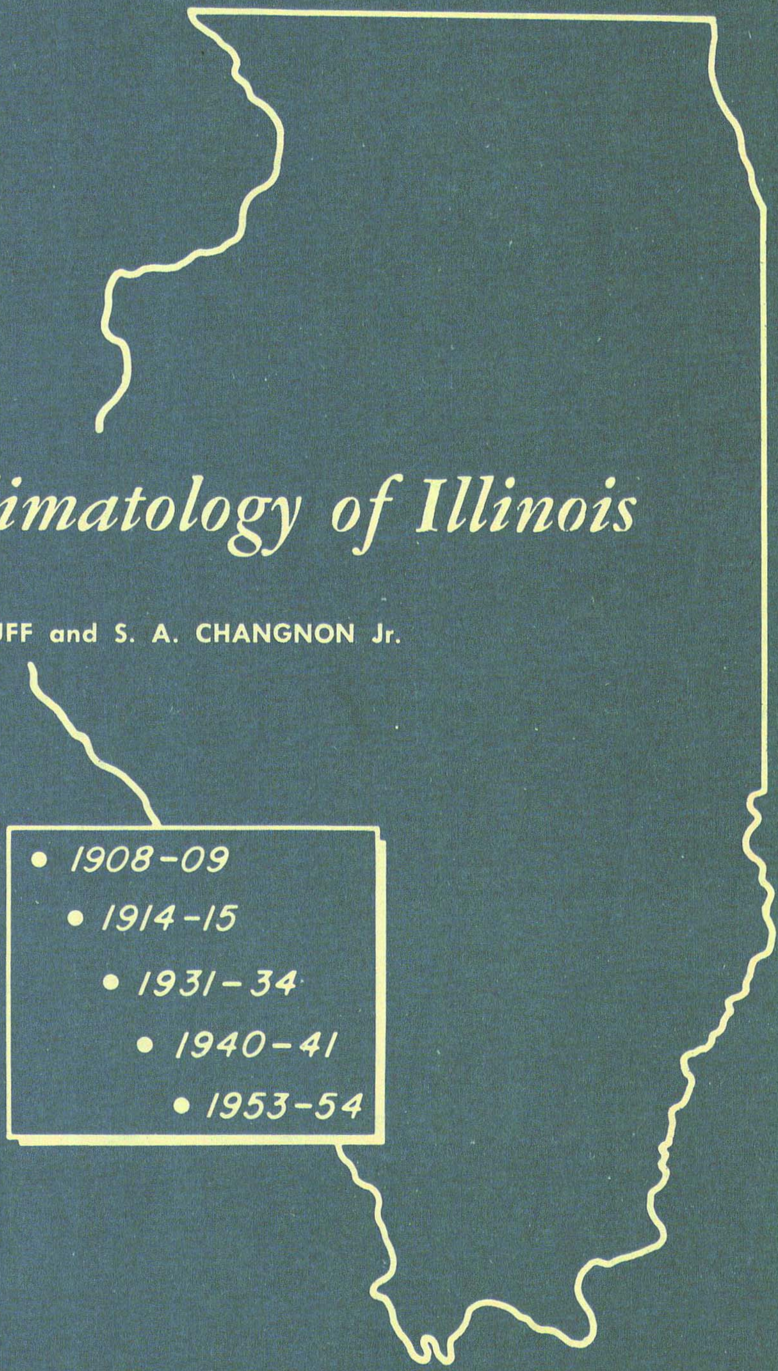
BULLETIN 50

STATE OF ILLINOIS

DEPARTMENT OF REGISTRATION AND EDUCATION

Drought Climatology of Illinois

by F. A. HUFF and S. A. CHANGNON Jr.



ILLINOIS STATE WATER SURVEY

URBANA

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CONTENTS

Figure 1. Location of precipitation stations used in drought study

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SUMMARY AND CONCLUSIONS

General. Analyses of the frequency distribution of droughts for periods of 3 to 60 months indicate that the relative severity of droughts, in general, is greatest in the southeastern, extreme southern, and southwestern regions of the state.

The relative severity of droughts decreases with increasing length of dry period, and extensive, severe droughts of more than 24 months are infrequent in Illinois.

The climatological investigation of droughts in the 1906-1955 period reveals that the severest droughts of long duration are associated with the occurrence of severe short-duration droughts. Therefore, knowledge of severe 3-, 6-, and 12-month droughts is important to the understanding of all precipitation droughts in Illinois.

Many of the basic characteristics of short-duration droughts are common to droughts of all durations. In general, the regions of greatest drought severity are elongated, and the orientation of this major axis varies from SW-NE in the shorter droughts to NW-SE and N-S in droughts of 36 months and longer. In most droughts these regions of maximum severity are portions of droughts occurring in nearby states. Frequently two distinct areas of severity occur in Illinois during a particular drought period.

Inspection of the time distribution of droughts of each duration does not produce evidence of drought cycles. For all durations, the worst drought in the 1906-1955 period with respect to severity and areal extent occurred in the 1930's. A major drought-free period extended from 1943 through 1951. For droughts of 3, 6, 12, and 24 months, analyses indicate a 50 percent probability that another drought of the same duration will occur somewhere in Illinois within about 30 months after a similar drought has terminated.

3-Month Droughts. The probability of 3-month droughts is greatest in winter (December-February) in all except the southeastern part of the state where fall has the greatest probability. However, the magnitude of the winter probability decreases gradually from north to south in the state. The 3-month droughts in northern and central Illinois are usually more extensive than those in southern Illinois, although those in southern Illinois tend to be more severe on the basis of percent of normal precipitation.

6-Month Droughts. The 6-month droughts tend to be concentrated in the period from late summer or early fall to late winter or early spring. In the northern part of the state, 6-month droughts occur most frequently from November to April, whereas in the central and southern sections, the most frequent occurrence is from September to February. Summer months are more likely to be part of a 6-month drought in southern Illinois than in the northern part of the state, and fall and winter months are less subject to drought conditions in the south.

12-Month Droughts. The 12-month droughts usually begin in the June-September period and end in the May-August period. The influence of 6-month droughts, which occur primarily in the colder half-year, is responsible for this centering of the 12-month droughts around the winter season. The two most severe 12-month droughts, in which more than 60 percent of Illinois received less than 60 percent of the normal 12-month precipitation, terminated in 1931 and 1934. Nearly 50 percent of all the 12-month droughts during 1906 through 1955 occurred in the 11-year period beginning in 1930.

Longer Droughts. The 24-month droughts tend to begin in late summer or early fall. A similar trend is noted for 36-month droughts. Late spring and summer is the preferred starting time of 48-month and 60-month droughts. The 24-month drought ending in 1941 was the only 24-month

drought to rank first and second in severity in both northern and southern Illinois; remaining 24-month droughts were more restricted in regional extent. Severe 24-month droughts are more widespread in southern Illinois than in central and northern Illinois, which is the opposite of regional differences with 3- and 6-month droughts. The statewide percents of normal for the eight 36-month droughts did not differ greatly, and all but one was characterized by above normal precipitation in certain portions of Illinois.

Associated Conditions. An investigation of the relation between the spatial distribution of drought and the climatic distribution of various meteorological elements reveals evidence of an inverse relationship between mean annual precipitation and relative drought severity in Illinois. A strong association is indicated between the coefficient of variation of annual precipitation and drought severity; that is, droughts tend to be more severe where the time variability of precipitation is greatest. A strong association is found also between thunderstorm frequency and drought severity.

Furthermore, the most severe drought regions are areas of maximum frequency of convective clouds (cumulus and cumulonimbus), while the regions of minimum drought severity are areas in . which the stable-type cloud, stratocumulus, maximizes. Relatively poor correlation is found between drought severity and the frequency of rainy days, that is, the number of days with measurable precipitation. Similarly, the atmospheric moisture content, as portrayed by depth of precipitable water, does not appear to correlate well with drought severity. These results suggest that decreased convective activity during droughts is the major cause of the differences in severity in Illinois, since the regions of greatest severity are more dominated by convective-type clouds and precipitation than are the regions of minimum severity.

In a study of associated characteristics of precipitation and temperature, analysis of hourly precipitation during drought and nondrought years for 1948-1957 indicates that drought periods are more closely related to frequency and duration of precipitation than to precipitation rate. The greatest difference in both frequency and rate of precipitation in drought and nondrought years occurs during winter and the least difference during spring. In the most severe droughts, monthly precipitation is below normal in all months of 3-month drought periods, but this percentage decreases gradually with increasing drought duration to 70 percent of the months during 60-month dry periods. Monthly mean temperature is above normal 75 percent of the time with the most severe 3-month droughts, decreasing to 62 percent of the time with 60-month droughts.

A successful method was developed for determining low flow frequency distributions for ungaged basins through use of precipitation data and empirically derived geomorphic indices. This method was found to be applicable for drought durations of 12 months or longer and recurrence intervals of 5 years or longer.

INTRODUCTION

Purpose and Scope

A study of drought characteristics in Illinois was undertaken to ascertain the spatial and temporal distribution of droughts, the relative severity of such droughts, synoptic climatological conditions associated with severe droughts, and the relationship of precipitation deficiency to low streamflow. Stress has been placed upon hydrologic application in the approach to the problem and in the presentation of results.

The study was based primarily upon monthly precipitation data for the same 50-year sampling period, 1906-1955. However, data available from a few precipitation stations for the 50-year period prior to 1906 have been used to evaluate partially the reliability of the drought relations developed from the 1906-1955 data.

Runoff data from 13 streamgage stations in the state were employed in ascertaining the relationship of precipitation deficiency to low streamflow.

The names and locations of the 62 precipitation stations used in the drought study are shown in figure 1. These included 57 stations in Illinois and 5 stations near the Illinois border in adjacent states. Each station had complete monthly precipitation records for the 1906-1955 period. The nine climatological sections of the state, as designated by the U. S. Weather Bureau, are shown by dashed lines in figure 1. These sections (Northwest, Northeast, etc.) have been used for grouping data in certain phases of the analyses. Stations with precipitation data prior to 1906 also are shown.

Geography and Climate

Illinois encompasses approximately 56,000 square miles, is centered near 40 degrees north latitude and 89 degrees west longitude, has a'humid continental climate, and is located within a major thunderstorm region of the United States. The state is a relatively flat plain with few striking

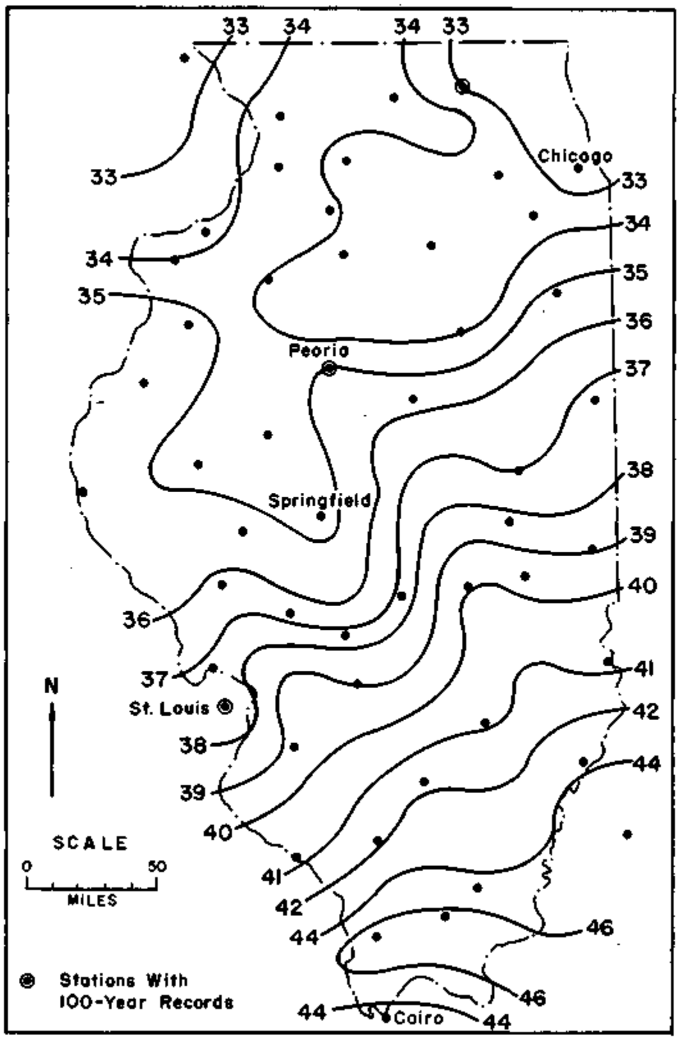


Figure 2. Mean annual precipitation, in inches

physiographic contrasts to influence the weather. The mean elevation above sea level is 600 feet, and elevation varies from a low of 260 feet in the south to a high of 1240 feet in the northwest.

Mean annual precipitation ranges from 32.6 inches in the northern part of the state to 47.5 inches in the extreme south (figure 2). Mean annual temperature varies from 49°F to 59°F from the northern to southern part of the state. From north to south, the precipitation varies during the warmer half-year from 20 to 24 inches and in the colder half-year from 12 to 23 inches. The driest month is February, and the wettest month varies from March in the southern region to June in the extreme north.

Definition of Drought

Percent of normal precipitation was used to define drought severity. Using precipitation deficiency to describe drought permits a realistic regional evaluation and allows the user to adapt the results to problems requiring different definitions of drought, since both the relative and absolute magnitudes of the precipitation deficiency are available from the analytical procedures employed. Obviously, no single definition of drought is applicable to the various drought problems encountered in hydrology and in agriculture. However, the selected method appears to be most adaptable for hydrologic application in periods of extended drought. Furthermore, applied research in agriculture has established to some extent the relation between rainfall deficiency and crop production, so that the results of this study will have limited application, at least, in agriculture and should become more useful in the future.

Treatment of Data

The frequency distribution of drought at each of the 62 stations was determined for dry periods of 3, 6, 12, 18, 24, 30, 36, 42, 48, and 60 months, based upon data for 1906-1955. Climatological relations were investigated for all except the 18-, 30-, and 42-month periods. The first step in the data analyses involved tabulation of all droughts at each station for each of the 10 periods, and selection of ranked independent values from this tabula*-tion for determination of the station frequency curves for each period.

Monthly precipitation amounts for each station during 1906-1955 were punched on IBM cards. Next, with an IBM calculator, running totals for each of the 10 periods (3 to 60 months) were entered on the cards. Then for each period the cards were arrayed on low to high ranking basis by an IBM sorter, and ranks for each station and precipitation period were entered on the cards by an IBM tabulator. A printout of the ranked data for each station was then made. The entire machine operation required approximately three hours per station.

The IBM printouts were used to obtain ranked independent data for each of the drought durations at each station. Independent drought periods were determined by a method similar to that used by Hudson and Roberts (1955). In essence, the method consists of eliminating the possibility of any month being included in different droughts used in the analysis of a particular drought period. For example, when a 12-month period was selected for ranking from the printout of all possible combinations at a station, the 11 running totals preceding and following the selected value were eliminated from further consideration. Initially, this step was done manually, but later the digital computer at the University of Illinois was used to expedite the analysis. Frequency distribution curves were then developed from the ranked data which also were used for various climatological analyses.

Acknowledgments

This report was prepared under the general direction of William C. Ackermann, chief of the Illinois State Water Survey, and Glenn E. Stout, Head of the Meteorology Section. Data which made this study possible were obtained from climatological records compiled by the U. S. Weather Bureau at its first-order and cooperative stations. Use of IBM equipment and digital computers at the University of Illinois greatly facilitated analyses of the data. The authors participated in the following manner: F. A. Huff conducted the drought frequency studies and prepared those portions of this report; the climatological analyses were performed and written by S. A. Changnon Jr.; other sections were prepared jointly.

FREQUENCY DISTRIBUTION OF DROUGHTS

As usual in the analysis of precipitation data for Illinois where great rainfall variability exists, no single statistical distribution was found which provided an excellent fit of the drought frequency data for all seasons and for each of the 10 periods analyzed at each station (Huff and Neill, 1959). In general, the most satisfactory fit of the frequency distributions for drought periods of 12 to 60 months was found by a log-log plotting of the data. The curve fitting on log-log paper is illustrated in figure 3 through use of the Chicago data. For drought periods of 3 and 6 months, the best data fit was found by plotting percent of normal precipitation against recurrence interval on log probability paper. This plotting procedure is illustrated with data for Chicago in figure 4. A straight line or curve was fitted to the data, as illustrated.

Frequency curves thus obtained for dry periods of 3, 6, 12, 18, 24, 30, 36, 42, 48, and 60 months at each of the 62 stations were used to evaluate the severity and spatial distribution of droughts within the state. The patterns for each period are discussed in the following pages. Frequency maps for selected recurrence intervals are

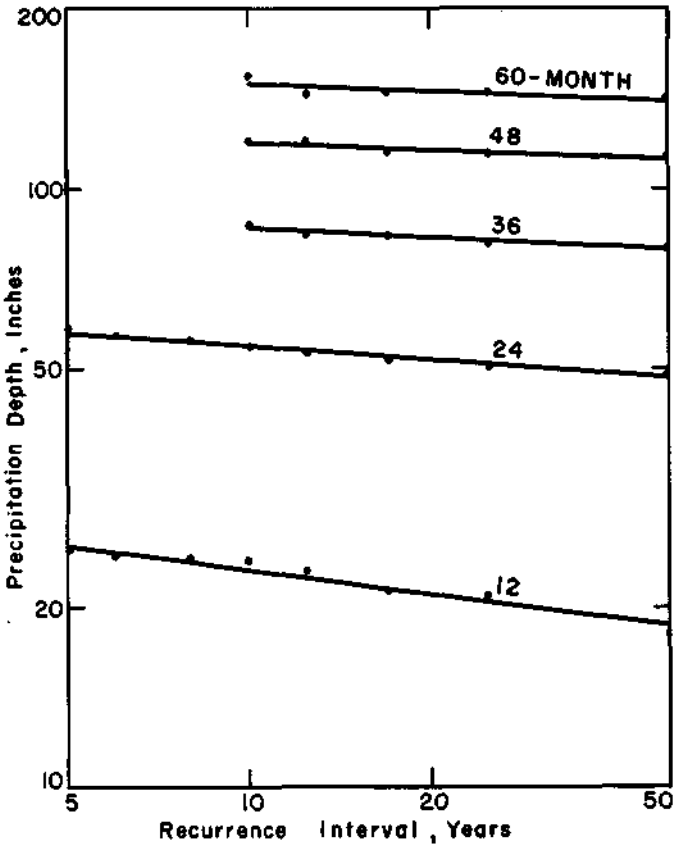


Figure 3. Drought frequency at Chicago

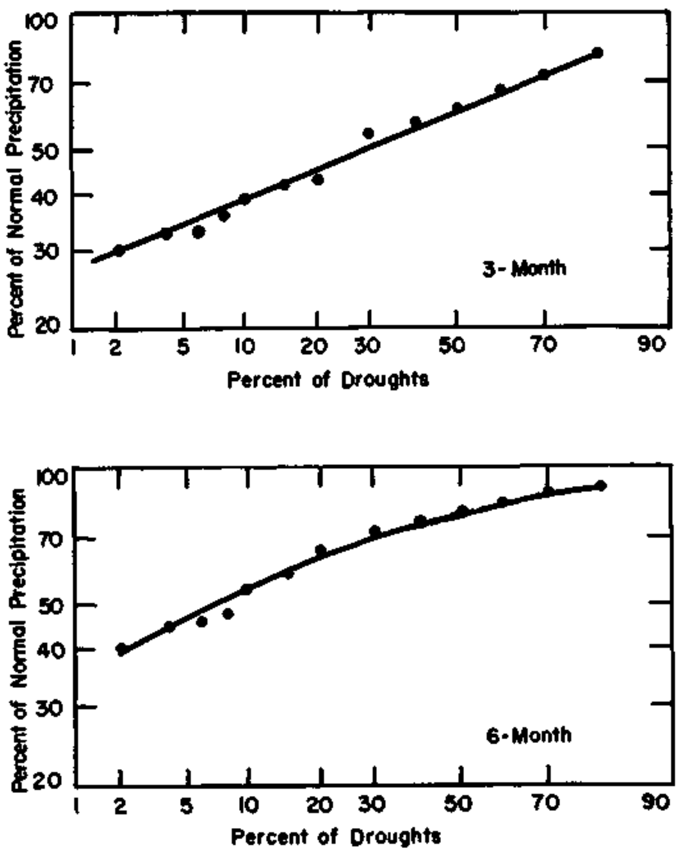


Figure 4. Frequency of 3- and 6-month droughts at Chicago

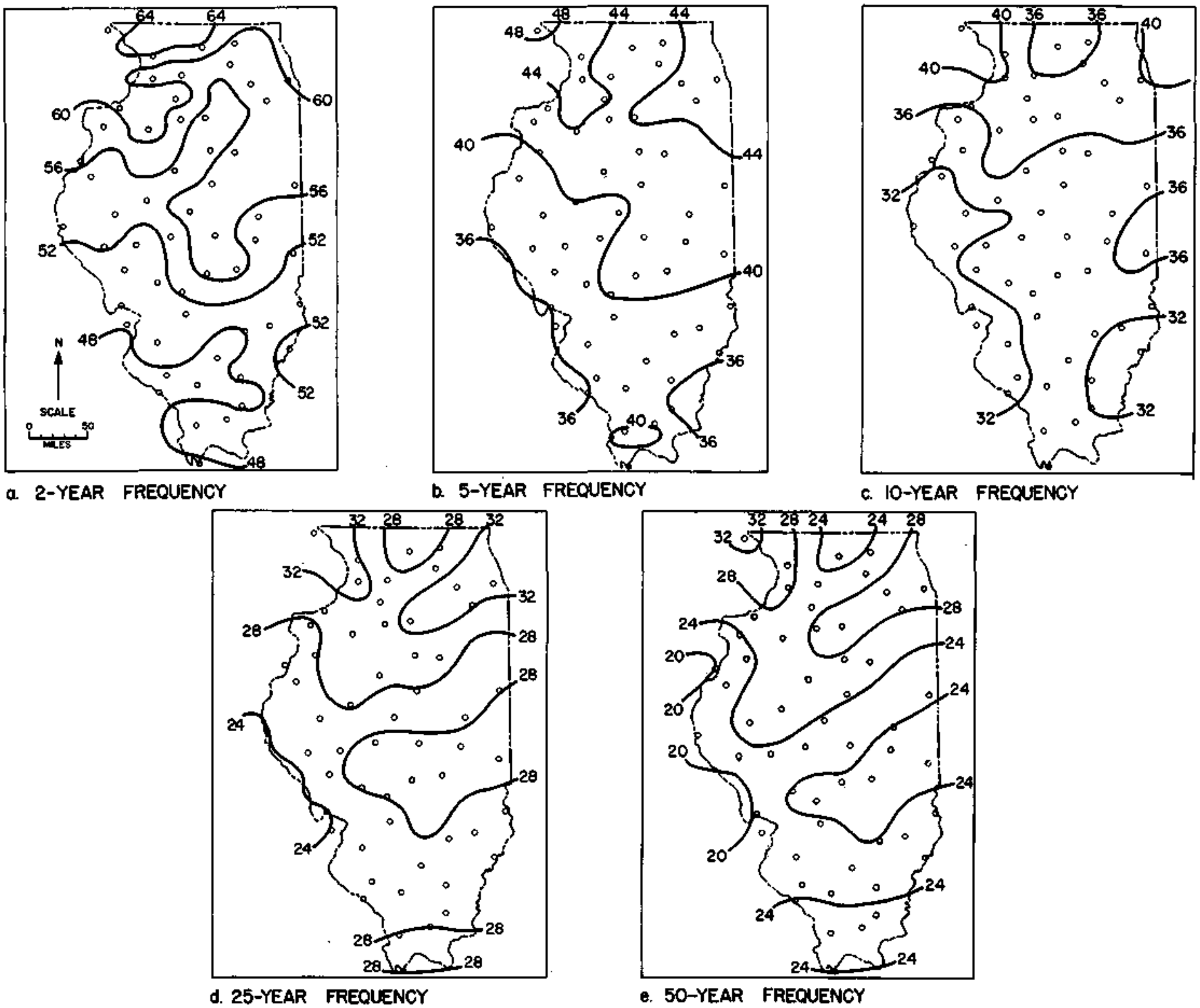


Figure 5. Frequency of 3-month drought periods, expressed as percent of normal 3-month precipitation

provided, beginning with the shortest recurrence interval which can be defined adequately from the data sample and extending to a recurrence interval of 50 years. No effort was made to extrapolate beyond 50 years, since a 50-year sampling period (1906-1955) was used in the study. Estimates of drought severity for recurrence intervals up to 50 years which are not shown by the selected maps may be made satisfactorily by interpolation between appropriate maps.

