the number of two year or greater frequency amounts for 30-minute periods recorded at each of the 24 recording raingages is depicted. If a normal number had occurred at a point, two or three such events would be expected during a five-year period. However, many raingages had more than twice the expected number, and some gages (B and S) had four to five times as many as could be expected. The two-year or greater frequency amounts recorded at each raingage for six-hour periods (Fig. 10c) and for 24-hour periods (Fig. 10d) show less areal variation than occurred with the 30-minute amounts, and most raingages recorded the statistically expected number of excessive 24-hour amounts.

To obtain a measure of the relationship between frequencies of excessive amounts at a point and the network or areal frequencies of excessive amounts, an areal-point comparison was made for each duration

TABLE 4.—Areal and Point Rainfall Frequency Values Equal to or Greater Than Two-Year Recurrence Values, 1958-62.

	Number of cases for given period						
	30 min	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
Median number per gage	6	5	4	4	5	3	3
Maximum number at any gage	12	10	5	8	8	6	6
Minimum number at any gage	2	3	2	2	2	1	2
Network total	57	44	28	26	27	18	15
Average ratio, network single (point) gage	9.5	8.9	5.6	6.5	5.4	6.0	5.0

TABLE 5.—Percent of Time that Excessive Amounts Occurred at Different Numbers of Gages During Storms.

Duration of excessive amounts	Average percent of the time that specified numbers of gages experienced two-year or greater amounts			
	2 or more gages	3 or more gages	4 or more gages	12 or more gages
30 min	86	63	50	5
1 hr	83	61	55	17
2 hrs	80	77	69	26
3 hrs	85	76	75	25
6 hrs	92	78	72	31
12 hrs	95	68	65	30
24 hrs	96	56	53	30

for the two-year frequencies (Table 4). A mean ratio for all durations of 6.7 was obtained for the frequency of areal to point occurrences. This indicates that, on the average, there were nearly seven times as many excessive rainfall amounts observed in the 550-square-mile network area as were observed at any point in that area. The average ratios for the seven durations differed, and the ratios decreased with increasing duration. Excessive rainfall amounts for 30-minute and one-hour periods occurred nine times more frequently in the 550-square-mile area than at a point within the area.

The areal extent of excessive amounts during storms with two-year or greater frequency amounts was also investigated. Using the 12 raingages lettered A through P (Fig. 1), which are evenly dispersed throughout the network, the relationship between the occurrence of excessive amounts of precipitation at different numbers of raingages was measured for individual storms. The number of raingages recording excessive amounts each time one of these 12 selected raingages had an excessive amount was recorded for each of the seven storm durations.

The long-duration excessive amounts, 12 to 24 hours, (Table 5) frequently were either relatively localized or relatively widespread. This is revealed by the relatively high percentages under two-or-more gages and under twelve-or-more gages, and by the relatively low percentages for three-or-more gages and four-or-more gages. The excessive storms with durations of two to six hours had relatively high percentages for the three-or-more gages and four-or-more gages categories, but the areal extent of excessive amounts was less than that for the storms with longer durations. The low percentages for the 30-minute and one-hour periods for the four-gage and twelve-gage categories reveal that such short duration excessive rainfall periods were considerably more localized

TABLE 6.—Percentage of all Excessive Amounts Occurring in Storms with Varying Durations and Amounts Equal to or Greater than Two-Year Frequency Values.

Duration	Total number of storms in network	Percent of total storms for each duration occurring with excessive amounts for indicated durations				
		30-min	1-hr	3-hr	12-hr	24-hr
30 min	57	—	68	42	23	19
1 hr	44	82	—	57	36	30
2 hrs	28	82	90	90	54	43
3 hrs	26	92	96	—	58	50
6 hrs	27	74	85	81	67	56
12 hrs	18	72	90	82	—	82
24 hrs	15	73	87	87	100	—

than those with longer durations.

Almost 30 percent of the 70 excessive storms first produced rainfall at the ten raingages in the network interior. Initiations at gages A, B, S, and M (Fig. 1) accounted for 46 percent of the 70 initiations. More than 50 percent of all 70 excessive storms initiated between 12 and 9 PM. The three-hour period with the greatest number of excessive rainstorm initiations was 12 to 3 PM in contrast with 12 to 3 AM for the storms producing network means of 0.5 inch or more. The average point duration of rainfall for the 70 storms was 6.3 hours.

The frequency with which excessive amounts for different durations occurred during the same storms was investigated, and the results are shown in Table 6. More than 72 percent of all storms with 12-hour and 24-hour frequency values also had two-year or greater frequency values for all the shorter durations. However, many of the storms with 30-minute frequency values did not produce other longer-duration excessive amounts. For instance, only 19 percent of the storms with 30-minute amounts were associated with 24-hour excessive values. A 30-minute value was associated most frequently with a one-hour excessive value; a three-hour value occurred most frequently with a one-hour value; and a 24-hour value occurred more frequently with a 12-hour value than with an excessive value for any other duration. The percentages in Table 6 for the 30-minute durations are much lower than those obtained for a 10-square-mile raingage network in central Illinois (Huff and Changnon, 1960).

SUMMARY

Five years of data from a network of 49 raingages within a 550-square-mile area of southern Illinois, after careful analysis, have provided highly useful and some new precipitation statistics. The findings have been sorted and studied according to climatological, meteorological, and hydrometeorological applications.

1. The average annual precipitation pattern for the 1958-62 period revealed considerable areal variation with a maximum difference of six inches between amounts at raingages separated by only a five-mile distance.

2. The distribution of the average annual precipitation during 1958-62 did not associate well with variations in the surface elevation, but the pattern did appear to be somewhat correlated with areal distribution of the number of excessive short duration rainfall amounts.

3. The average seasonal precipitation patterns for all but the winter season had much greater areal variability than did the long-term mean seasonal precipitation patterns for the network areas.

4. The average annual number of storms within the network was 140.

5. The average annual number of hours with precipitation at any point within the network was 770 which is nine percent of the year.

6. Nearly 50 percent of all network storms were associated with thunderstorms.

7. Nine types of precipitation patterns for storms were found to recur frequently, and many summer storms were composed of a series of four or more small rain cells.

8. More than 75 percent of all storms in the network were produced by systems moving into the area from the southwest, west, or northwest.

9. Storms initiated most frequently in the early afternoon and least frequently near midnight.

10. In a 225-square-mile area an average of 17 storms developed locally in summer, principally between 9 AM and 3 PM, and on the average 34 storms developed within this area during an entire year.

11. All network storms had an average point duration of 5.6 hours; the average was 11.5 hours for winter storms and 2.6 hours for summer storms.

12. In all seasons except summer, precipitation occurred most frequently during the hours between 4 and 10 AM; precipitation was most frequent between 12 and 5 PM in summer.

13. Nineteen percent of all storms had network mean values of 0.5 inch or more, and these storms yielded 68 percent of the total network rainfall.

14. Seventy storms produced excessive rainfall amounts for durations of 30 minutes through 24 hours, and most occurred during the summer season.

15. In general, the number of excessive amounts for durations of 6 hours and less was much greater than expected statistically.

16. The network experienced nearly seven times as many storms with excessive rainfalls as did a given point within the network.

17. Excessive rainfall of short duration normally did not extend over a large portion of the network.

18. Most excessive amounts of longer duration (12 and 24 hours) covered large portions of the network and they also were frequently associated with excessive rainfalls for all shorter durations.

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