3-Month Droughts

Figure 5 shows the frequency distribution of 3-month drought periods expressed as percent of normal precipitation for recurrence intervals of 2, 5, 10, 25, and 50 years. The 2-year frequency map shows a gradual increase in drought severity from northwestern to southern and southwestern Illinois, with the percent of normal precipitation decreasing from 64 percent in the Mt. Carroll-Rockford-Dubuque region to less than 48 percent in the vicinity of Chester. The 5-year frequency map shows a similar distribution of drought severity with 48 percent in the northwestern part of the state and approximately 36 percent in the southern and southwestern portions. A slight decrease in severity is indicated in the Shawnee Hills region in the southern part of the state on the 2-year and 5-year maps, and a minimum severity is located in the Rock River Hills region of northwestern Illinois. The decrease in severity in the hill areas suggests that these topographic features may be instrumental in the development of showers which alleviate the drought conditions, particularly during relatively mild droughts (2-year to 5-year occurrences). Also, evidence of the possible modifying influence of Lake Michigan on precipitation in the northeastern part of the state can be seen.

With longer recurrence intervals, the difference in drought severity over the state decreases. Thus, with 3-month droughts in the 2-year frequency, the severity ranges from 46 to 64 percent over the state. This range decreases to 30 to 41 percent for the 10-year frequency, and then remains nearly constant with 24 to 35 percent for 25-year and 20 to 32 percent for 50-year frequencies. Apparently, regional or local factors which tend to either alleviate or intensify drought conditions with the milder droughts are less effective with the more severe droughts. However, on the 10-year, 25-year, and 50-year maps, the modifying influence of the Rock River Hills in the northwest, Lake Michigan in the northeast, and the Shawnee Hills in the extreme south can be discerned to some extent.

Analysis of 3-month droughts throughout the state indicates a tendency for the probability distribution to vary geographically with season. This relation is illustrated in table 1, where the percentage distribution of the 25,worst droughts is shown for each of the nine climatological sections of the state (see figure 1). Table 1 shows the percent of the 25 worst 3-month droughts (as found by ranking all droughts with respect to percent of normal precipitation) ending in each of the 12 months, and ending in given 3-month periods. Thus, in the Northwest Section, 37 percent of the 3-month droughts ended in February and 73 percent ended in December through February during the 50-year sampling period.

Table 1 indicates that the probability of 3-month droughts is greatest in winter (December-February) in all except the southeastern part of the state, where fall has the greatest probability. However, the magnitude of-the winter probability decreases gradually from north to south in the state, ranging from 37 percent in the Northwest Section to 24 percent in the East-Southeast Section and to 12 percent in the Southeast Section. The least probability of a 3-month drought throughout the state is in the April-June period. The seasonal distribution of droughts is much more skewed toward the cold season in the northern part of the state than in the southern part, since spring, summer, and fall droughts are more common and winter droughts are less frequent in the south. Agriculturally, crop failures due to drought are less likely in the north and central portions of the state

Table 1. Percentage Frequency of 3-Month Droughts

Percent of all 3-month droughts ending in given month

Climatological section	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Northwest	26	37	12	5	2	0	1	1	0	3	3	10
Northeast	22	29	19	7	1	0	3	0	1	1	4	14
West	14	34	16	3	2	1	2	3	2	2	8	13
Central	16	33	13	3	3	1	2	3	3	5	9	9
East	15	26	10	7	3	1	5	4	5	7	8	9
West-Southwest	17	25	12	4	4	1	4	6	5	7	9	6
East-Southeast	11	24	10	8	3	2	10	3	5	9	9	6
Southwest	13	13	8	8	3	2	8	9	7	9	11	9
Southeast	9	12	6	6	3	3	10	9	9	10	14	9

Percent of all 3-month droughts ending in given 3-month period

	Nov-Jan	Dec-Feb	Jan-Mar	Feb-Apr	Mar-May	Apr-Jun	May-Jul	Jun-Aug	Jul-Sep	Aug-Oct	Sep-Nov	Oct-Dec
Northwest	39	73	75	54	19	7	3	2	2	4	6	16
Northeast	40	65	70	55	27	8	4	3	4	1	5	19
West	35	61	64	53	21	6	5	6	7	7	12	23
Central	34	58	62	49	19	7	6	6	8	11	17	23
East	32	50	51	43	20	11	9	10	14	16	20	24
West-Southwest	32	48	54	41	20	9	9	11	15	18	21	22
East-Southeast	26	41	45	42	21	13	15	15	18	17	17	24
Southwest	33	35	34	29	19	13	13	19	24	25	27	29
Southeast	32	30	27	24	15	12	16	22	28	28	33	33

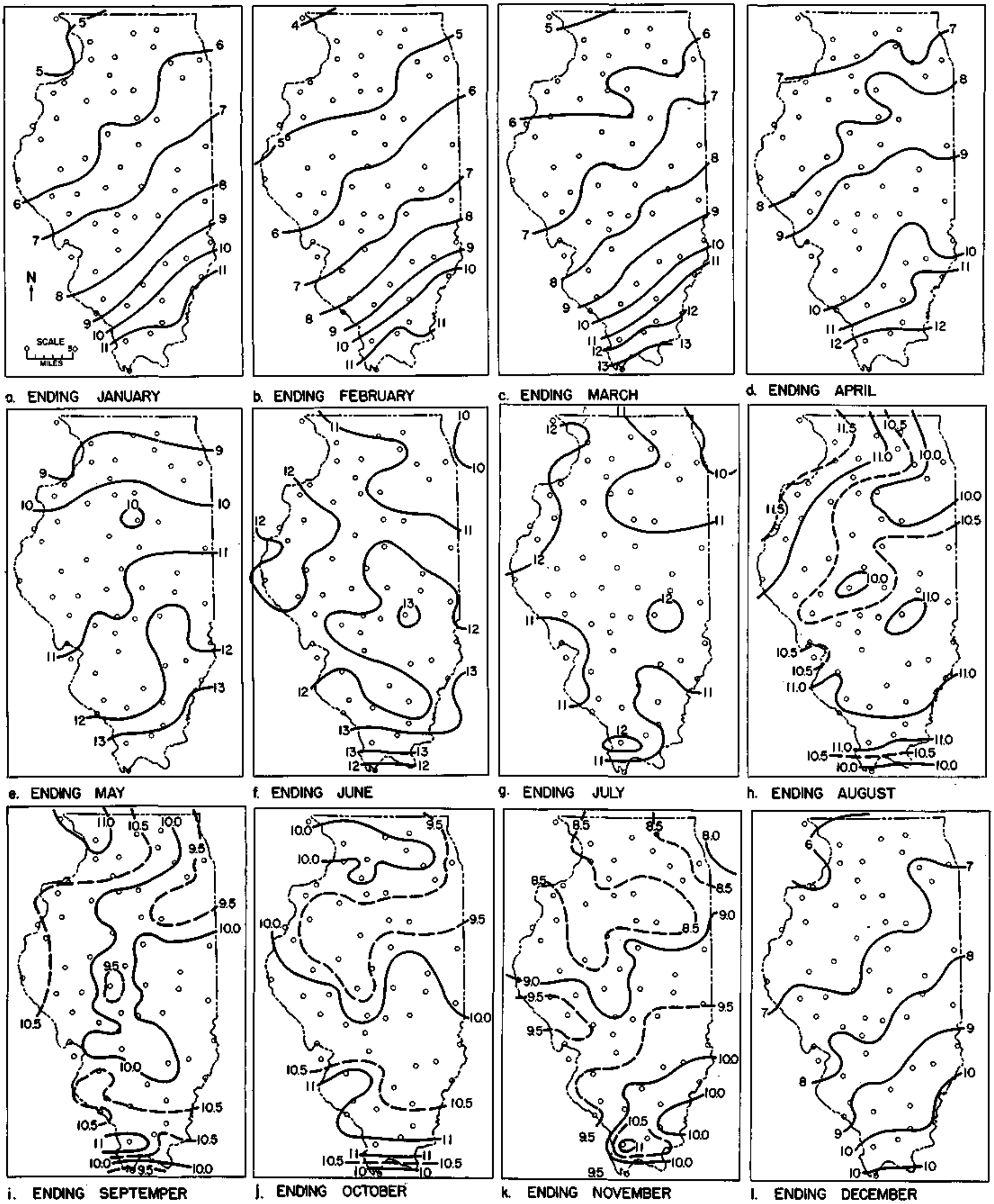


Figure 6. Three-month mean precipitation, ending in months indicated

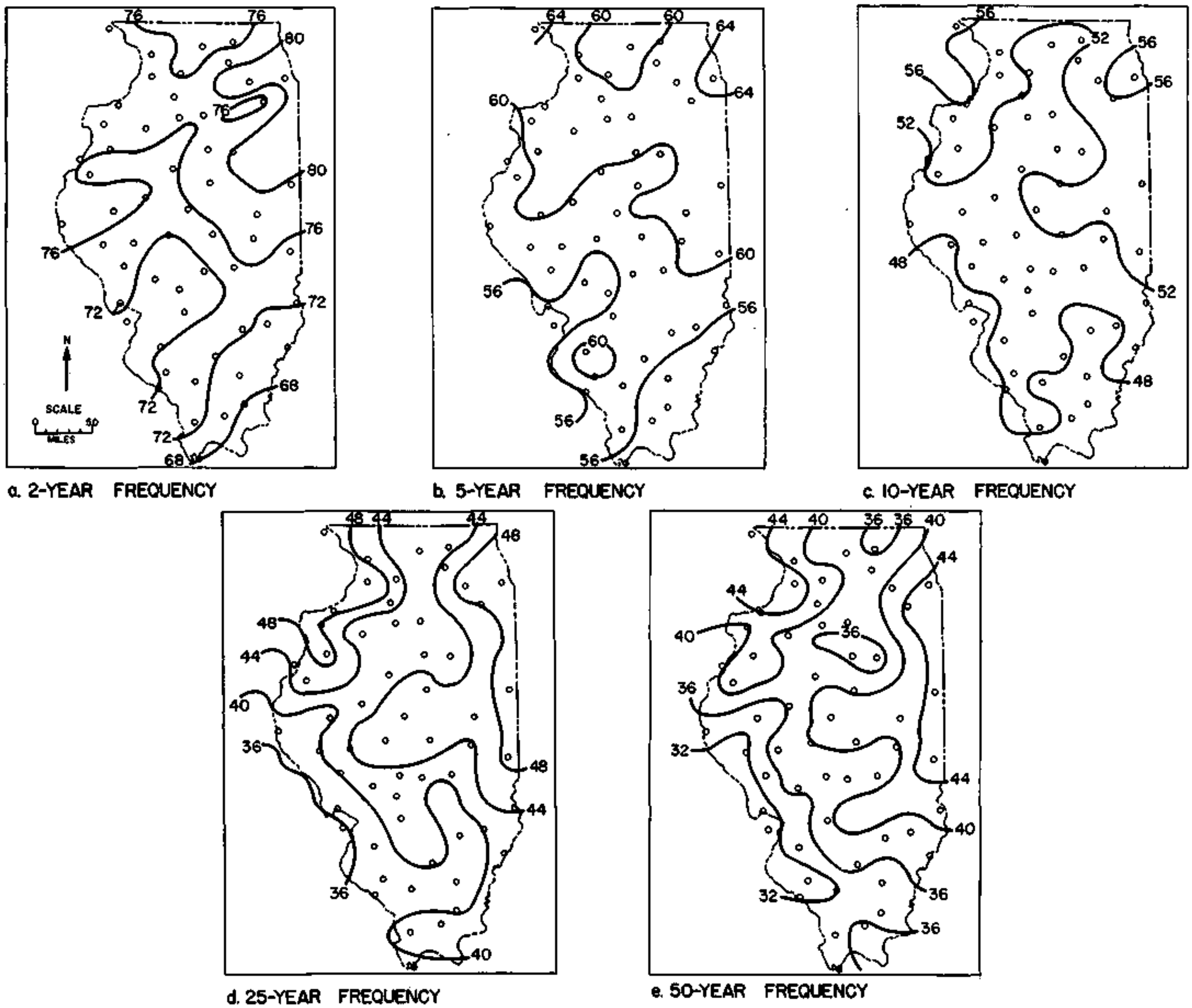


Figure 7. Frequency of 6-month drought periods, expressed as percent of normal 6-month precipitation

than in the southern part, since growing season droughts have a smaller probability. Conversely, the greater normal precipitation and smaller probability of winter droughts in the southern part of the state are more favorable for replenishment of surface and ground water supplies which have declined because of high evapotranspiration during the warmer part of the year.

Figure 6 shows normal precipitation for 3-month periods ending in each of the 12 months of the year. This figure can be used in conjunction with figure 5 to convert percent of normal precipitation to precipitation in inches. For example, assume one wishes to determine the amount of precipitation associated with a 3-month drought in the 2-year frequency at Springfield when such a drought ends in January. From figure 5, the percent of normal is 53. The 3-month normal precipitation ending in January at Springfield is 6.4 inches. Multiplying 6.4 inches by 53 percent gives a 3-month drought value of 3.4 inches.

If drought severity is desired for recurrence intervals other than those shown in figure 5, it can be determined satisfactorily by interpolating between maps. For example, assume one wishes to determine the drought severity in percent of normal and in actual depth of precipitation for a 15-year-frequency, 3-month drought at Springfield ending in January. From figure 5, the 10-year and 25-year percent of normal are 33 and 29, respectively. The estimated 15-year percent of normal would be 32, that is, 33 minus one-third of the difference between the 10-year and 25-year values. The actual precipitation depth is then found as illustrated in the preceding example by multiplying the normal 3-month precipitation in inches by the percent of normal; in this case, multiplying 6.4 inches by 32 percent yields 2.0 inches for this drought.

6-Month Droughts

The general pattern of 6-month droughts shown in figure 7 is similar to the 3-month pattern of figure 5; that is, for a given recurrence interval, severity of drought tends to increase southward and southwestward in the state. Minimum severity, as indicated by percent of normal precipitation, is found in the northeastern and/or northwestern regions of the state, and regions of maximum severity occur in the southeastern, extreme southern, and southwestern parts of the state. As the recurrence interval increases to 25 and 50 years, the maximum severity region becomes better-defined and is restricted to the southwestern region of the state. For the longer recurrence intervals, the minimum severity region in the northeast extends southward into eastern Illinois.

A tendency similar to that in the 3-month droughts exists for the probability distribution of 6-month droughts to vary geographically by season within the state. This tendency is illustrated in table 2, where the percentage distribution of the 25 worst 6-month droughts is shown for each of the nine climatological sections (figure 1). The percentage of the droughts ending in each month and in given 3-month periods is shown, as was done in table 1. Table 2 indicates that the 6-month droughts tend to be concentrated in the period from late summer or early fall to late winter or early spring. In all sections the maximum probability is for the 6-month periods, September-February, October-March, or November-April. In the northern part of the state (Northwest and Northeast Sections), 6-month droughts occur most frequently from November to April. In the central and southern parts of the state, the most frequent occurrence is September to February. Summer months are more likely to be part of a 6-month drought in southern Illinois than in the northern part of the state, while fall and winter months are less subject to drought conditions in the south. Similar to 3-

Table 2. Percentage Frequency of 6-Month Droughts

Climatological section	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Northwest	8	22	26	29	8	0	3	0	1	0	0	3
Northeast	8	23	21	33	9	0	3	0	1	0	0	2
West	11	28	23	15	6	4	4	3	0	1	1	4
Central	14	30	20	13	7	3	3	3	0	0	2	5
East	6	32	19	12	9	5	5	1	1	0	5	5
West-Southwest	13	22	18	17	10	1	4	5	0	1	2	7
East-Southeast	9	25	17	10	7	2	11	3	2	3	3	8
Southwest	11	17	17	5	4	3	6	6	2	4	13	12
Southeast	12	16	13	6	6	1	8	10	3	6	12	7

Percent of all 6-month droughts ending in given 3-month period

	Nov-Jan	Dec-Feb	Jan-Mar	Feb-Apr	Mar-May	Apr-Jun	May-Jul	Jun-Aug	Jul-Sep	Aug-Oct	Sep-Nov	Oct-Dec
Northwest	11	33	56	77	63	37	11	3	4	1	1	4
Northeast	10	33	52	77	63	42	12	3	4	1	1	2
West	16	43	62	66	44	25	14	11	7	4	2	5
Central	21	49	64	63	40	23	13	9	6	3	2	7
East	16	33	57	63	40	26	19	11	7	2	2	5
West-Southwest	22	42	53	57	45	28	15	10	9	6	3	10
East-Southeast	20	42	59	52	34	19	20	16	16	8	8	14
Southwest	36	40	45	39	26	12	13	15	14	12	19	29
Southeast	31	35	41	35	25	13	15	19	21	19	21	25

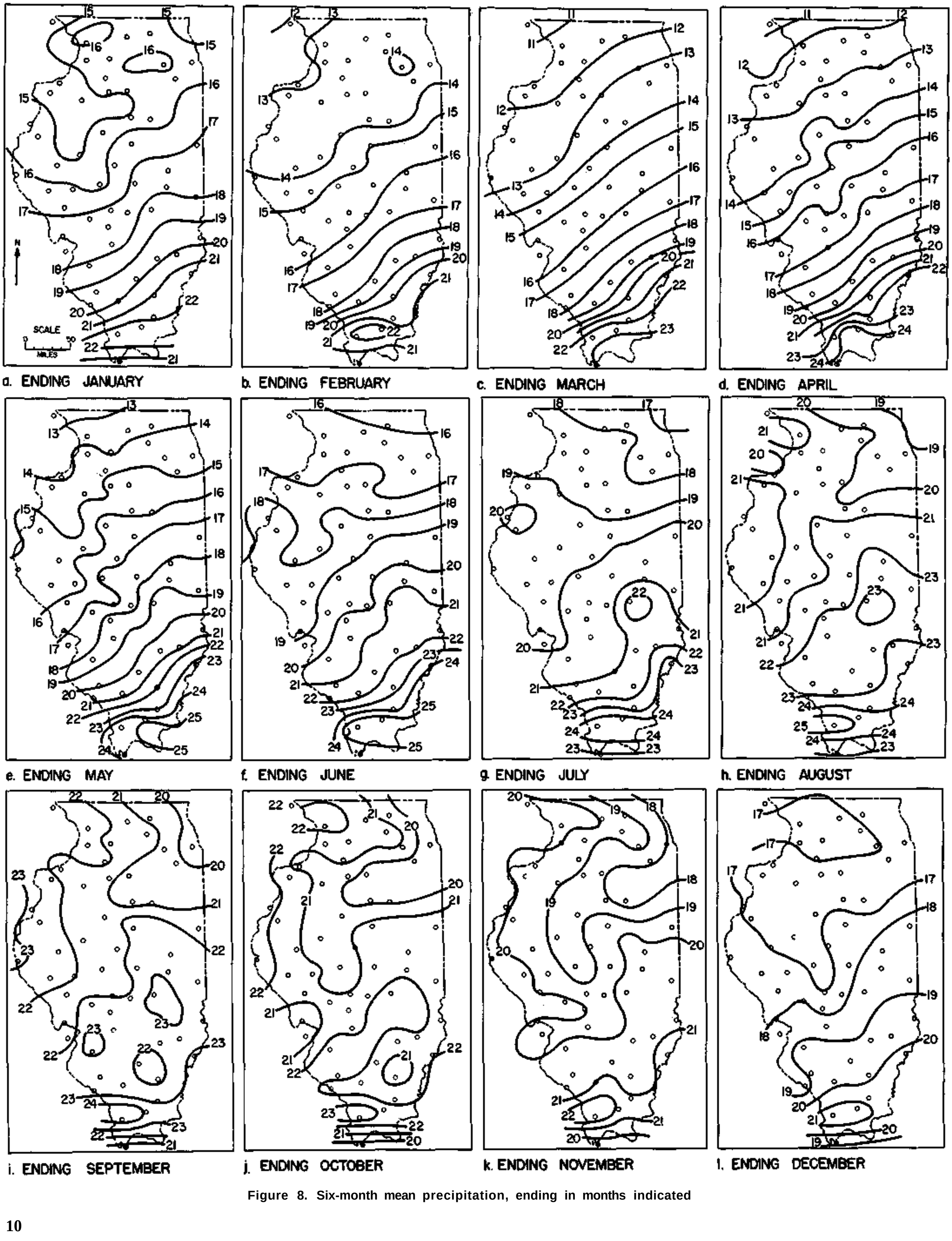


Figure 8. Six-month mean precipitation, ending in months indicated

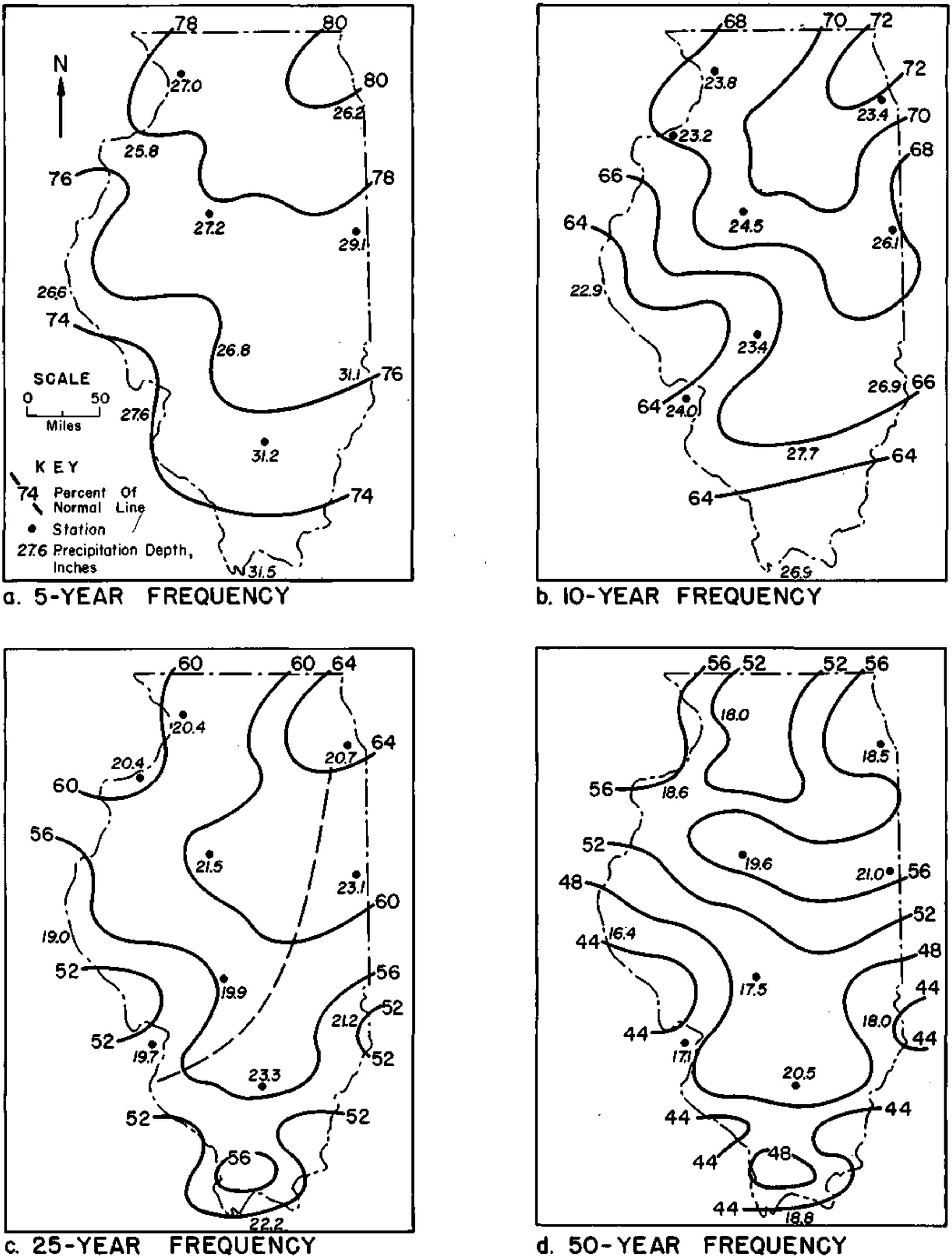


Figure 9. Frequency of 12-month drought periods, expressed as percent of normal annual precipitation

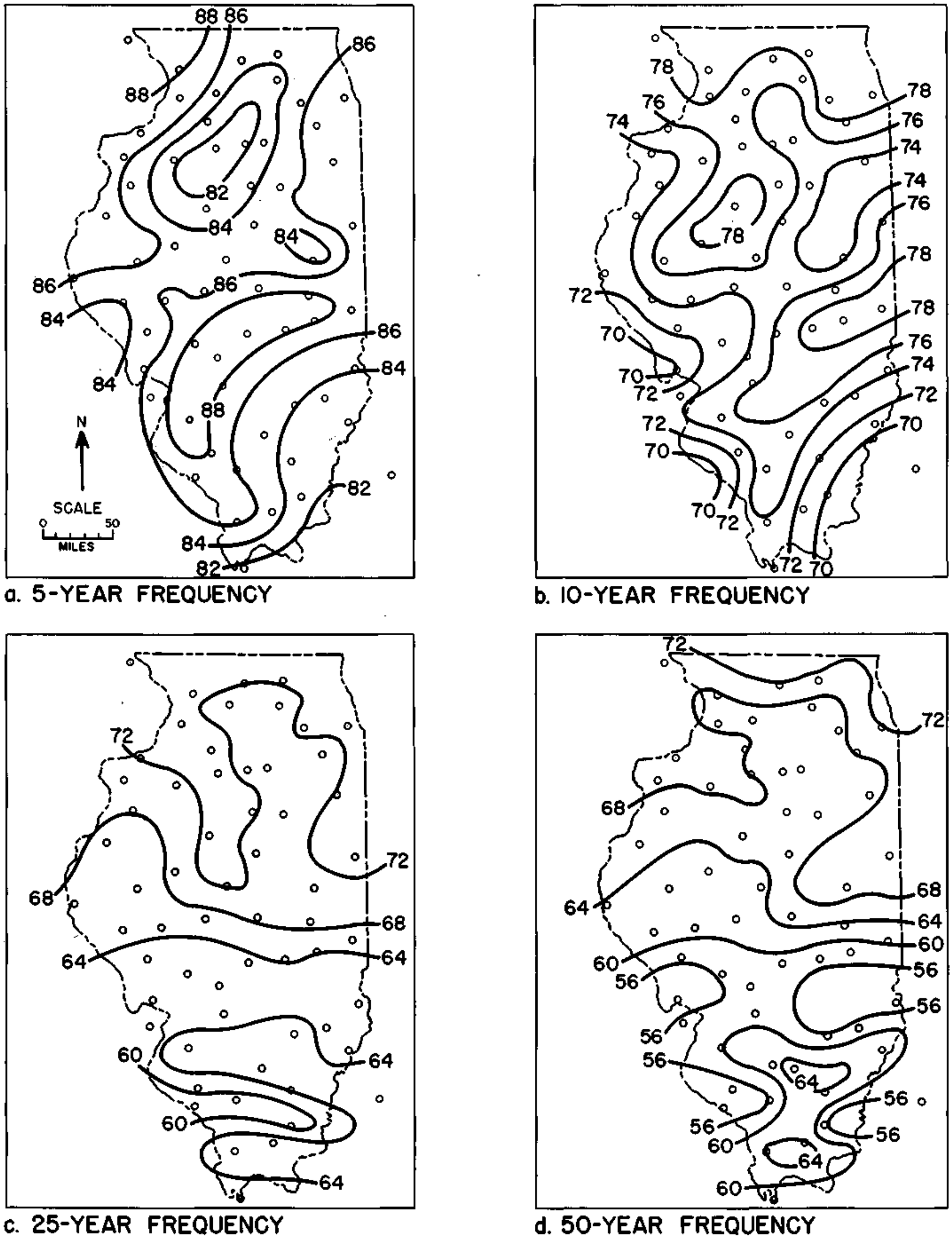


Figure 10. Frequency of 18-month drought periods, expressed as percent of normal 18-month precipitation

month droughts, the seasonal distribution of 6-month droughts is much more skewed toward the cold season in the northern part of the state than in the southern part. For example, in the Northwest Section, 77 percent of the 6-month droughts end in the period from February through April, and only 1 percent end in the period from August to October. In the Southeast Section, the maximum frequency of 41 percent ends in the January-March period, whereas the minimum frequency of 13 percent ends in the April-June period.

Figure 8 shows normal precipitation for 6-month periods ending in each of the 12 months of the year. This figure can be used in conjunction with figure 7 to convert percent of normal precipitation at any location to precipitation in inches for a 6-month drought ending in any given month.

12-Month Droughts

The frequency distribution of 12-month droughts is shown in figure 9 for recurrence intervals of 5, 10, 25, and 50 years with drought severity expressed as percent of normal of the annual precipitation. Precipitation depths in inches corresponding to the percentage values are shown for selected stations. When used in conjunction with the mean annual precipitation (figure 2), figure 9 provides an estimate of both the relative severity and absolute magnitude of various recurrence intervals.

Figure 9 indicates that, for a given recurrence interval, droughts are most severe in the southwestern, extreme southern, and southeastern Illinois and least severe in the northeastern section of the state. In general, drought severity decreases northward and eastward through the state, and the differences in severity increase with increasing recurrence interval. The state pattern of relative severity, as shown by percent of normal precipitation, is similar to the 3-month and 6-month patterns.

The patterns of figure 9 reflect the effects of several features of the mean circulation and climate of the central United States upon drought occurrence and severity in Illinois. As pointed out by Tannehill (1947), droughts tend to be more frequent and severe in the Great Plains which lie west of Illinois; consequently, an eastward decrease in drought severity is to be expected across Illinois. The region of minimum severity in northeastern Illinois may be associated with the moderating influence of Lake Michigan which borders this area, as indicated earlier in the discussion of 3-month droughts. The increasing severity in extreme southern Illinois is at least partially the result of the mean circulation pattern during drought periods which retards the penetration of low pressure systems and fronts into this region. Circulation patterns and meteorological conditions associated with droughts will be discussed in more detail later.

18-Month Droughts

Figure 10 shows the frequency distribution of 18-month droughts. Comparison with the 12-month droughts of figure 9 shows some appreciable differences in the general patterns, particularly on the 5-year and 10-year maps. Whereas the 5-year map for 12-month droughts indicates a general increase in relative severity from northeastern Illinois to the southern and southwestern parts of the state, the 5-year map for 18-month droughts shows a zone of increasing severity extending northeastward approximately along the Illinois River Valley with a center near LaSalle (figure 10). Also, the map for 18-month droughts shows a zone of decreasing severity extending southwestward through south-central Illinois, not indicated on the map for 12-month droughts. Similarities between the two 5-year maps are relatively low values of severity in the northeastern and northwestern parts of the state and relatively high values of severity in the extreme southern and southeastern portions.

Comparison of the 10-year maps for 12-month and 18-month droughts indicates pattern differences similar to those for the 5-year maps. In 18-month droughts the 10-year map has a zone of relatively high severity in the Illinois River Valley centered in the Peoria region (figure 10) and a zone of relatively low severity in the south-central part of the state; neither zone shows on the map for 12-month droughts. However, both 10-year maps show areas of minimum severity in the northeastern part of the state and regions of maximum severity in the southwestern to western regions of the state and in the extreme southern and southeastern regions.

The 25-year maps for 12-month and 18-month droughts show the same general trend, although orientation of the isopercentiles are dissimilar in some respects. As the 50-year frequency is reached, the 12-month and 18-month maps become quite similar with respect to location of major zones of maximum and minimum severity. Thus, in general, the 12-month and 18-month drought patterns become more alike as the recurrence interval increases.

The actual depth of precipitation in inches at any location on the 18-month maps for droughts ending in any given month can be obtained from the mean annual precipitation map (figure 2) combined with the 6-month mean precipitation map of figure 8. The seasonal distributions of 6-month droughts presented in table 2 may be used as a guide in estimating the probability of an 18-month drought ending in a given month or season.

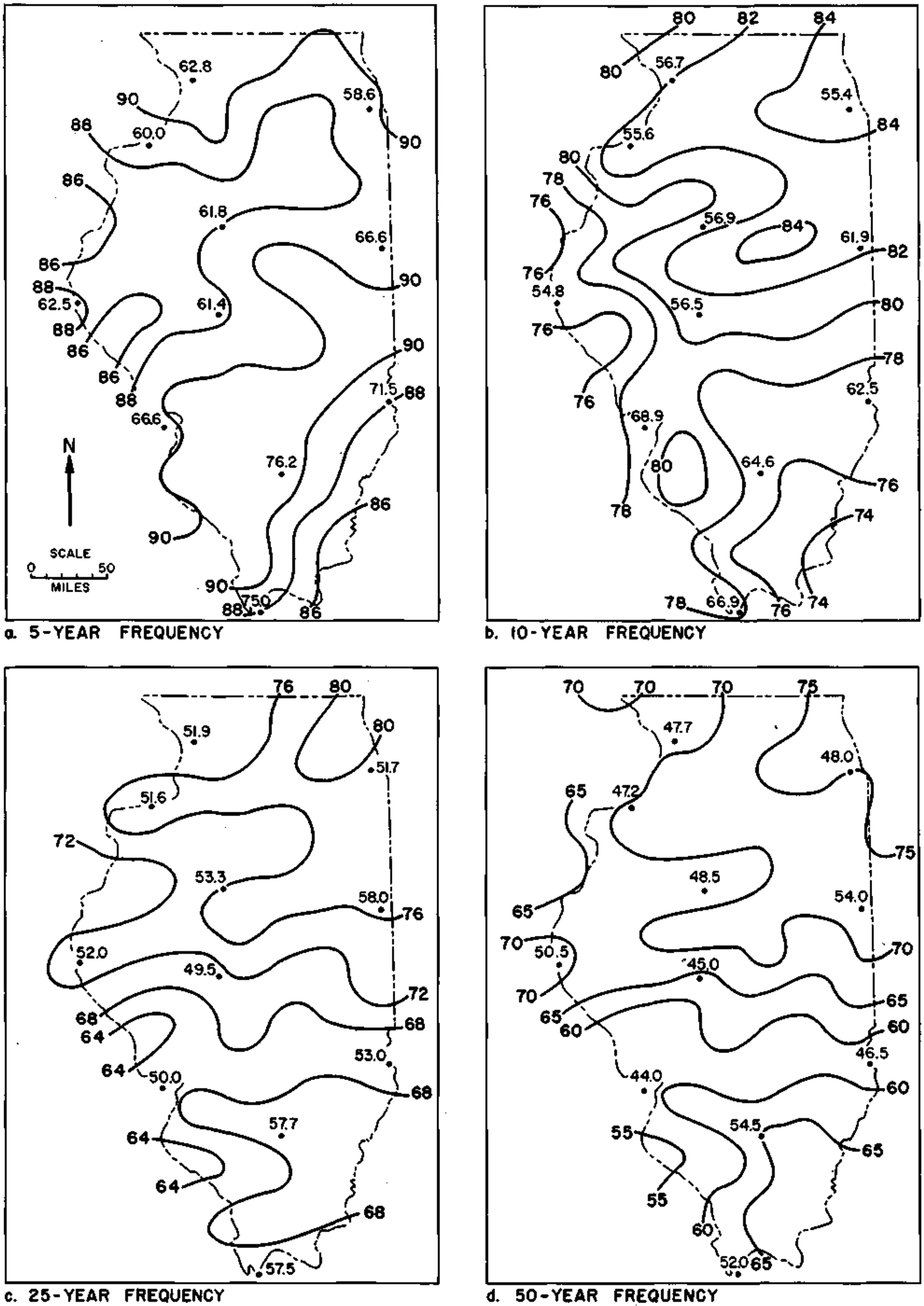
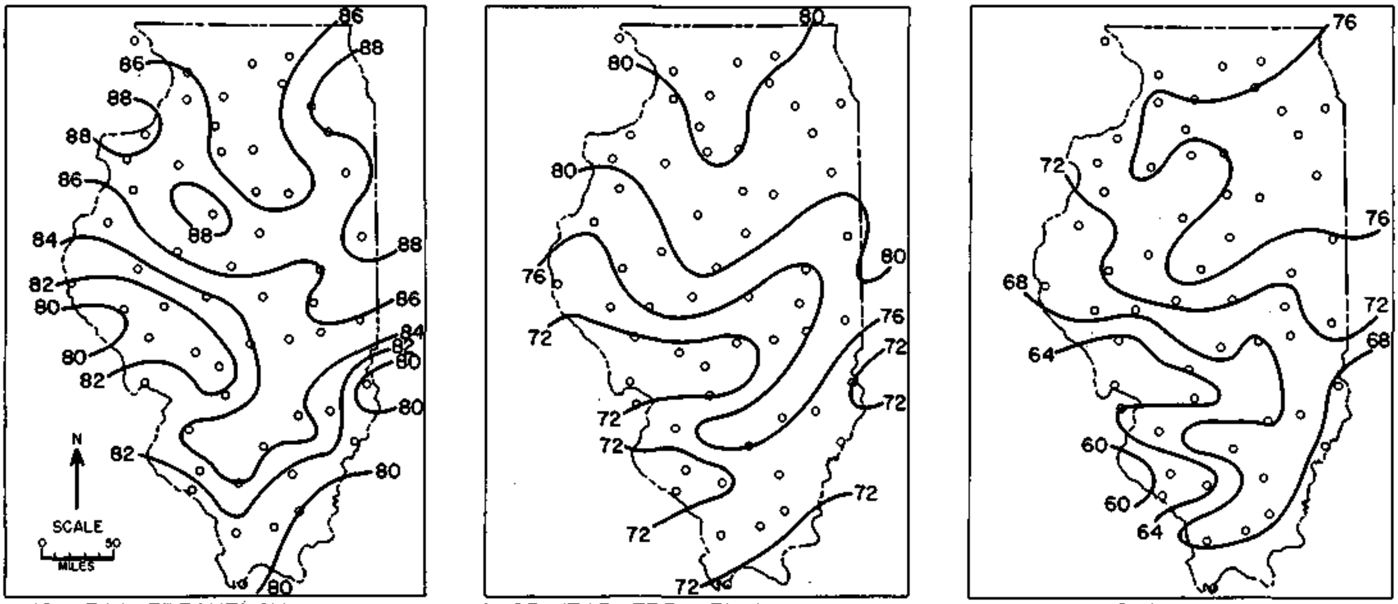


Figure 11. Frequency of 24-month drought periods, expressed as percent of normal 2-year precipitation



a. 10-YEAR FREQUENCY b. 25-YEAR FREQUENCY c. 50-YEAR FREQUENCY

Figure 12. Frequency of 30-month drought periods, expressed as percent of normal 30-month precipitation

For example, assume the precipitation depth is desired for an 18-month drought of the 10-year frequency ending in February at Chicago. Figure 10 shows 78 percent of normal for this drought. At Chicago, the annual mean precipitation (figure 2) is 32.7 inches, and the 6-month mean precipitation ending in February (figure 8) is 13.5 inches. Adding 32.7 and 13.5 and multiplying the sum by 78 percent gives 36.0 inches for the 10-year, 18-month drought.

24-Month Droughts

The frequency distribution of 24-month droughts is presented in figure 11 for selected recurrence intervals. As on previous maps, drought severity has been expressed as percent of normal precipitation. Precipitation depths in inches corresponding to the percentage values are shown for selected stations. The isopercentile maps of 24-month drought can be used in conjunction with the map of mean annual precipitation (figure 2) to obtain actual depths of precipitation at any location and for any recurrence interval. Naturally, the annual mean precipitation must be multiplied by two to obtain the 24-month normal precipitation.

Examination of the frequency maps for 12-, 18-, and 24-month periods shows that the 24-month patterns are more similar to the 12-month patterns than to those for 18 months. The 5-year and 10-year maps for both 12-month and 24-month droughts show minimum severity of drought in the northeastern part of the state and a gradual increase to maximum severity (low percentages) in the southwestern, extreme southern, and extreme southeastern parts of the state. The 25-year and 50-year maps for 24 months, however, show a major difference from the corresponding 12-month maps in the southeastern part of the state. Whereas the 12-month maps indicate a region of increasing relative severity throughout this area, the 24-month maps indicate decreasing severity. Also, the 50-' year-frequency 24-month map indicates a region of maximum severity extending west-east across south-central Illinois in the region from St. Louis to Palestine (figure 11), whereas most of this region is a zone of decreasing severity on the 12-month map. The St. Louis-Palestine zone of maximum severity on the 25-year and 50-year maps was produced to a large extent by the very severe drought of 1952-1954 in southern and south-central Illinois.

30-Month Droughts

The drought patterns for 30-month droughts and recurrence intervals of 10, 25, and 50 years are shown in figure 12. Drought severity is expressed in percent of normal precipitation which may be converted to actual depth of precipitation at any location and for any recurrence interval through use of the maps for annual mean precipitation (figure 2) and mean 6-month precipitation (figure 8) in conjunction with the isopercentile maps. Thus, the 10-year-frequency 30-month drought at Chicago is 88 percent of normal. To determine the actual depth of precipitation for the 10-year, 30-month drought ending in February, add twice the annual mean precipitation in Chicago

(32.7 inches) and the mean 6-month precipitation ending in February (13.5 inches). This results in a sum of 78.9 inches which multiplied by 88 percent gives 69.4 inches for the 10-year, 30-month drought.

The 30-month drought patterns of figure 12 show a general trend for the relative drought severity to increase southward and southwestward in the state, resulting in maximum areas of severity in southeastern, extreme southern, southwestern, and western Illinois. The minimum severity region is in the northeastern part of the state. The range of severity is from 80 to 89 percent for the 10-year frequency distribution, 71 to 81 percent for 25-year frequencies, and 60 to 77 percent for 50-year recurrence intervals. Thus, the range of severity increases with increasing recurrence interval. A similar trend was found with the 12-month, 18-month, and 24-month droughts.

36-Month Droughts

The frequency distribution of 36-month drought periods is shown in figure 13 for recurrence intervals of 10, 25, and 50 years; and, as in previous frequency maps, drought severity is expressed as percent of normal precipitation. The isopercentile maps of 36-month droughts can be used in conjunction with the map of annual precipitation (figure 2) to obtain actual precipitation depths for any location and recurrence intervals by multiplying the appropriate percent of normal by 3 times the appropriate annual precipitation.

The 36-month drought pattern is similar to that for 30-month periods and shows a general increase in relative drought severity southward and southwestward throughout the state. Maximum areas of severity are found in the extreme southern and west-southwestern parts of the state, and minimum severity is indicated in the northwestern, north-central, and east-central portions. The state range is from 83 to 91 percent for the 10-year recurrence interval, 75 to 85 percent for 25-year, and 67 to 81 percent for 50-year occurrences. The range of severity increases with increasing recurrence interval, which is similar to the trend of the 12-month to 30-month drought periods.

42-Month Droughts

The pattern of 42-month drought periods is illustrated in figure 14. Again, drought severity is shown by percent of normal precipitation maps for recurrence intervals of 10, 25, and 50 years. Actual depth of precipitation for a given point and given recurrence interval is obtained by adding the 6-month mean precipitation (figure 8) to 3 times the annual mean precipitation (figure 2) and multiplying the sum by the percent of normal precipitation at the given point on the 42-month drought map.

The 42-month drought pattern is similar to the typical Illinois pattern shown in previous discussions of shorter drought periods; that is, relative drought severity increases generally southward and southwestward throughout the state. Max-

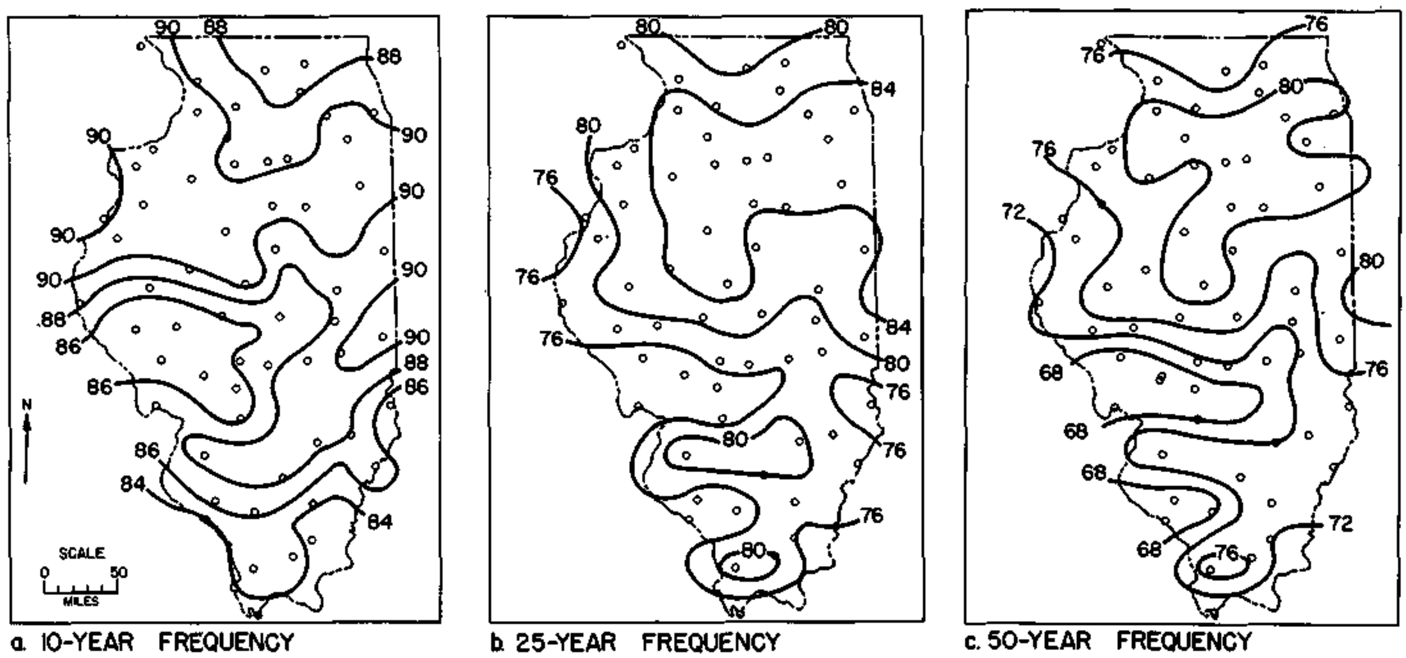


Figure 13. Frequency of 36-month drought periods, expressed as percent of normal 3-year precipitation

imum regions of severity (low percentage values) are indicated in the extreme south, southeastern, and southwestern parts of the state. Minimum drought severity (high percentage values) occur in the northern and eastern regions of the state. As with the shorter drought periods, the statewide range of relative severity increases with increasing recurrence interval.

48-Month Droughts

The 48-month drought patterns shown in figure 15 indicate that severe droughts of such duration are uncommon in Illinois. For a 10-year recurrence interval, the relative severity ranges from 89 to 95 percent of the normal 48-month precipitation in various regions of the state. The

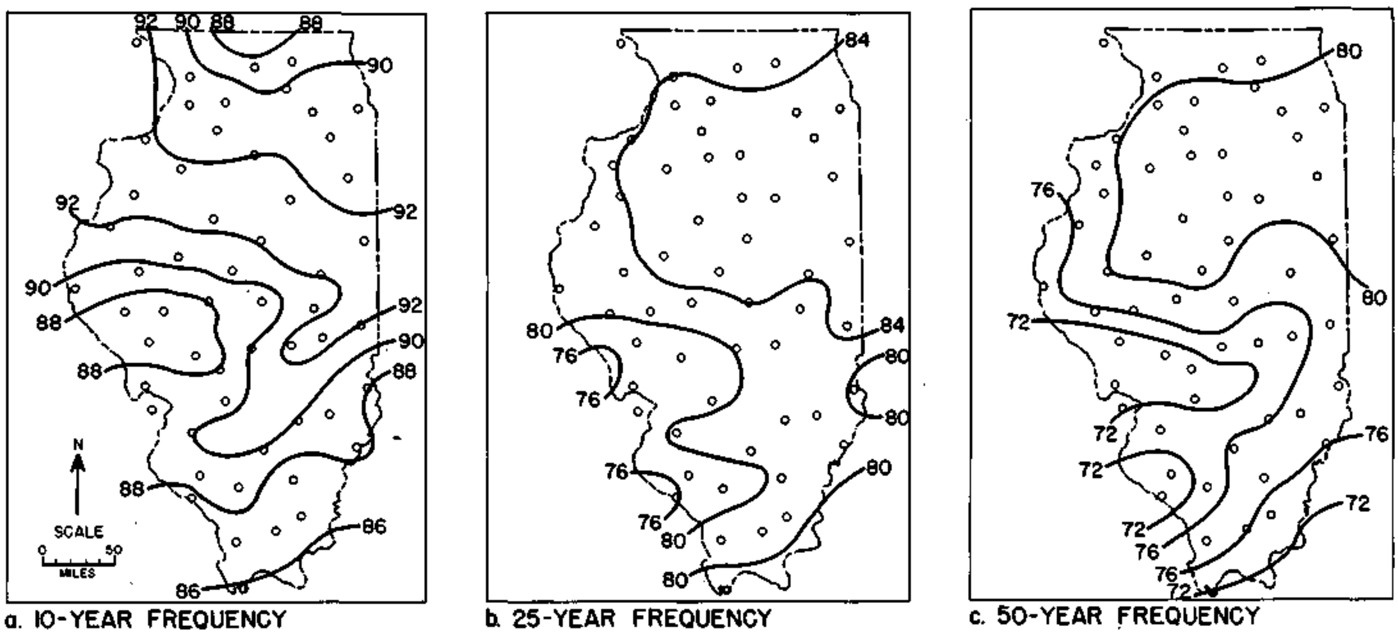


Figure 14. Frequency of 42-month drought periods, expressed as percent of normal 42-month precipitation

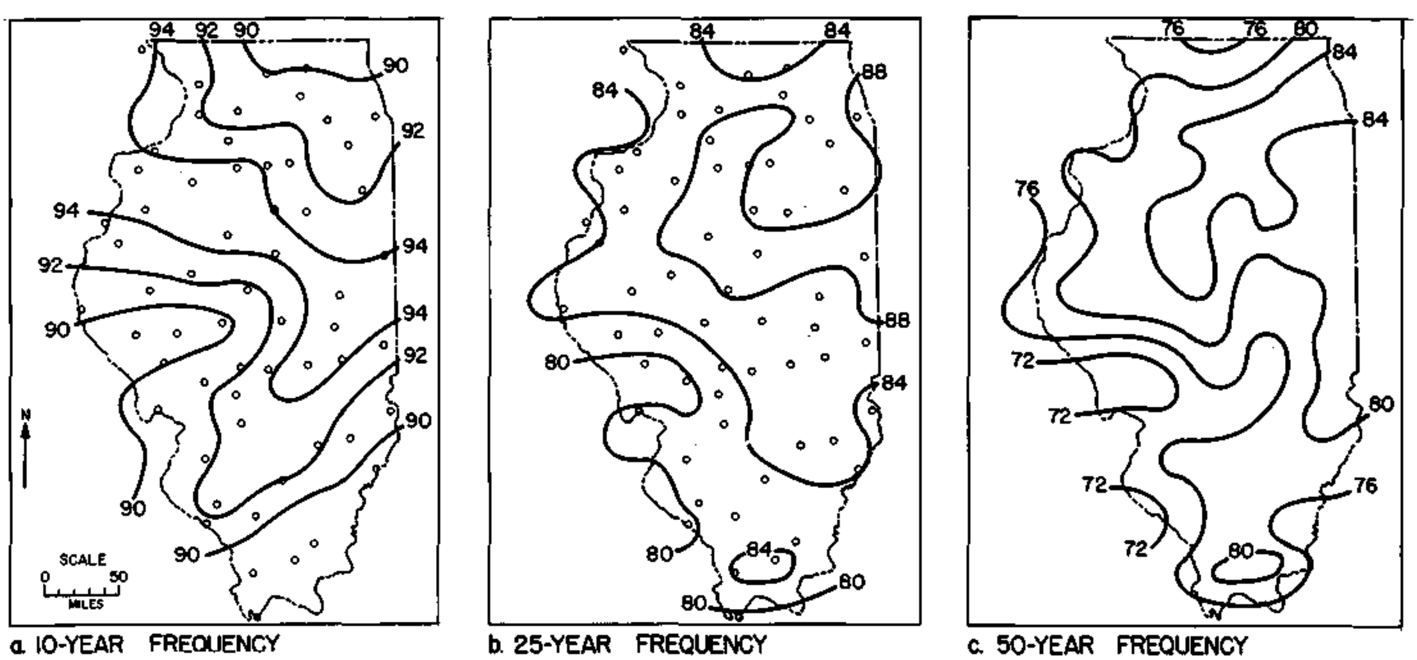


Figure 15. Frequency of 48-month drought periods, expressed as percent of normal 4-year precipitation

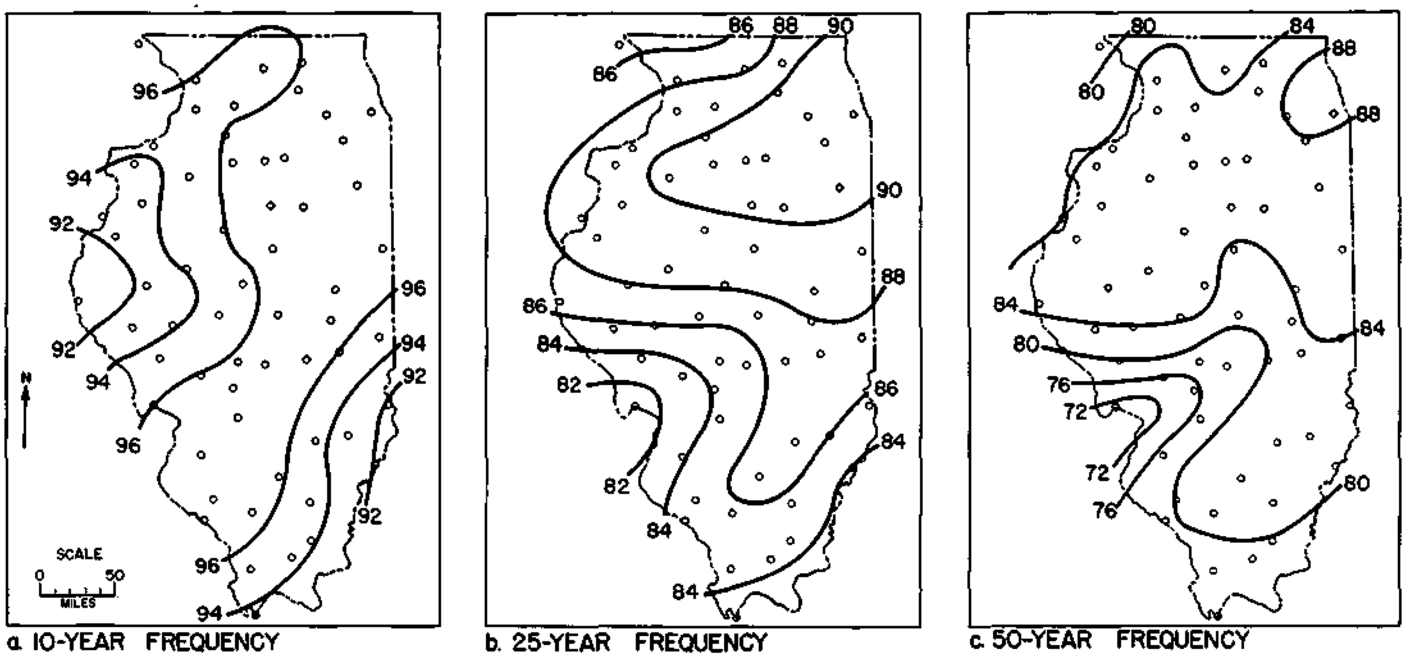


Figure 16. Frequency of 60-month drought periods, expressed as percent of normal 5-year precipitation

48-month droughts show a relative severity range from 79 to 89 percent of normal precipitation in the 25-year recurrence interval and from 72 to 85 percent in the 50-year occurrences. In comparison, the relative severity of 24-month droughts ranges from 74 to 84 percent of normal for a 10-year-frequency drought, 63 to 81 percent for a 25-year frequency, and 55 to 76 percent for a 50-year occurrence.

As with the drought periods discussed earlier, the maximum severity of 48-month droughts is found in the extreme southern, southeastern, and southwestern regions of the state. The minimum severity, in general, is found in the northern half of the state, but the center shifts position with different recurrence intervals. This shifting appears to be largely the result of sampling variations, rather than any real shift in drought susceptibility with increasing recurrence interval.

As pointed out in earlier discussions, the actual precipitation for a given location and recurrence interval can be determined from the isopercentile maps and the mean annual precipitation map of figure 2. For the 48-month drought, multiply 4 times the mean annual precipitation by the 48-month percent of normal for the given location and recurrence interval.

60-Month Droughts

Drought patterns for recurrence intervals of 10, 25, and 50 years for 60-month dry periods, expressed as percent of normal 60-month precipitation, are shown in figure 16. The typical pattern of relative severity in Illinois droughts is maintained, with maximum values in the south, southeast, and southwest and minimum values in the north and central portions of the state. The relative severity over the state ranges from 91 to 97 percent of normal for a 10-year-frequency drought, from 82 to 91 percent for a 25-year occurrence, and from 72 to 88 percent for a 50-year occurrence.

Actual values of precipitation at a given point and for a given recurrence interval can be determined from use of the mean annual precipitation map (figure 2) in conjunction with the isopercentile maps of 60-month droughts. The 60-month isopercentile maps clearly indicate that pronounced dry periods of this duration are rare in Illinois, particularly in the northern half of the state.

CLIMATOLOGY

A climatological investigation of precipitation droughts in Illinois during the 1906-1955 period was performed to ascertain various spatial and temporal characteristics of actual droughts. This investigation also permitted a study of the relationships between droughts of different durations.

All droughts of each of seven different duration categories were classified as to statewide severity and then ranked according to severity. Durations of drought analyzed in this investigation were of 3, 6, 12, 24, 36, 48, and 60 months. A total of 70 drought periods of varying durations were obtained from the 1906-1955 data. The location and orientation of the areas of lowest percentage of normal values on each drought map were analyzed and classified, and unusual regional features displayed in these patterns noted. Climatological descriptions of monthly frequencies of above and below normal temperatures and precipitation amounts were obtained for the severest droughts.

In the temporal analysis of droughts, the droughts in each duration classification were examined for possible cyclic patterns. This analysis also included the determination of the maximum and minimum elapsed time between droughts and the calculation of probabilities for varying time intervals between droughts. A comparison of the severity of droughts in Illinois prior to 1906 with that in droughts since 1906 also was made. The times of occurrence of droughts of different durations were compared to ascertain the relationship between short-period and long-period droughts, and to investigate possible causes for the development of the long-period droughts.

Data and Analytical Procedures

The selection of discrete periods which eventually were classified as droughts in the 1906-1955 period was based on a comparison of precipitation data from the 62 stations shown in figure 1. For each station, detailed listings of low precipitation amounts were prepared by machine analysis for each of seven drought durations. This listing included the amounts of precipitation, the percent of normal precipitation, and the rank of the drought periods based on the percent of normal precipitation. Inspection and comparison of the data for the dates of low precipitation occurrence from several stations revealed the presence of several major dry periods occurring on or about the same dates at many stations. Other dry periods of lesser significance were detected in the listings of only a few stations, but these were also noted. All of these dry periods were then mapped, and at each station location the percent of normal precipitation, its rank value, and the ending month of the dry period were recorded. These maps were further analyzed by constructing isopercentile lines which depicted the areas of greatest and least departure from normal. For each dry period, the percent of normal precipitation for all 62 stations was averaged to obtain a statewide value, and a count was made of the number of stations for which the dry period ranked from 1 to 5 in severity during the 50-year sampling period.

Additional criteria were employed to make the final selection of the dry periods which were to be classified as droughts. A dry period had to meet two qualifications to be classified a drought. The first qualification was that the dry period precipitation had to have a statewide percentage of normal below a predetermined level. This level was determined from curves based on the lowest statewide percentages of normal and on the lowest station percentages for each of the seven drought durations. These two curves were fitted as straight lines on semi-logarithmic paper and found to be parallel. The curve selected as the upper limit for drought selection was drawn parallel to these two curves through the 100 percent of normal point for 60-month droughts. The second qualification was that the dry period had to have a number of stations with rank values of 1 through 5 exceeding a predetermined level.

The levels of qualification and the total number of droughts selected are shown in table 3. This table reveals that the qualifications varied according to drought duration and that increasing percentages of normal and numbers of stations were required as the drought durations increased. The selection procedure eliminated 15 dry periods of varying durations from classification as droughts.

To determine whether the selected droughts incorporated all major dry periods for each duration, a count was made of the number of stations for which each of the selected droughts ranked

Table 3. Qualifications for Selecting Droughts from Dry Periods

	Drought duration, months						
	3	6	12	24	36	48	60
Qualifications:							
1) State percent or normal had to be equal to or less than	59	69	80	88	93	96	100
2) Number of station ranks of 1-5 had to equal or exceed	4	8	11	14	17	18	20
Percent of possible station ranks of 1-5 in selected droughts	82	85	90	90	90	82	82
Total selected droughts	16	13	11	9	8	7	6

from 1 to 5 in severity during the 50-year sampling period. The total number of l-to-5 ranks incorporated in the selected drought periods of a given duration was then expressed as a percentage of the total number of l-to-5 ranks (62 x 5 or 310) for the given duration in the 1906-1955 period. These percentages in table 3 reveal that the selected droughts accounted for more than 80 percent of all of the five highest station ranks for any of the durations. The few low ranks not accounted for by the selected droughts were widely scattered among several very minor dry periods. The selected droughts for each duration included all of the possible first and second station ranks.

Drought periods of 12 months and longer generally did not begin and end in the same month throughout the state. Therefore, two beginning and two ending months were listed for each drought to define the peak period and overall period of drought in the state. The peak of the drought period was defined from temporal data in the area of greatest drought severity. This peak period frequently did not begin or end on the same months as did the drought period in other areas of the state where the drought was less severe. Thus, on a statewide basis, many 12-month drought periods occurred during time periods ranging from .13 to 20 months in total duration. This total duration is defined as the drought span in discussions which follow.

Since many droughts in Illinois have occurred in rapid succession with little time separation, it was necessary to devise a procedure for deciding whether two droughts closely related in time were to be classified as one or two drought periods. After inspection of the data sample, it was decided to consider two periods as separate droughts if either of two conditions were met. The first condition was that the number of months between the ending and beginning time of the peak period of two consecutive droughts had to be greater than one-half of the drought duration under analysis. For instance, there would have to be six months or more between the ending and beginning months of the peak periods of two consecutive 12-month dry periods for these to qualify as separate droughts.

The other condition used for separation of successive drought periods was based on a combination of two closely related factors. If the two areas of lowest percentages of normal were in distinctly different areas of the state, and if the less severe drought periods at intervening stations did not display a gradual transition in time of drought occurrence between the two peak periods, the two apparent droughts were considered as separate events. An example of this separation of two closely spaced droughts is shown in figure 17

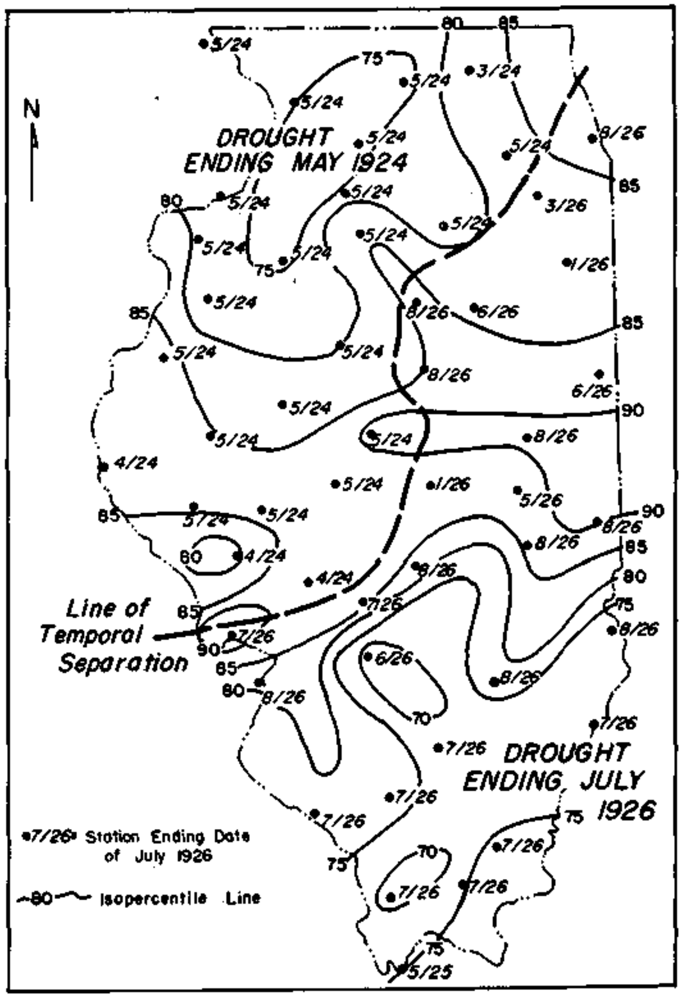


Figure 17. Isopercentile pattern and ending dates of driest 24-month periods in 1922-1927 era, separated into two droughts

for 24-month droughts ending in 1924 and 1926. In effect, this second condition for separating drought periods was an attempt to separate two closely time-related droughts which were probably caused by entirely different combinations of weather conditions. The temporal overlapping was more prevalent with the droughts of 24-months duration and longer. The second condition for separating drought periods was employed on only four cases.

To perform the climatological study of droughts it was necessary to classify the severity of each and to rank the droughts in each duration period. Precipitation drought severity can be classified on the basis of extremely low percentage of normal values recorded at a few locations or by an average percentage of normal using data from the entire state. The latter basis was selected as the most representative for this study.

A procedure was devised for evaluating the statewide severity of droughts using two parameters. The average statewide percentages of normal became the primary parameter for defining severity and ranking the droughts, that is, the lower the average statewide percentage, the higher was the rank of the drought. A second parameter was employed to help refine the ranking. All of the drought periods listed for each precipitation station had initially been ranked, and for each specific drought period a count was made of the number of stations for which the drought ranked from 1 to 5 in severity during the 50-year sampling period. These additional data were useful in selecting the more severe of two droughts which had equal or nearly equal average percentage of normal. Thus, for all droughts in each of the seven duration categories a rank based on statewide severity was determined.

A measure of the general temperature conditions in Illinois during severe drought periods was obtained. The frequency of months with above and below normal monthly mean temperatures was ascertained for the four severest droughts on record in each of the seven durations. This was based on temperature data from 10 stations distributed throughout Illinois, including Aledo, Cairo, Carlinville, Chicago, Mt. Vernon, Palestine, Peoria, Quincy, Rockford, and Urbana (see figure 1).

A similar measure of the frequency of months with above and below normal precipitation during the four most severe droughts was obtained. However, instead of using data from a given group of stations dispersed throughout Illinois, the analysis was based on data from the 12 stations which had the lowest station percentages of normal in Illinois for each of the four droughts in each of the seven drought durations.

Precipitation records of at least 34 years or longer prior to 1906 for seven stations were analyzed to detect the periods of extremely low precipitation. The low precipitation associated with these earlier dry periods was compared with the precipitation in the 1906-1955 droughts to obtain a measure of the representativeness of the 1906-1955 droughts for calculation of frequency relations. These stations and their length of record are shown in table 4; their locations are shown in figure 1.

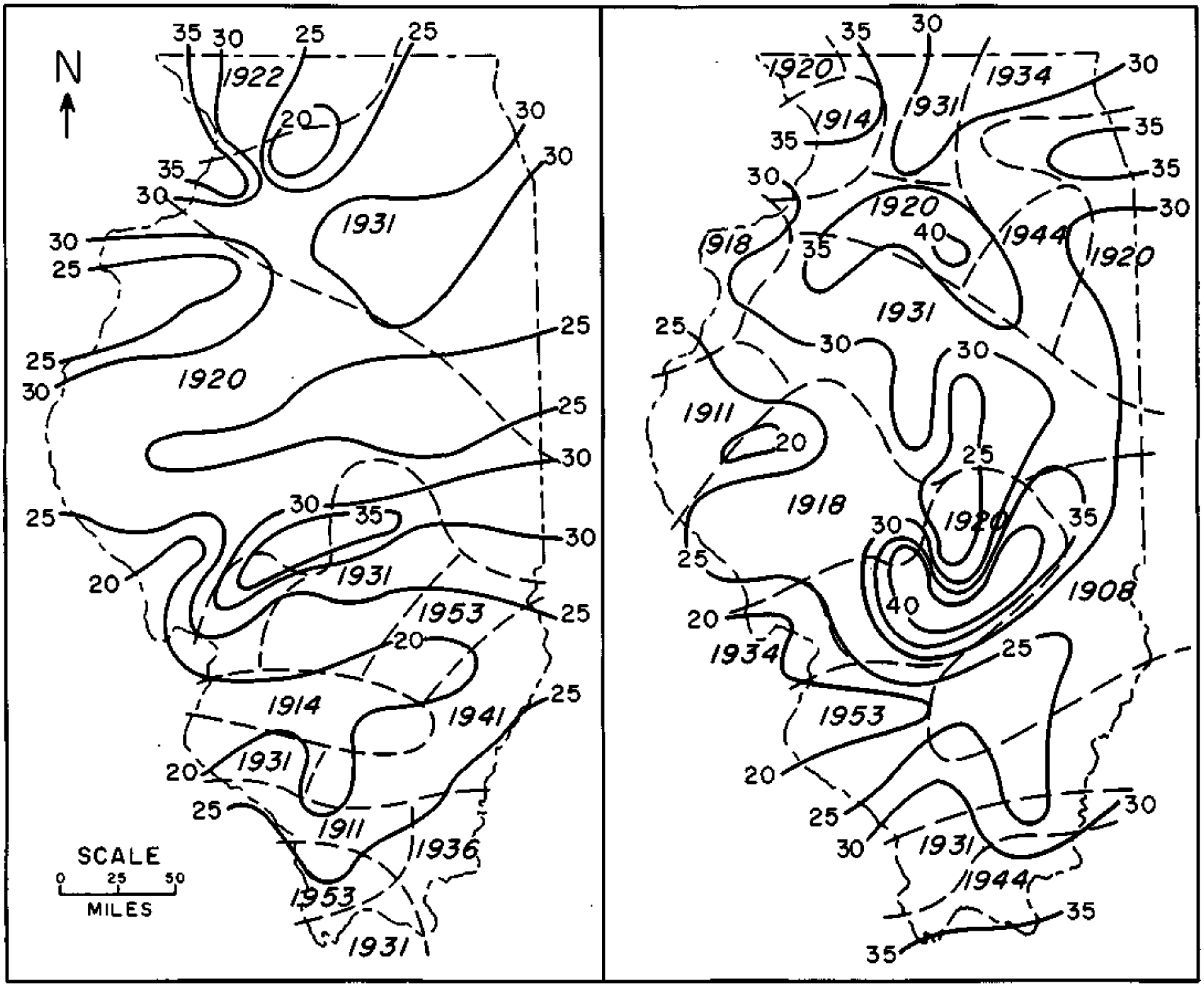
Table 4. Precipitation Records Analyzed for Drought Severity in the Period Prior to 1906

Station	Period of record	Length of record; years
Cairo	Jul 1871-Dec 1905	34+
Chicago	Jul 1871-Dec 1905	35
Davenport	Jun 1871-Dec 1905	34+
Dubuque	Jan 1858-Dec 1871 and Jul 1873-Dec 1905	46+
Marengo	Jan 1856-Dec 1905	50
Peoria	Jan 1856-Dec 1905	50
St. Louis	Jan 1856-Dec 1905	50

3-Month Droughts

Figure 18 shows the location, time of occurrence, and relative intensity of the two most severe 3-month droughts in Illinois. Droughts ending in 1931 and 1920 were responsible for the highest station ranks throughout most of the northern two-thirds of the state. Because of their great areal extent, these two 3-month droughts also ranked first and second, respectively, in severity on a statewide basis. The temporal patterns in figure 18 are not very homogeneous in the southern one-third of the state where 3-month droughts ending in 1908, 1911, 1914, 1934, 1936, 1944, and 1953 ranked first or second in severity over moderate-sized areas. Thus, the data in figure 18 indicate that the very severe 3-month droughts are more widespread in northern and central Illinois than in the southern part of the state.

The isopercentile patterns of figure 18 portray the relative intensity of the first and second ranked droughts throughout the state, based upon percent of normal percipitation. These patterns show that the first and second ranked droughts have been most severe (lowest percent of normal) in the south-central, southwestern and extreme western parts of the state. They have been least



a. FIRST RANKED b. SECOND RANKED

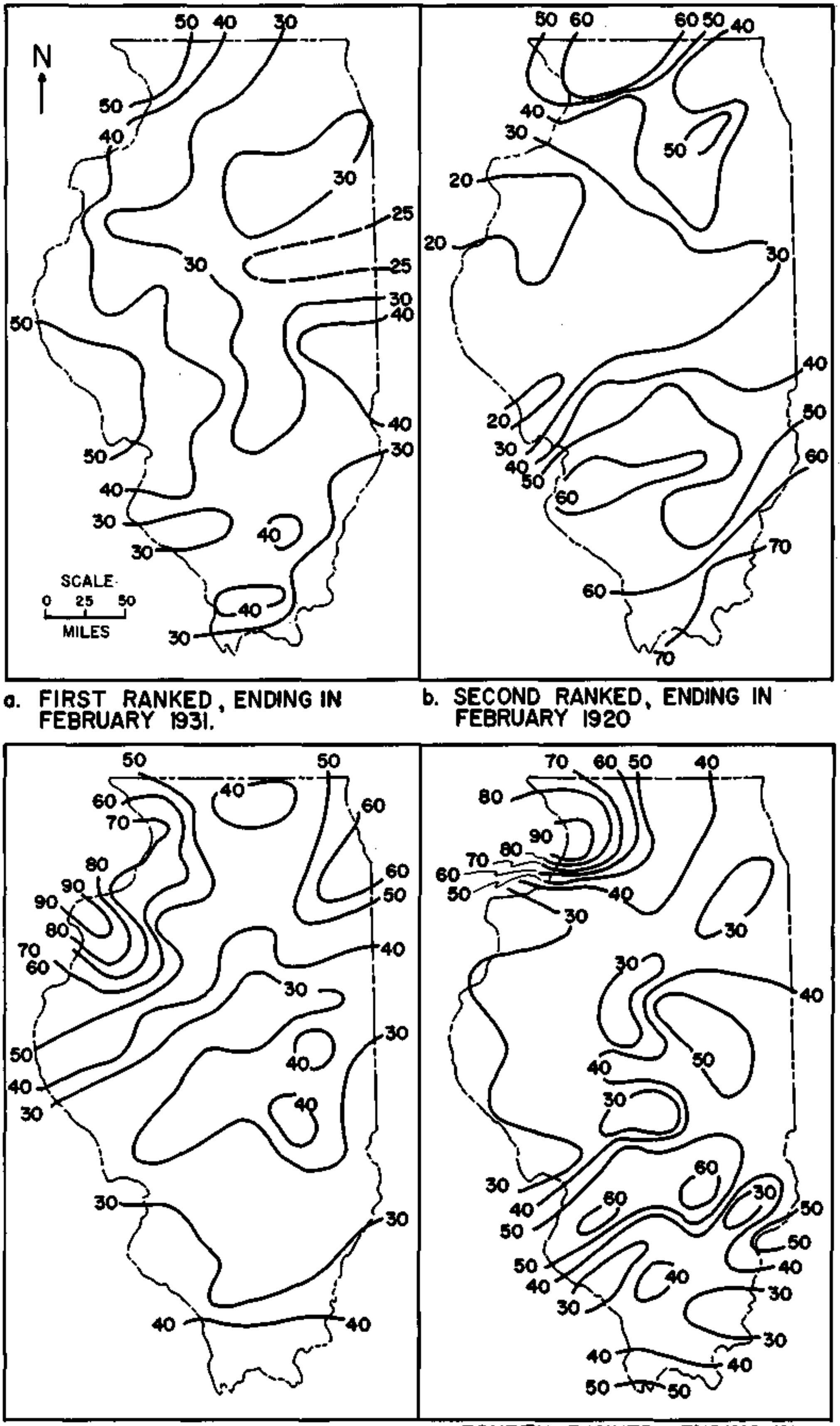
Figure 18. Ending dates and percent of normal precipitation values for first and second ranked 3-month droughts

severe in the extreme northwestern and northeastern regions of the state, and in a band across the central portion of the state. The locations of the above regions of greatest and least severity are reflected in the 25-year and 50-year frequency distribution maps of figure 5.

All 12 stations in the area of greatest severity of the four severest 3-month droughts had, during the drought's peak period, below normal monthly precipitation amounts in all months. Temperature conditions at 10 stations in Illinois during the four severest 3-month droughts were relatively warm. Eighty percent of all station-months had above normal temperatures. Twenty of the 26 station-months with below normal temperatures occurred during the winter season. Thus, severe 3-month droughts are always associated with below normal monthly precipitation amounts in the area of severity and with above normal monthly temperatures throughout Illinois.

Figure 19 depicts the isopercentile patterns of the four worst, or highest ranked, 3-month droughts in Illinois during the 1906-1955 period. The rank and other pertinent data for all sixteen 3-month droughts in this period are presented in table 5.

The 3-month drought ending in 1931 (figure 19a) was the most widespread and most severe drought in Illinois. Percentages of normal of less than 30 extended from extreme southern Illinois to extreme northeastern Illinois. The Sparta and Hoopeston stations (figure 1) both recorded percentages of 22. The portion of this drought in southern Illinois ended in December 1930, whereas February 1931 was the ending month in central and northern Illinois.



a. FIRST RANKED, ENDING IN FEBRUARY 1931.

b. SECOND RANKED, ENDING IN FEBRUARY 1920

c. THIRD RANKED, ENDING IN OCTOBER 1908.

d. FOURTH RANKED, ENDING IN AUGUST 1936.

Figure 19. Four highest ranked 3-month droughts

Table 5. Characteristics of the Sixteen 3-Month Droughts in the 1906-1955 Period

Rank	Drought span	Ending month of peak period	State average percent of normal	Lowest percent	Number of 1-5 ranks	Areas of peak severity: Section location	Areas of peak severity: Pattern orientation
1	5/30-2/31	2/31	36	22	42	NE,C,E,ESE,SE,SW	SSW-ENE
2	12/19-2/20	2/20	40	17	37	W,WSW,C,E	W-E
3	8/08-12/08	10/08	41	20	19	C,WSW,ESE,SW,SE	SW-NE
4	5/36-12/36	8/36	42	18	8	WSW,C,W,NE;	SW-NE
						and SW,SE	W-E
5	11/33-7/34	1/34	45	17	19	WSW,C,NE	SW-NE
6	7/53-2/54	9/53	45	16	17	WSW,ESE,SW,SE	WSW-ENE
7	12/13-7/14	7/14	45	18	11	WSW,ESE,SW,SE	W-E
8	8/17-3/18	1/18	48	23	20	WSW,W,C	SW-NE
9	9/39-2/40	11/39	48	18	9	W,NW;	SW-NE
						and WSW,ESE	W-E
10	9/10-3/11	1/11	50	24	12	W,NW;	SSW-NNE
						and SW,SE	NW-SE
11	10/43-1/44	1/44	51	26	12	C,NE;	WSW-ENE
						and SW,SE	S-N
12	9/22-2/23	9/22	53	21	8	NW	NW-SE
13	8/52-2/53	11/52	54	11	4	WSW,ESE;	W-E
						and NW	SW-NE
14	7/40-4/41	11/40	57	18	9	WSW,E,ESE,SW,SE	SW-NE
15	8/16-3/17	2/17	59	31	12	W	W-E
16	10/35-5/36	2/36	59	33	4	NW,WSW,SW,SE	W-E

The 3-month drought ending in February 1920 (figure 19b) had a basically different pattern of drought than the one ending in 1931, and neither pattern is typical of those found with many of the other 3-month droughts. The area of severity was more restricted to one section of the state in the 1919-1920 drought than in the 1930-1931 drought.

The drought ending in October 1908 (figure 19c) was the third worst. Although this drought was severe over a major portion of the state, precipitation was near normal in the Aledo area of northwestern Illinois. The fourth ranked drought, which ended in August 1936, also was the worst of the four summer season droughts among the 3-month droughts. Dry conditions in the 1936 drought were widespread but there were two distinct areas of severeness, and this characteristic was typical of several other 3-month droughts.

Simple descriptions of the patterns for the sixteen 3-month droughts are given in table 5. In this table, the rank of each drought is followed by the drought span, the ending month of the worst 3 months of drought during the span, the average percent of normal precipitation for the state, the lowest percent of normal in any region of the state, the number of stations at which the drought ranked between 1 and 5 among the 16 droughts, the climatological region (or regions) where the severity was greatest, and the orientation of the drought pattern. The climatological regions used in table 5 are the nine areas outlined in figure 1. If a drought produced more than one distinct area of low percentages, each region is listed in the section location column of the table. This column shows that the West-Southwest, Southwest, and Southeast Sections were most frequently located in the most severe region of the 3-month droughts. The Northwest, Northeast, and East Sections were most frequently on the outer fringes of the drought zone; that is, the droughts tended to be less severe in these sections.

Inspection of the various isopercentile maps revealed that certain similar shapes or patterns existed in the regions of severest drought for the 16 droughts. Occasionally two different shapes appeared on the same drought map. In general, the severe drought regions were elongated and could be described as assuming one of three general geometric shapes: oblate, elliptical, and rectangular. Inspection of the shape data revealed that the rectangular, or narrow band shape, was the most frequent shape assumed by the regions of severe drought. These and the elliptical patterns usually suggested that a drought in Illinois was an extension of droughts in nearby states (figure 19).

The orientations of the long axes, which were derived for each of the shapes of the severe drought regions, are indicated in table 5. Eight of these areas were oriented W-E and another eight had SW-NE orientations. All but two of the 24 regions listed in table 5 had orientations varying from S-N clockwise to W-E. Summarizing, the area of greatest severity in a 3-month drought in Illinois is most likely to be rectangular in shape, to have a SW-NE orientation, and to occur in southern Illinois.

The times between the beginning and ending month of the peak periods for all sixteen 3-month droughts were plotted chronologically to ascertain whether cyclic trends of occurrence were in evidence. The chronological progression of time between droughts after the 1908 drought ran 24, 40, 28, 8, 22, 28, 98, 32, 22, 3, 36, 9, 33, 103, and 7 months. The average time between 3-month droughts was 32 months and the median was 28 months. However, the extremes varied from 3 to 103 months. In general, no readily identifiable cycles could be determined between the droughts. However, there were two notable long periods without any 3-month droughts. One was of 8 years (1923-1930) and the other of 8-1/2 years (1944-mid 1952). In the 13 years between these periods a total of seven 3-month droughts occurred; in the 15 years prior to 1930 a total of seven droughts also occurred.

The average duration of drought conditions which produce 3-month droughts in specific regions is 7 months on a statewide basis, although the span varied from 10 months (1930-1931) to 3 months, as shown in table 5. Examination of the "ending months of peak period" listed in table 5 reveals that eight of these droughts existed during the winter season, four during the fall, four in the summer, and none during the spring.

Based on the observed elapsed times between 3-month droughts, probabilities for varying elapsed times between droughts were calculated. The resulting probability graph plotted according to Frechet distribution (Gumbel, 1956) is shown in figure 20. This figure indicates that 20 percent of the time another 3-month drought will occur somewhere in Illinois within eight months after one drought has ended, and 80 percent of the time a 3-month drought will occur within 72 months after one has ended.

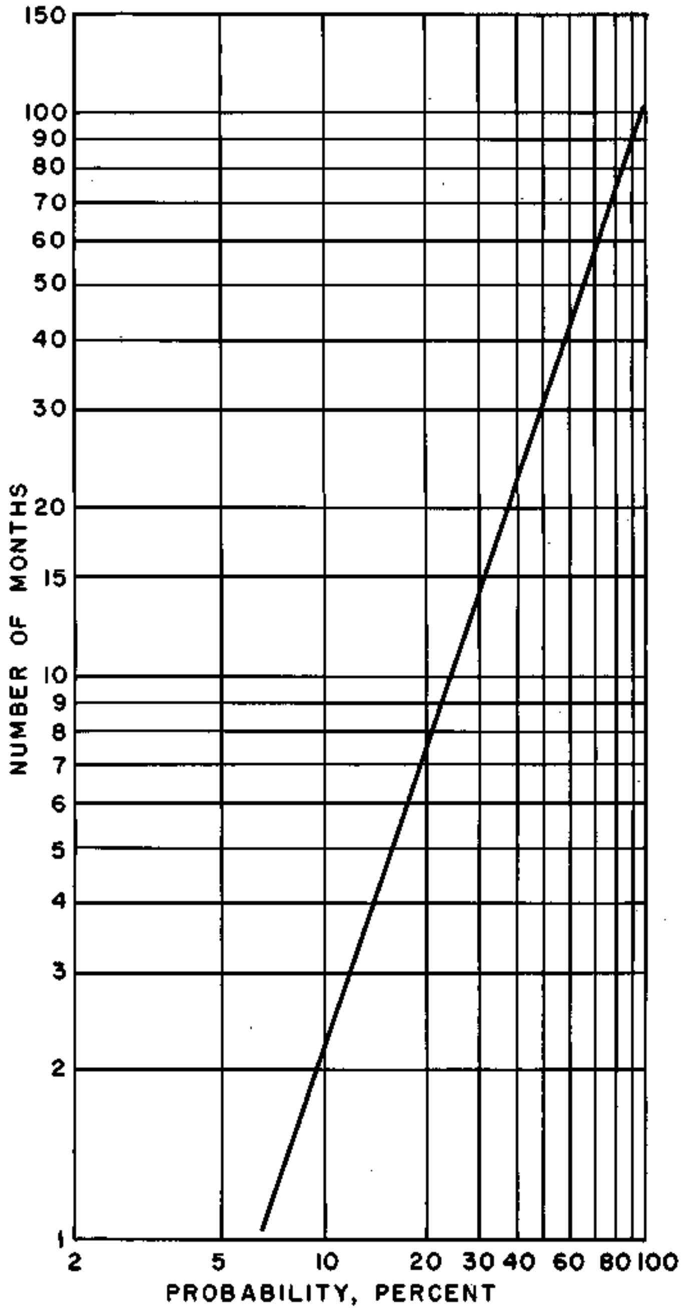
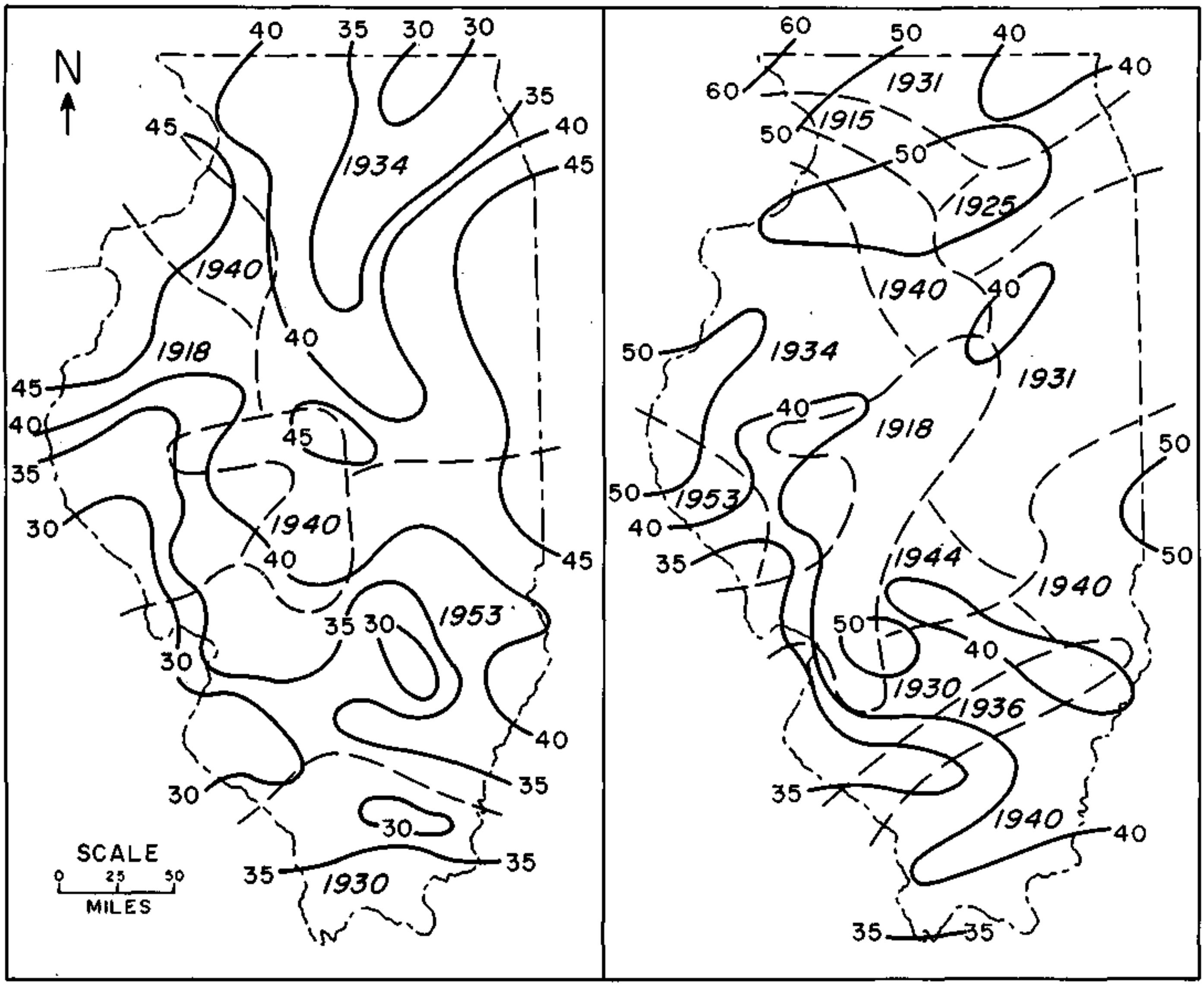


Figure 20. Probability that a 3-month drought will occur within a number of months after a 3-month drought terminates

6-Month Droughts

The regional and temporal patterns of severe 6-month droughts are shown in figure 21, based on the first and second ranked drought values at each station. Figure 21a reveals that five of the 6-month droughts were responsible for all of the first ranks recorded in the immediate state area. On a basis of regional extent, the 1934 and 1953 droughts were the most extensive in first rank values. Comparison of figure 21a with figure 21b, which portrays the isopercentile lines and ending years for the second ranked station values, reveals the transition in rank values of the five worst droughts. For example, in western Illinois (figure 21b), the 1934 drought ranks second in the region to the west of where it ranked first in severity. The area of effect of the 1918 drought is shown to extend eastward in figure 21b into central Illinois where it ranks second in severity. Similar regional extensions are shown for the 1940, 1953, and 1930 droughts. Four droughts that did not achieve first rank any place in the state appear as significant



a. FIRST RANKED

b. SECOND RANKED

Figure 21. Ending dates and percent of normal precipitation values for first and second ranked 6-month droughts

droughts on the map of the second ranked 6-month droughts. These were the 1931, 1915, and 1925 droughts in northern and eastern Illinois and the 1936 drought in southern Illinois. The isopercentile patterns based on the first and second ranked drought values of all the stations reveal that the lowest statewide percentages of normal precipitation occurred in the southern, southwestern, and north-central portions of Illinois.

The 12 stations with the lowest percentages of normal in the four severest 6-month droughts were found to have below normal monthly precipitation values 99 percent of the time. In only three months out of a possible 288 (12 stations × 6-month droughts × 4 droughts = 288) did above normal precipitation occur. Monthly temperatures in Illinois during the peak periods of the four severest 6-month droughts were found to be above normal 72 percent of the time. The below normal monthly temperatures with these droughts occurred most frequently in spring (42 percent) and winter (38 percent) and least frequently in summer (9 percent) and fall (15 percent). Thus, the severe 6-month droughts had below normal precipitation in nearly all months in the area of major severity and were also associated with above normal temperatures more than 70 percent of the time.

The thirteen 6-month droughts which occurred in the 1906-1955 period are listed in table 6. Interpretation of the data is the same as for table 5 under 3-month droughts. Isopercentile maps of the four severest, or highest ranked, droughts are presented in figure 22.

The drought ending in April 1934 (figure 22a)

Table 6. Characteristics of the Thirteen 6-Month Droughts in the 1906-1955 Period

Rank	Drought span	Ending month of peak period	State average percent of normal	Lowest percent	Number of 1-5 ranks	Areas of peak severity: Section location	Areas of peak severity: Pattern orientation
1	8/33-7/34	4/34	48	26	35	WSW,W,C,NW,NE;	SW-NE
						and SW,SE	Unknown
2	6/53-7/54	12/53	50	27	34	WSW,ESE,SW,SE	WSW-ENE
3	9/35-8/36	8/36	50	30	18	WSW,W,C,NE;	SW-NE
						and SW,SE,ESE	SW-NE
4	7/39-4/40	2/40	54	33	37	WSW,W,C;	W-E
						and NW	Unknown
5	7/17-4/18	3/18	56	30	25	WSW,W,C	WSW-ENE
6	8/30-4/31	3/31	59	30	20	NE;	Unknown
						and E,ESE	W-E
7	6/08-1/09	1/09	60	41	14	WSW,C,E;	WSW,ENE
						and ESE,SE	W-E
8	8/43-2/44	1/44	61	41	15	C,NE;	SW-NE
						and WSW,ESE	NW-SE
9	8/29-8/30	8/30	61	29	12	WSW,ESE,SW,SE	W-E
10	9/24-6/25	3/25	64	43	12	ESE,SE;	W-E
						and NE,E	W-E
11	11/14-6/15	4/15	64	47	9	NW,NE	W-E
12	6/44-3/45	11/44	67	35	9	SW,SE;	W-E
						and E,NE	Unknown
13	6/20-2/21	11/20	69	34	8	C,E	SSW-NNE

was the most severe (highest ranked) of the 6-month droughts. Percentages of normal of less than 40 extended from southwestern Illinois to extreme northeastern Illinois and also were evident in extreme southern Illinois. This drought was produced primarily by a 3-month drought period ending in January 1934 (table 5) which was ranked fifth among the 3-month droughts. The lowest percentages were in northeastern Illinois (figure 22a) where Marengo experienced a 6-month precipitation of 26 percent of normal, the lowest percentage recorded in any 6-month drought (table 6).

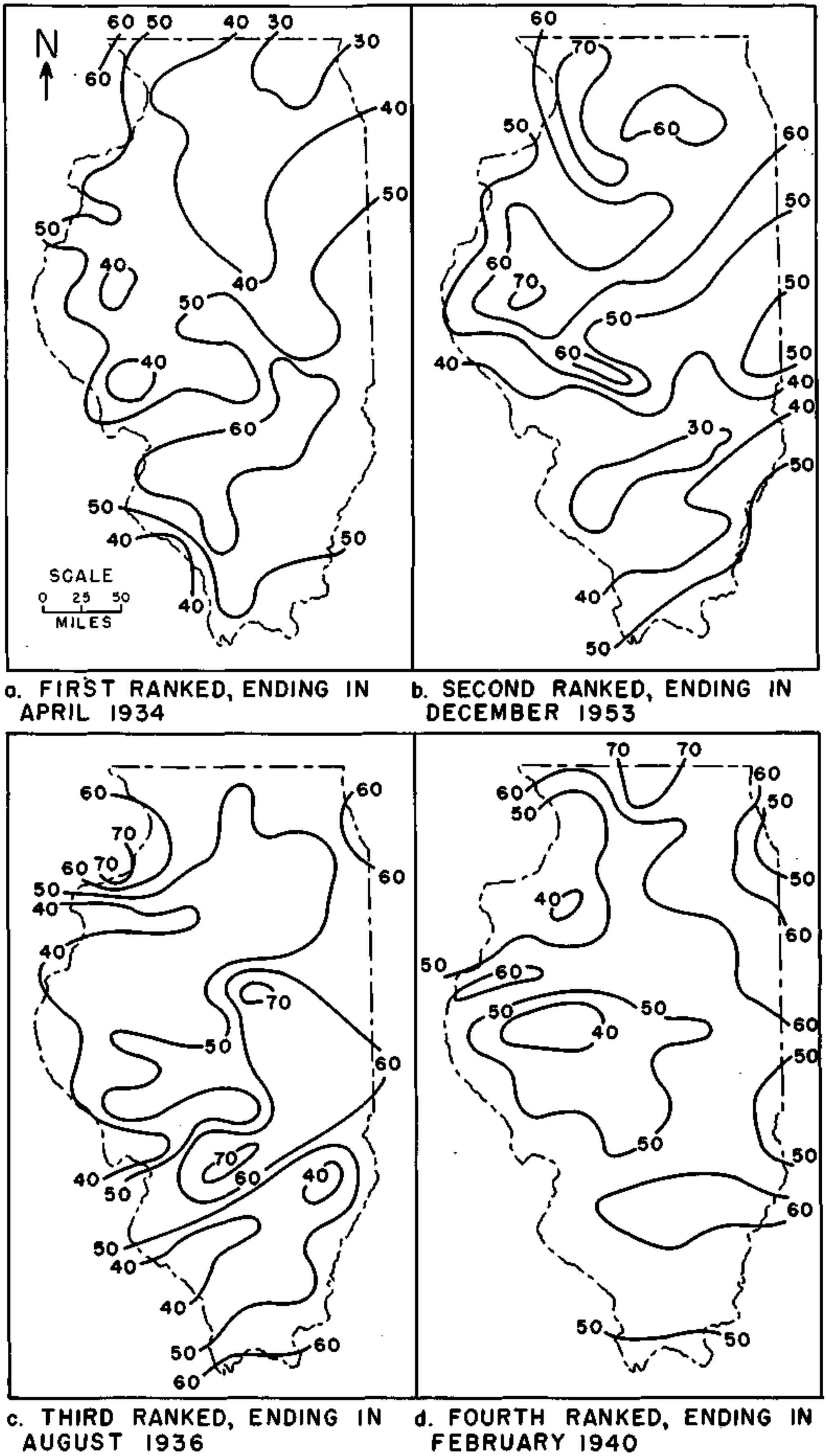
The second ranked 6-month drought ended in December 1953 (figure 22b) and was concentrated in the southern one-half of the state. However, none of the state had above normal percentages of precipitation, the highest being 76 percent at Mt. Carroll (see figure 1). This drought had 2500 square miles of area with less than 30 percent of normal precipitation. This produced a more extensive low area than that found in the 1934 drought. The 1953 drought resulted largely from the sixth ranked 3-month drought which ended in September of 1953 (table 5).

The third ranked drought ended in August 1936, and as shown in figure 22c there were two separate areas of maximum severity in the state. This 6-month drought was derived from the fourth ranked 3-month drought (figure 19d) which also had two separate areas of maximum severity in nearly identical locations. The influence of the 3-month drought in 1936 on the pattern of the 6-month drought for that year can be appreciated best by comparing the patterns of the two maps associated with these droughts.

The fourth ranked 6-month drought resulted primarily from a 3-month drought which ranked ninth in statewide severity, as shown in table 5. The 6-month drought which ended in February 1940 (figure 22d) had two major areas of drought severity. One was an oblate-shaped area in central Illinois, and the other was an area in northwestern Illinois that appeared to be an extension of drought conditions in Iowa.

Table 6 reveals that the regions of greatest severity occurred most frequently in the West-Southwest, Southeast, Northeast, and Central climatological sections of the state. Severe 6-month drought regions occurred least frequently in Western and Northwestern Sections.

The orientations of the major axes of the drought cores were classified and are listed in table 6. The preferred orientation was W-E, and all but one of the known orientations ranged from SSW-NNE clockwise through W-E. Thus, it appears that the average core region of 6-month droughts is elongated on a W-E or SW-NE orientation and



a. FIRST RANKED, ENDING IN APRIL 1934

b. SECOND RANKED, ENDING IN DECEMBER 1953

c. THIRD RANKED, ENDING IN AUGUST 1936

d. FOURTH RANKED, ENDING IN FEBRUARY 1940

Figure 22. Four highest ranked 6-month droughts

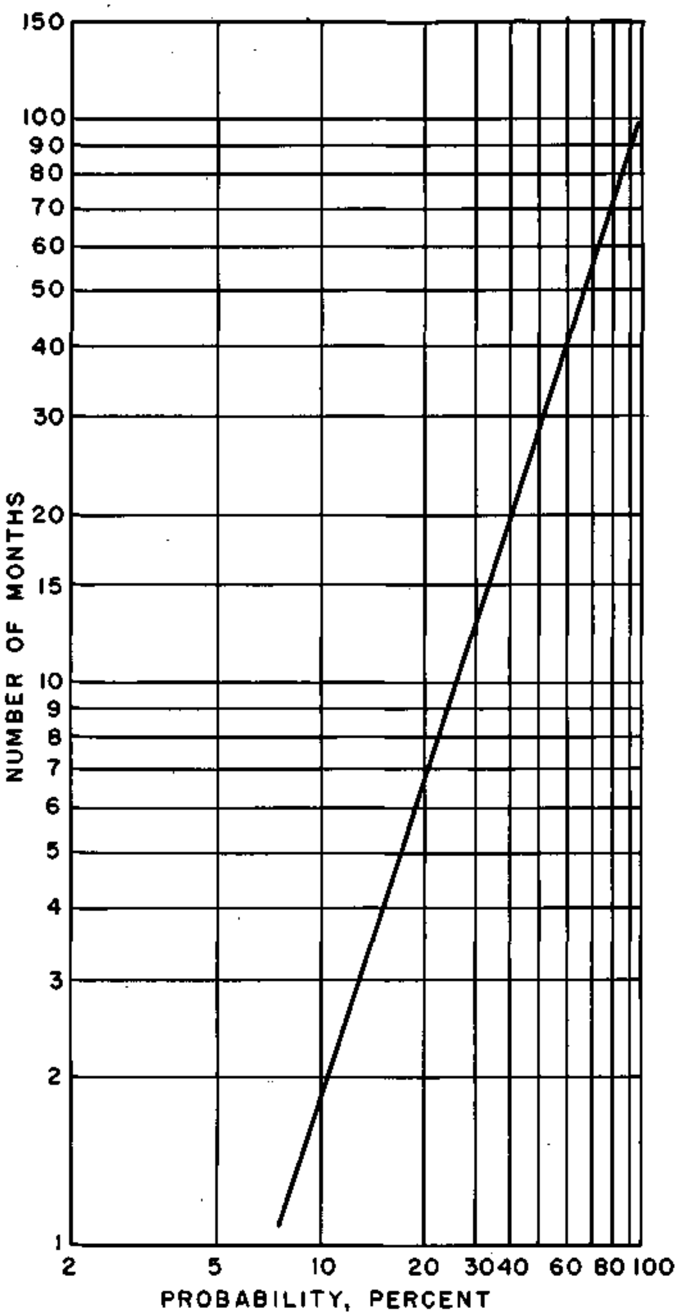


Figure 23. Probability that a 6-month drought will occur within a number of months after a 6-month drought terminates

is most frequently found in the area extending from west-southwestern to central to northeastern Illinois.

Characteristics of the temporal distribution of droughts can be obtained from the statistics for the peak periods and for the statewide span of drought periods listed in table 6. The average span or duration of the statewide drought periods for 6-month droughts was 10 months. The longest period was 14 months for the 1953-1954 drought, and the shortest period or span was 7 months in the 1943-1944 drought.

The time between the ending month of a peak period and the beginning month of the ensuing peak period was listed chronologically for each of the 13 droughts. This was done to ascertain possible cyclic trends in drought occurrence and to determine the average and extreme times for the intervals between 6-month droughts. This tabulation did not indicate the presence of cycles. The average number of months between peak drought periods was 39 months, and the median value was 34 months. The longest drought-free period was 103 months and the shortest was only 1 month. Three of the four highest ranked 6-month droughts occurred within a 6.5-year period from August 1933 to February 1940. The 10.5-year period from August 1929 through February 1940 contained five of the 6-month droughts. No other comparable period of frequency occurred in the 1906-1955 period.

In figure 23, probabilities for the interval between the termination of one drought and the initiation of another are shown. Examination of the probability results in figure 23 reveals that 10 percent of the time another 6-month drought will occur within two months after a 6-month drought terminates, and 80 percent of the time another will occur within 78 months after termination.

12-Month Droughts

The regional variations in severity and dates of occurrence for the most severe 12-month droughts are depicted in figure 24. The isopercentile and temporal patterns depicted in these maps are composites based on the first and second ranked droughts at each of the 62 stations, 1906-1955.

As shown in figure 24a, four 12-month droughts were responsible for all of the first ranks. These included droughts ending in 1914, 1931, 1934, and 1954. The drought ending in 1934 was first in severity over more of the state than any other drought. In figure 24b the temporal pattern based on the second rank values is presented, and this pattern is much more diversified than the pattern of first ranks in figure 24a.

The isopercentile pattern of the first ranked 12-month droughts reveals that the lowest percentages of normal precipitation occurred in the southern one-third of Illinois where percentages dropped below 45 percent in some regions.

The first ranked droughts were least severe in portions of northwestern, northeastern, and central Illinois where percentages exceeded 55. In figure 24b the isopercentile pattern based on the second ranked droughts reveals much the same pattern as in figure 24a with the lowest percentages located in west-southwestern and extreme southern Illinois and the highest percentages in eastern and northeastern Illinois.

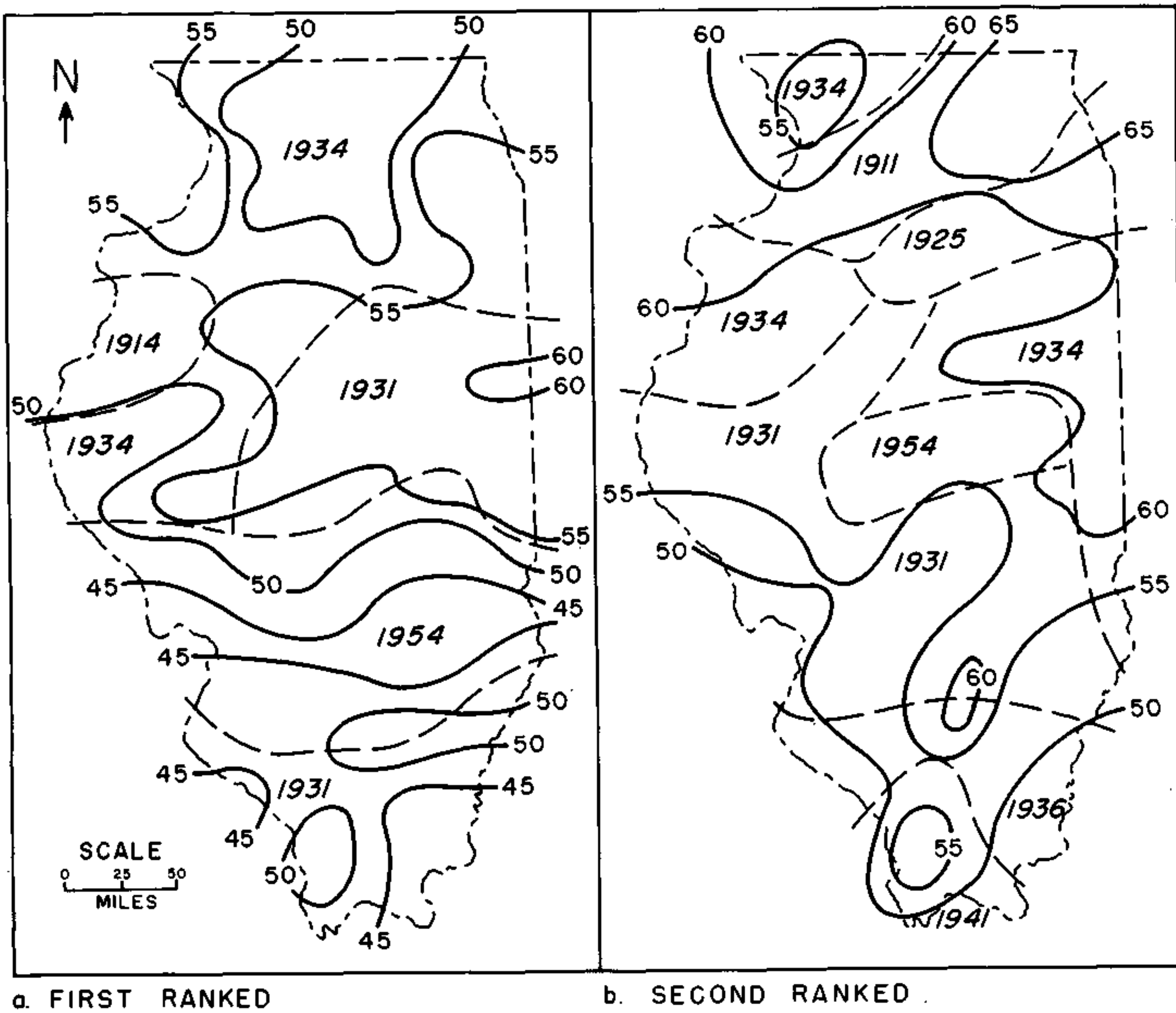


Figure 24. Ending dates and percent of normal precipitation values for first and second ranked 12-month droughts

The frequency of months with above and below normal precipitation was determined for the peak period of the four severest 12-month droughts using data from the 12 stations located in the region of greatest drought severity. On an annual basis 94 percent of the station-months had below normal precipitation values. In all seasons except fall 98 percent of the monthly values were below normal, but in fall only 83 percent were below normal.

During the peak periods of the four severest droughts the monthly mean temperatures at 10 stations in Illinois were above normal 71 percent of the time. Above normal temperatures were most frequent in summer months (90 percent) and least frequent in the spring (60 percent).

In table 7 several of the more important characteristics of the eleven 12-month droughts which occurred during the 1906-1955 period are presented. These include the span of time that the drought period persisted throughout the state, the ending month of the peak period, the statewide severity by percentage and by the number of high station ranks, the regions of greatest severity, and the drought pattern orientations.

The 12-month droughts ending in 1931 and 1934 were easily the two most severe 12-month droughts in Illinois. As table 7 shows, the statewide percentages of these droughts are about 10 percent lower than those of any other droughts, and both of these severe droughts had much larger numbers of stations with ranks in the 1-5 category.

Table 7. Characteristics of the Eleven 12-Month Droughts in the 1906-1955 Period

Rank	Drought span	Ending month of peak period	State average percent of normal	Lowest percent	Number of 1-5 ranks	Areas of peak severity: Section location	Areas of peak severity: Pattern orientation
1	4/33-10/34	5/34	58	46	45	WSW,W,NW,NE	SW-NE
2	2/30-8/31	2/31	61	41	42	WSW,ESE,SW,SE	Unknown
3	4/53-7/54	7/54	70	42	25	WSW,ESE,SW,SE	W-E
4	8/35-11/36	8/36	70	47	21	SW,WSW,SE	W-E
5	2/13-11/14	6/14	73	51	21	W,C	W-E
6	4/39-10/40	9/40	74	58	15	SW,WSW,C;	SSW-NNE
						and NW,NE	W-E
7	6/24-9/25	8/25	75	55	11	SW,ESE,SE;	SSW-NNE
						and C,NE,E	W-E
8	1/10-10/11	1/11	76	49	18	W,NW	Unknown
9	1/20-10/21	5/21	77	59	11	NW,NE,E	NW-SE
10	3/21-7/23	5/23	79	61	11	NW,W;	SSW-NNE
						and WSW	WSW-ENE
11	4/40-8/41	5/41	80	47	11	SW,SE,ESE	Unknown

The drought ending in May 1934 was the worst 12-month drought. This drought evolved from the most severe 6-month drought which terminated in April 1934 (table 6). Two large areas of less than 50 percent of normal are apparent in figure 25a, one in western Illinois and one in northern Illinois. More than one-half of Illinois experienced 12-month precipitation amounts of less than 60 percent of normal. The lowest percentages of normal occurred at Dixon and Ottawa (figure 1) both of which had 46 percent of normal precipitation.

The second ranked 12-month drought ended in February 1931 (figure 25b) and was concentrated in the southern one-half of Illinois. This drought resulted from two 6-month droughts which occurred in close succession during the 1929-1931 period, but the extremely severe 6-month drought ending in 1930 in southern Illinois was primarily responsible for the extremely low percentages found in this 12-month drought. The lowest 12-month value in Illinois was 41 percent at Harrisburg (figure 1), and as shown in table 7, this is the lowest percentage recorded for any 12-month drought. Almost all of Illinois south and east of the Illinois River had percentages of less than 60 percent of normal, and the entire state had below normal precipitation during this drought.

The third ranked 12-month drought ended in July 1954, and as portrayed in figure 25c, the most severe portion of this drought was concentrated in south-central Illinois. As with the 1931 and 1934 droughts, more than 50 percent of the state experienced precipitation of less than 60 percent of normal. However, unlike the 1931 and 1934 droughts, the one ending in 1954 had a large area of the state with above normal precipitation. An extreme gradient of change in percentage exists between the above normal area in north-central Illinois and the area experiencing severe drought in the south (figure 25c). This drought resulted largely from the second ranked 6-month drought which terminated in December 1953 (table 6).

The fourth ranked drought was similar to the second ranked and third ranked droughts in that the area of greatest severity occurred in southern Illinois. The fourth ranked drought ended in August 1936 (figure 25d) and was concentrated in the Shawnee Hills area (Leighton and others, 1948) of the state. It included the third ranked 6-month drought which also terminated in August 1936.

For each of the regions of greatest severity in the eleven 12-month droughts, abbreviated geographical descriptions were prepared. Several of the less severe 12-month droughts had two regions of maximum severity, and descriptions of all these regions are presented in table 7.

The study of the locations within the state where these regions of severity occurred was based upon regional occurrence within the nine climatological areas depicted on figure 1. The regions of severity of 12-month droughts occurred most frequently in the West-Southwest, Southwest, and Southeast Sections of Illinois. The severe regions were least frequent in the Central and Eastern Sections of the state.

The isopercentile patterns of these regions frequently assumed definable shapes, and, when enough of the region was in Illinois to allow definition, the shapes were always found to be elongated. The orientations of the major axes of the drought cores were classified and are listed in table 7. The preferred orientation was W-E, and all but

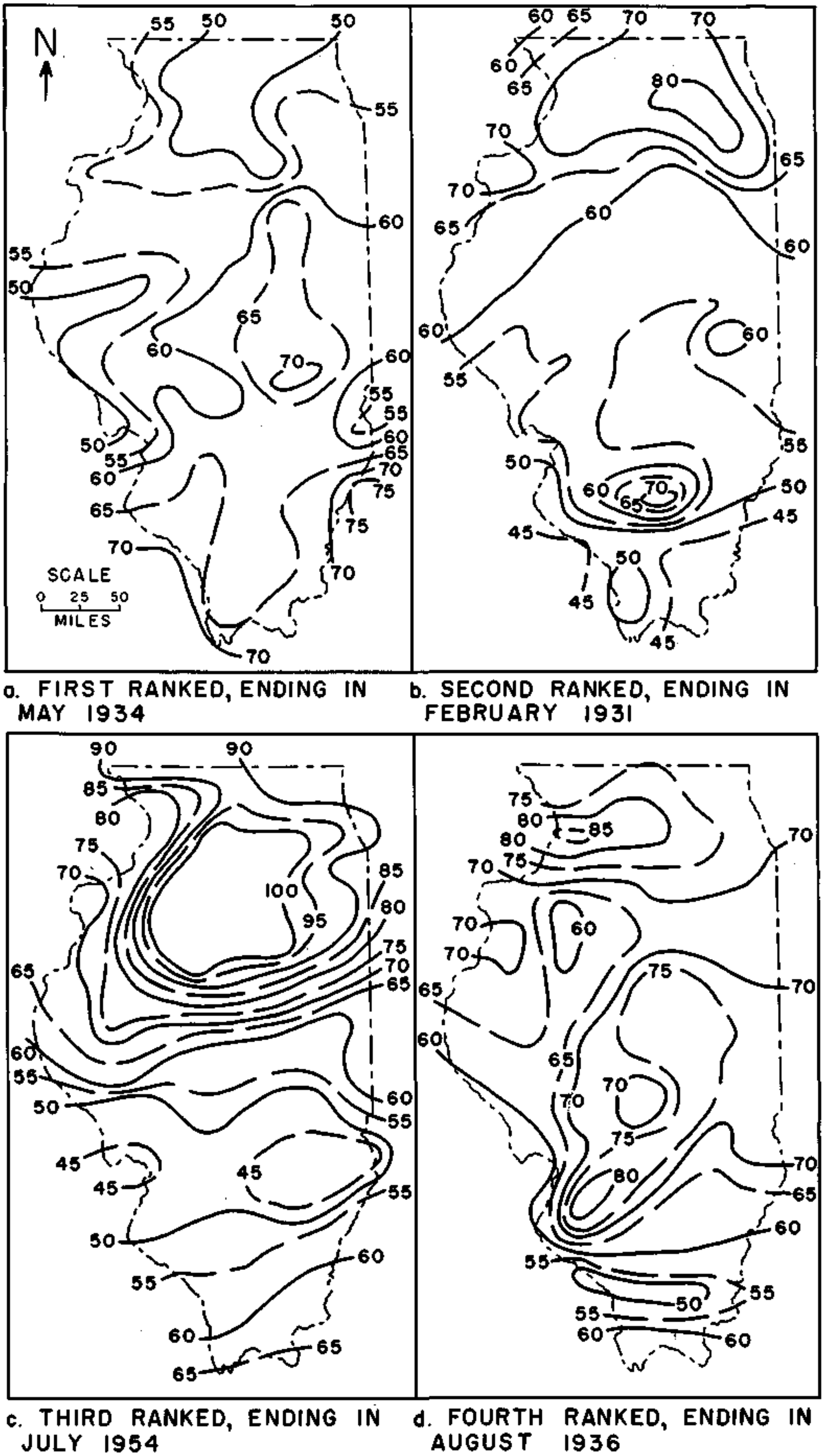


Figure 25. Four highest ranked 12-month droughts

one of the known orientations occurred in the arc from SSW clockwise through W. The region of greatest severity in 12-month droughts in Illinois most frequently is oriented W-E, and occurs in southern Illinois.

The average span or duration of the state-wide drought periods was 19 months for the 12-month droughts; that is, the maximum 12-month period of drought varied in time within the state, but everywhere was contained within a consecutive 19-month period. The median duration was also 19 months, and the longest span was 22 months recorded for the 1911, 1914, and 1921 droughts. The shortest span was 16 months recorded for the 1925, 1936, and 1954 droughts.

On a basis of the months when the peak periods of the 12-month droughts began and ended, most 12-month droughts began in the June-September period and ended in the May-August period. The influence of the 6-month droughts, which occur primarily in the colder half-year, is responsible for this centering of 12-month droughts around the winter season. Only two peak periods began in the winter months and only one in a fall month.

The times between the ending months of peak periods and the beginning months of ensuing peak periods were listed chronologically for all 11 droughts. Examination of these intervals indicated no cycles of drought occurrence. The average duration between peak drought periods was 40 months and the median was 28 months. The longest period without a 12-month drought was 146 months. The shortest period occurred with overlapping droughts when the 1941 drought in southern Illinois began during the tenth month of the 1940 drought which occurred primarily in northern Illinois. Three of the four worst 12-month droughts in Illinois occurred in the 6-year period beginning in 1930. In the 11.5-year period beginning in 1930, which represents 23 percent of the period investigated, five or nearly 50 percent of all 12-month droughts occurred. No other comparable period of drought frequency occurred in the 1906-1955 period.

In figure 26 probabilities for the time between the termination of one 12-month drought and the initiation of another drought are shown. Figure 26 reveals that 30 percent of the time a 12-month drought will begin within 12 months after another drought terminates. Eighty percent of the time another 12-month drought will begin within 96 months after one terminates.

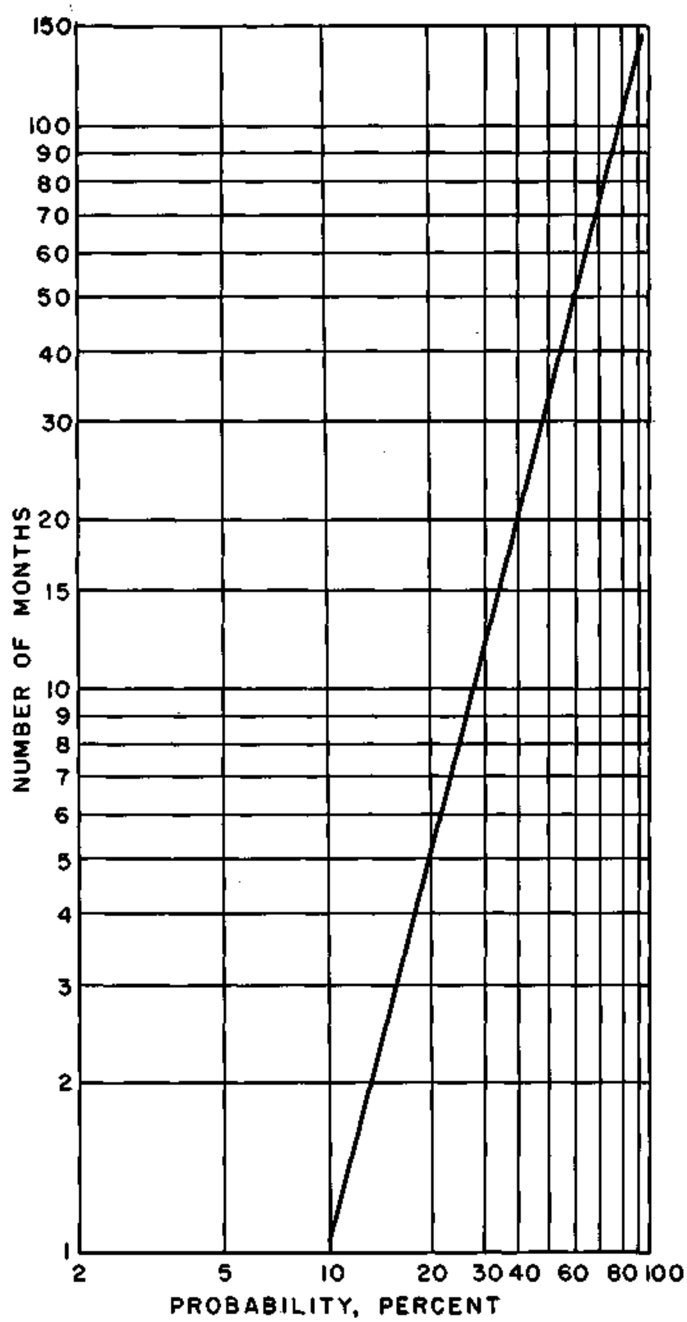


Figure 26. Probability that a 12-month drought will occur within a number of months after a 12-month drought terminates

24-Month Droughts

The regional and temporal patterns of the severest 24-month droughts, as based on the first and second ranked droughts at each of the 62 stations, are shown in figure 27. Figure 27a reveals that six 24-month droughts were responsible for all of the first ranks at individual stations. Based on regional extent of first ranks, the 1915, 1941, and 1954 droughts were most extensive. Comparison of these temporal patterns with those in figure 27b reveals that the 1941 drought ranked second in the area where the 1954 drought ranked first, and, conversely, the 1954 drought ranked second in extreme southern Illinois where the 1941 drought was ranked first. The 1931 drought was ranked first in only a small portion of extreme northwest-

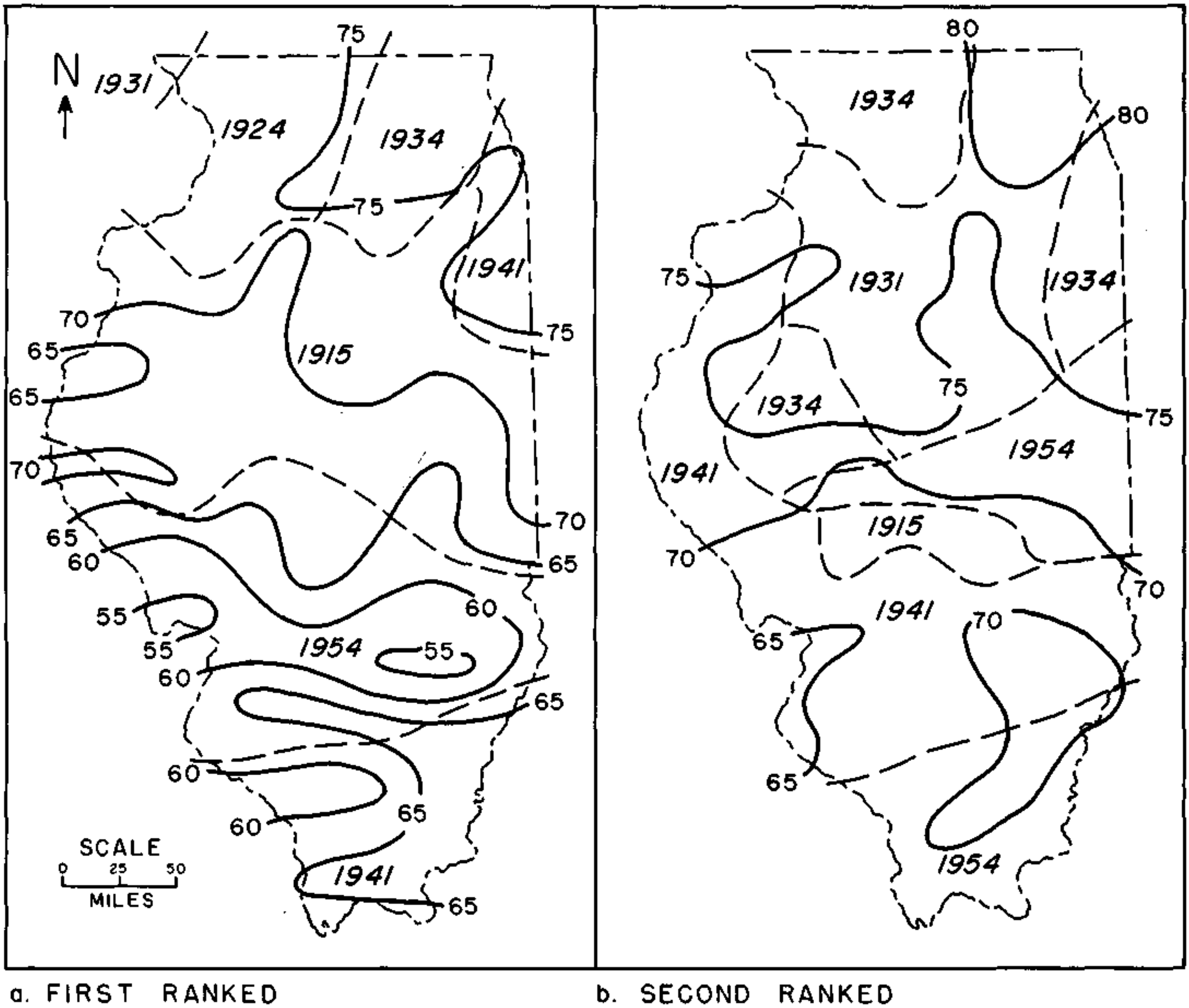


Figure 27. Ending dates and percent of normal precipitation values for first and second ranked 24-month droughts

ern Illinois, but ranked second throughout large portions of north-central Illinois. The 24-month droughts ending in 1915, 1924, 1931, 1934, and 1941 were the severest in the northern half of Illinois, whereas those in 1941 and 1954 were most severe in the southern portions of the state. The 1941 drought was the only one to achieve first and second ranks in northern and southern Illinois; the other notable 24-month droughts were more restricted to specific regions. Severe 24-month droughts in southern Illinois appear to be more widespread than those elsewhere, and this is the reverse of the condition found with 3- and 6-month droughts.

The isopercentile patterns displayed by the rank 1 and rank 2 values are similar. The lowest values on both maps are present in the southwestern portion of the state. This is the same area where the state's lowest values were obtained for the severest 3-month (figure 18), 6-month (figure 21), and 12-month (figure 24) droughts. However, the isopercentile maps for these shorter duration droughts all revealed a secondary area of low percentages in north-central Illinois, but this area is not apparent on the 24-month drought maps. This secondary low in the droughts of 3- to 12-month durations was due to the severity of the 1931 and 1934 droughts in that region. Although these

Table 8. Characteristics of the Nine 24-Month Droughts in the 1906-1955 Period

Rank	Drought span	Ending month of peak period	State average percent of normal	Lowest percent	Number of 1-5 ranks	Areas of peak severity: Section location	Areas of peak severity: Pattern orientation
1	8/38-8/41	8/41	75	57	46	WSW,ESE,SW,SE	WSW-ENE
2	9/12-6/15	4/15	76	63	38	W,C,E,WSW,ESE;	WNW-ESE
						and SW	Unknown
3	8/29-4/32	7/31	77	66	42	C,WSW,ESE,SW,SE;	W-E
						and W,NW	WSW-ENE
4	12/51-11/55	7/54	77	53	27	WSW,ESE,SW,SE	W-E
5	6/32-5/35	8/34	84	70	20	W,WSW,NE,NE	Unknown
6	2/16-8/19	8/18	84	70	16	WSW,ESE;	W-E
						and NW	Unknown
7	10/20-8/24	5/24	87	74	16	W,NW	SW-NE
8	6/23-8/26	7/26	87	66	15	SW,SE,ESE	SW-NE
9	6/09-12/12	7/12	88	70	14	NW;	NW-SE
						and C,E	WNW-ESE

droughts were the severest 24-month droughts in north-central Illinois, they were not sufficiently severe to produce an area of low percentages detectable on the isopercentile pattern.

The highest percentages in figure 27 are located in the northeastern portion of Illinois. These percentages are from 25 to 45 percent greater than the lowest 24-month percentages.

On the basis of data from the four severest 24-month droughts, the frequency of months with above and below normal precipitation amounts was determined for the 12 stations with lowest departures in each drought. Of the 1152 total station months (24 x 12 x 4) investigated, 932 or 81 percent had below normal precipitation. On a seasonal basis, 90 percent of all summer months were below normal, as were 86 percent of the spring months, 75 percent of the fall months, and 73 percent of the winter months.

A similar investigation of the frequency of below and above normal monthly mean temperatures for 10 stations revealed that 68 percent of all months during the peak periods of severe 24-month droughts experienced above normal temperatures. On a seasonal basis, above normal temperatures occurred most frequently in summer (82 percent) and winter (74 percent) and less frequently in fall (68 percent) and spring (45 percent). A severe 24-month drought typically has a predominance of months with below normal precipitation and above normal temperatures.

The more important characteristics of the nine 24-month droughts are described in table 8; temporal, regional, and severity factors are listed for each drought. Table 8 indicates there was very little statewide difference in the severity of the three worst 24-month droughts. All three had nearly equal statewide percentages and nearly equal numbers of stations at which these dry periods ranked 1 to 5 in severity. As shown in figure 28, none of the state had above normal percentages in these three droughts.

The drought ending in August 1941 was the worst 24-month drought. It evolved from two moderately severe 12-month droughts which occurred in close succession during the 1939-1941 period (table 7). The drought was concentrated in the southern one-third of the state with a low of 57 percent of normal recorded at DuQuoin (figure 1).

The second most severe 24-month drought ended-in April 1915 and was concentrated across central Illinois. A secondary area of severity occurred in extreme southern Illinois. This drought evolved from the fifth ranked 12-month drought which was concentrated in central Illinois. The lowest station values in this drought were 63 and 64 percent of normal at Tuscola and La Harpe (figure 1), respectively.

The third ranked drought which ended in July 1931 was characterized by an area of major severity in central and southern Illinois and another smaller severe area in western and north-western Illinois (figure 28c). The area of greater than 75 percent of normal located in south-central Illinois separates the major areas of severity. In the area south of this separation, the drought terminated in September 1931 rather than July 1931. This third ranked drought resulted largely from the second ranked 12-month drought (table 7) which ended in February 1931. The lowest station percentage in this drought was 66 percent at White Hall and at Harrisburg, which are widely separated (figure 1).

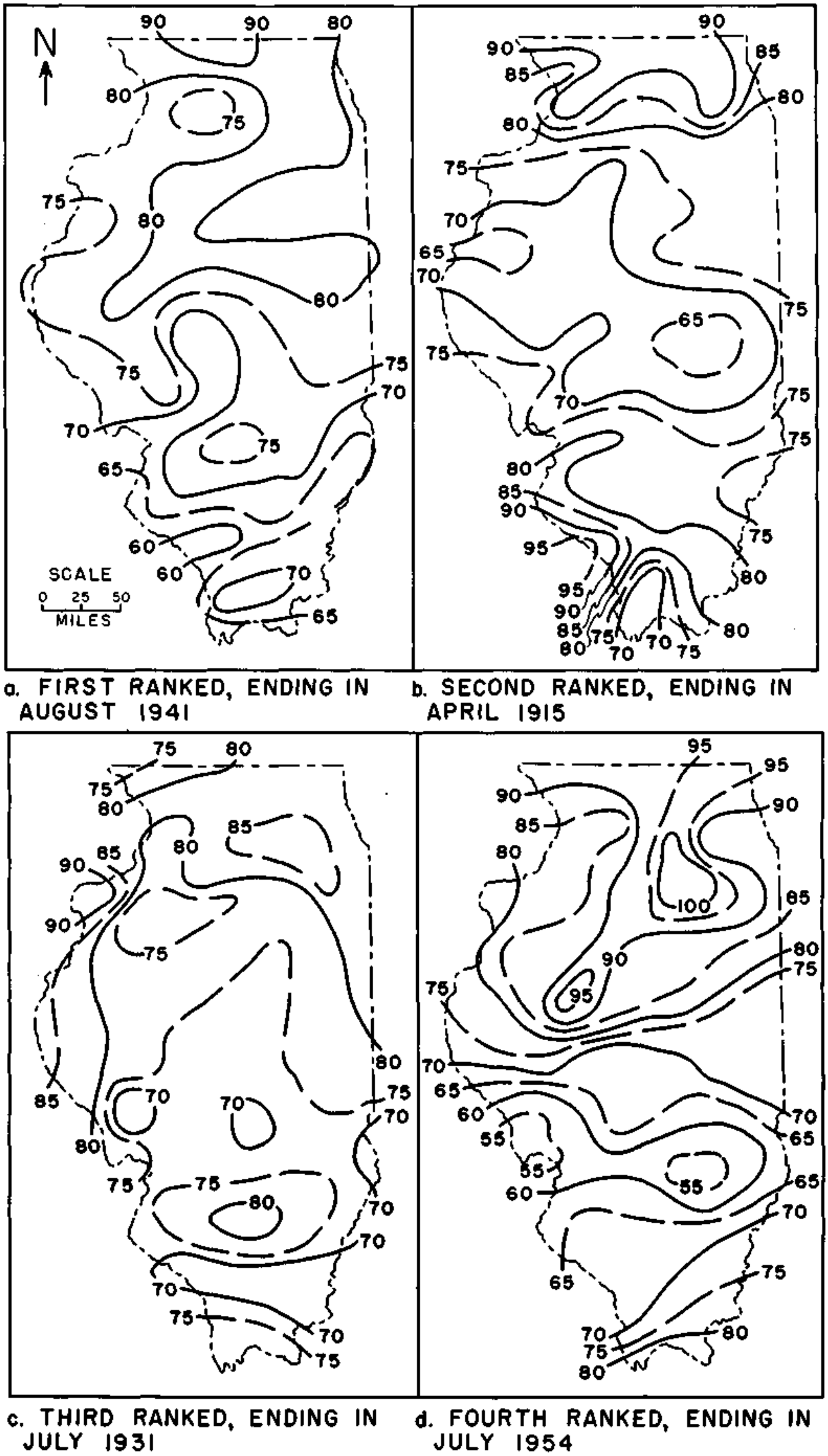


Figure 28. Four highest ranked 24-month droughts

Several conditions unusual in 24-month droughts occurred in the fourth ranked drought which ended in July 1954 (figure 28d). This drought recorded the lowest station percentage (table 8) of any 24-month drought, 53 percent of normal at both Grafton and Flora. Of the four severest 24-month droughts, the 1952-1954 drought was the only one in which portions of the state had above normal precipitation. The highest percentage was 112 percent of normal at Aurora, and near normal percentages occurred throughout most of northern Illinois. In four of the remaining five 24-month droughts, portions of Illinois had above normal precipitation.

For each of the regions of greatest severity in the nine 24-month droughts, abbreviated geo-gr-aphical-geometric descriptions were prepared. Four of the droughts had two distinct areas of severity, and descriptions of these 13 areas appear in table 8.

The geographical distribution of the severe regions were recorded according to the nine areas depicted in figure 1. The regions of severe drought occurred most frequently in South-Central, Southwestern, and Northwestern Sections. These regions of severity occurred least frequently in Northeastern and Eastern Sections.

The long axis of these elongated severe regions was determined when possible, and data in table 8 reveal the major axial orientations to be most frequently in the arc from WSW-ENE through W-E to WNW-ESE. The typical severe 24-month drought is elongated, has an E-W major axis, and occurs in south-central Illinois.

Temporal data for the 24-month droughts are available -for the entire drought span in Illinois and for the peak period (most severe 24 months) of the droughts. The average span or duration of the statewide drought periods was 40 months, and the median duration value was 39 months. The longest span was 48 months (July 1954 drought) and the shortest 33 months (July 1931 drought).

Analysis of the months when the peak periods began and ended revealed that seven began in either August or September. The remaining two peak periods began in the spring months. Thus, all the peak periods of 24-month droughts incorporate two complete colder half-years and only one complete warmer half-year. For 6-month and longer periods, significant departures from normal precipitation occur most frequently in the cold season in Illinois, and these cold season departures strongly affect the time distribution of droughts of 12 months and longer.

The elapsed times between the ending month of the peak periods and the beginning month of ensuing peak periods were listed on a chronological basis for all nine droughts. No cycles of occurrence were apparent. The average interval between peak periods of drought was 39 months and the median was 26 months. The longest interval without a peak period of a 24-month drought was 131 months and the shortest was 2 months.

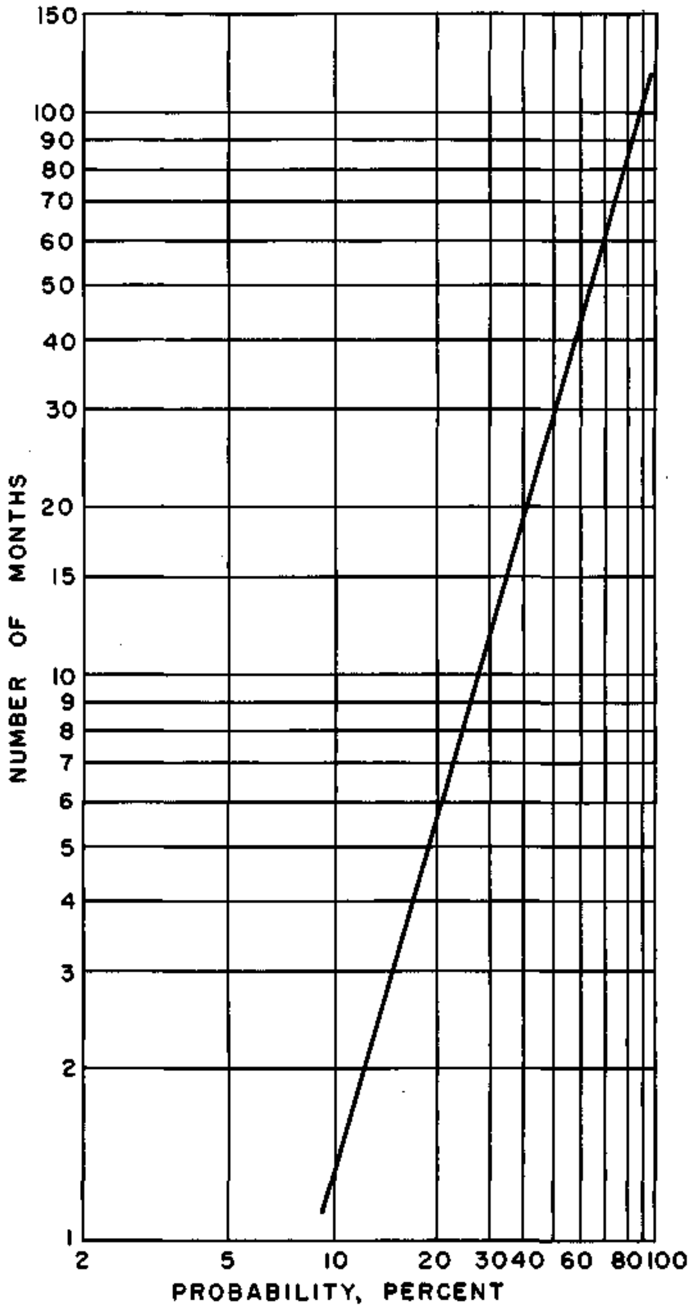
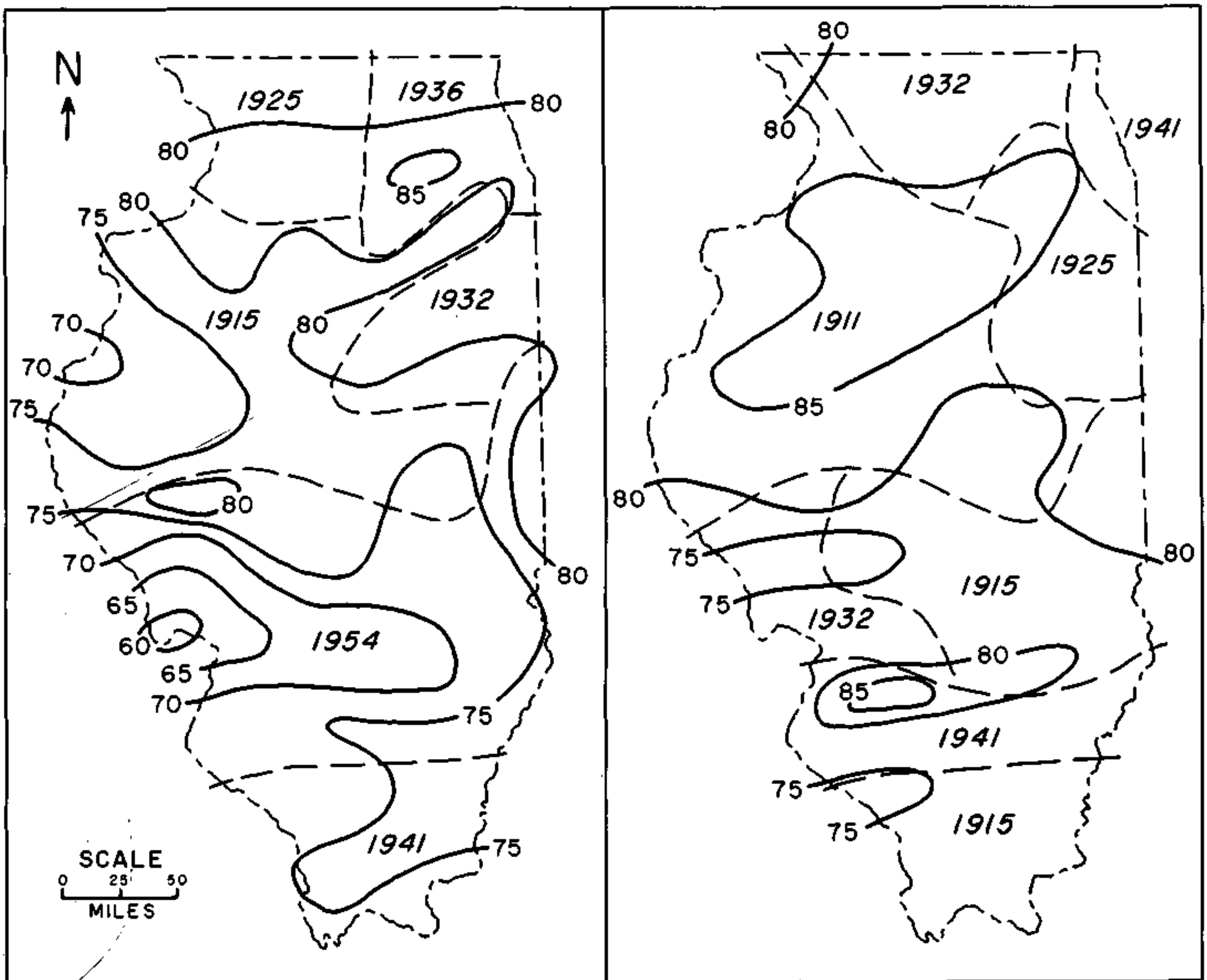


Figure 29. Probability that a 24-month drought will occur within a number of months after a 24-month drought terminates

Figure 29 shows the probabilities for the time between the termination of one peak period and the initiation of another, fitted to a Frechet distribution. Examination of this figure reveals that 30 percent of the time a 24-month drought peak period will begin within 12 months after another terminates. Seventy percent of the time a 24-month peak period will begin within 60 months after another terminates.



a. FIRST RANKED b. SECOND RANKED

Figure 30. Ending dates and percent of normal precipitation values for first and second ranked 36-month droughts

Table 9. Characteristics of the'Eight 36-Month Droughts in the 1906-1955 Period

Rank	Drought span	Ending month of peak period	State average percent of normal	Lowest percent	Number of 1-5 ranks	Areas of peak severity: Section location	Areas of peak severity: Pattern orientation
1	1/12-11/16	4/15	84	69	35	W,WSW,C,E,ESE,SE	NW-SE
2	7/51-12/55	11/54	85	58	29	E,WSW,ESE,SW,SE	W-E
3	3/28-2/33	7/32	86	73	34	WSW,C,ESE;	SW-NE
						and SW,SE	W-E
4	4/38-4/42	8/41	86	70	30	SW,SE,WSW	W-E
5	5/22-12/26	5/25	87	75	30	NW,NE;	SW-NE
						and SW,SE,ESE	Unknown
6	7/32-10/36	8/36	87	75	30	WSW,SW,SE,NW,NE	Unknown
7	6/08-5/12	8/11	89	79	22	NW,W,C,E	NW-SE
8	3/15-10/20	8/19	91	78	20	WSW,SW	NW-SE

36-Month Droughts

The regional and temporal patterns of the most severe 36-month droughts are shown in figure 30. The patterns displayed on this figure are based upon data for the first and second ranked droughts at each of the 62 stations used in the study.

Figure 30a shows the distribution of the first ranked or worst droughts and reveals that six droughts were responsible for all the first ranked station values in Illinois. The 36-month droughts ending in 1954 and 1915 were the most extensive. Comparison of the temporal drought data in figure 30a with that in figure 30b indicates that the drought ending in 1915 assumed second rank severity throughout much of southern Illinois. The 1932 drought achieved second rank importance in northern and southwestern Illinois. Interestingly, the 1954 drought which produced first rank values over a large area did not achieve second rank stature at any station.

The isopercentile pattern displayed in figure 30a indicates that the severity of the 1954 drought was greatest in southwestern Illinois. The lowest percentage of normal was 58 percent recorded at Grafton (figure 1). The effect of the 1915 drought also is shown by the 75-percent line in western Illinois. This isopercentile pattern based on the second ranked droughts (figure 30b) has little areal variation in percentage values. Again the state's lowest values are shown in southwestern Illinois. On both maps, the highest state percentages are found in north-central Illinois.

The frequencies of months with above and below normal temperatures and precipitation values were determined for the peak periods of the four severest 36-month droughts. The monthly mean temperatures were above normal 69 percent of the time and monthly precipitation values were below normal 75 percent of the time. On a seasonal basis, monthly temperatures were above normal most frequently in the summer (76 percent) and winter (76 percent) and least frequently in the fall (71 percent) and spring (52 percent). Months with below normal precipitation during severe 36-month droughts occurred most frequently in spring (80 percent) and summer (78 percent) and least frequently in fall (73 percent) and winter (68 percent). As with the severe droughts of shorter durations, the 36-month droughts were periods with a predominance of months with above normal temperatures and below normal precipitation. However, these predominant monthly conditions were slightly less frequent in the 36-month droughts than they were in the shorter droughts.

Abbreviated descriptions of the eight 36-month droughts are presented in table 9, which includes temporal, regional, and severity data for each drought. In the statewide average percentage of normal there is very little difference between the eight droughts. Somewhat greater variation occurred with the number of 1-5 ranks and lowest station percentages. The drought ending in 1941 was the only 36-month drought in which above normal precipitation was not experienced somewhere in Illinois.

The drought ending in April 1915 was the worst 36-month drought (figure 31a). It did not have station percentages as low as some recorded in the 1954 drought, but the 1915 drought had a slightly lower statewide percentage of normal and also had many more stations with l-to-5 ranks than did the 1954 drought. As shown in figure 28, this drought evolved from the second ranked 24-month drought and to some extent from the ninth ranked 24-month drought. As shown in table 8, these two 24-month droughts had regions of severe drought which overlapped in central and eastern Illinois.

The second most severe 36-month drought ended in November 1954. This drought, as shown in figure 31b, was concentrated in south-central Illinois. Percentages of normal precipitation increased rapidly to the north and south of this W-E oriented drought. In areas of lesser severity this drought ended during the spring and summer months of 1955.

The third ranked drought (figure 31c) also was most severe in southern Illinois with a low value of 73 percent of normal at White Hall. As with the 24-month drought ending in July 1931 from which this drought evolved, the severe area in southern Illinois was separated by an area of higher percentages centered in the Mascoutah-Mt. Vernon (figure 1) region.

The fourth ranked drought, which ended in August 1941, was only slightly less severe than the 1932 third ranked drought. As table 9 shows, both droughts had equal statewide average percentages and only a slight difference in the number of l-to-5 ranks. The 1941 drought was also concentrated in southern Illinois with a low value of 70 percent at DuQuoin. This was the only 36-month drought without some portion of the state experiencing above normal precipitation. However, Rockford and Dubuque had 96 percent of their normal precipitation for the period.

Descriptions of the regions of greatest severity in the eight droughts are presented in table 9. Two of the droughts had two separate areas of severity, The geographical distribution of the severe regions within the state were recorded according to the nine climatological sections depicted on figure 1. The regions of severe drought were found to occur most frequently in Southwestern and Southern Sections. The Western and Northeastern Sections experienced severe droughts least frequently. Isopercentile patterns of the 36-month

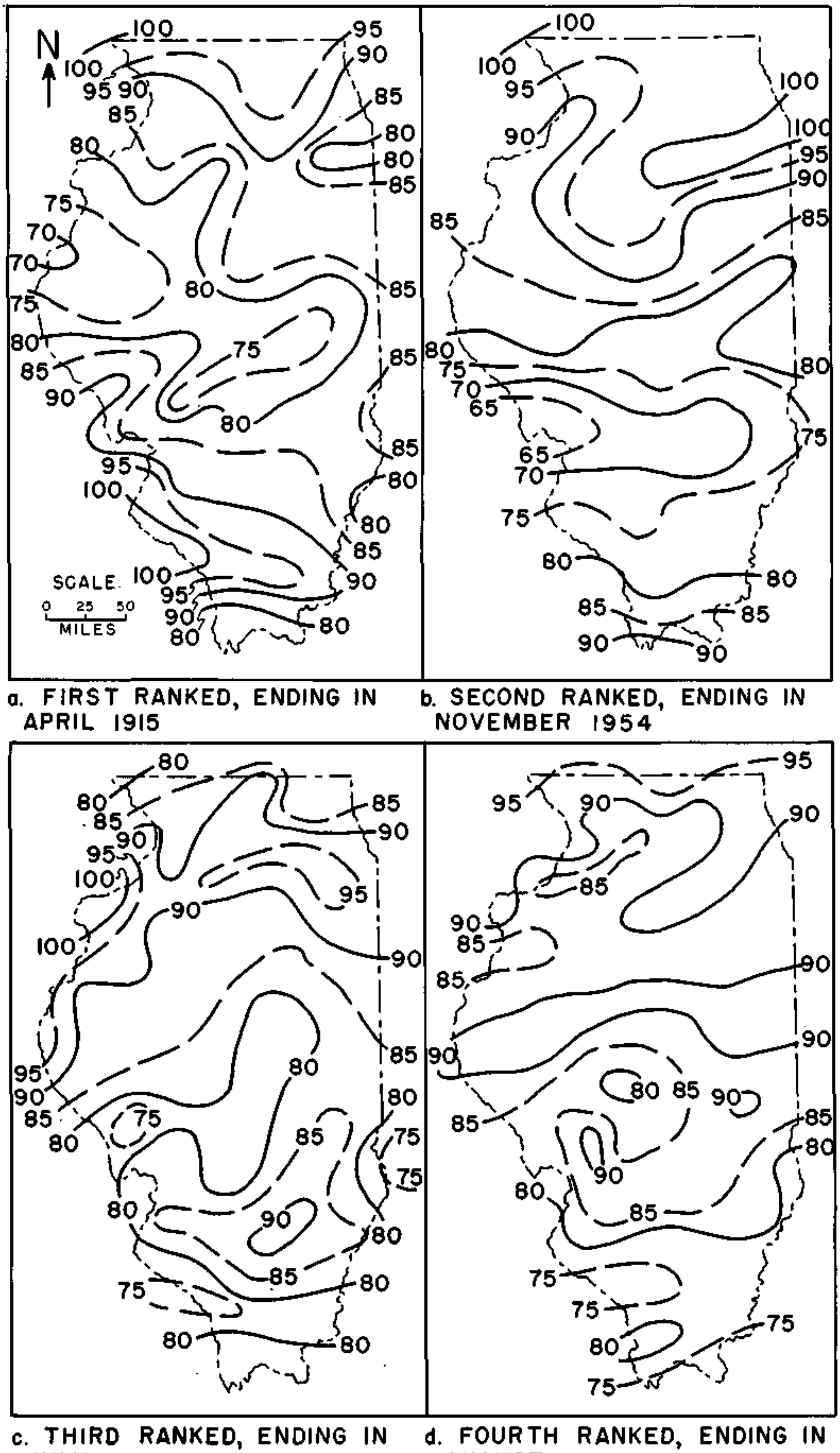


Figure 31. Four highest ranked 36-month droughts

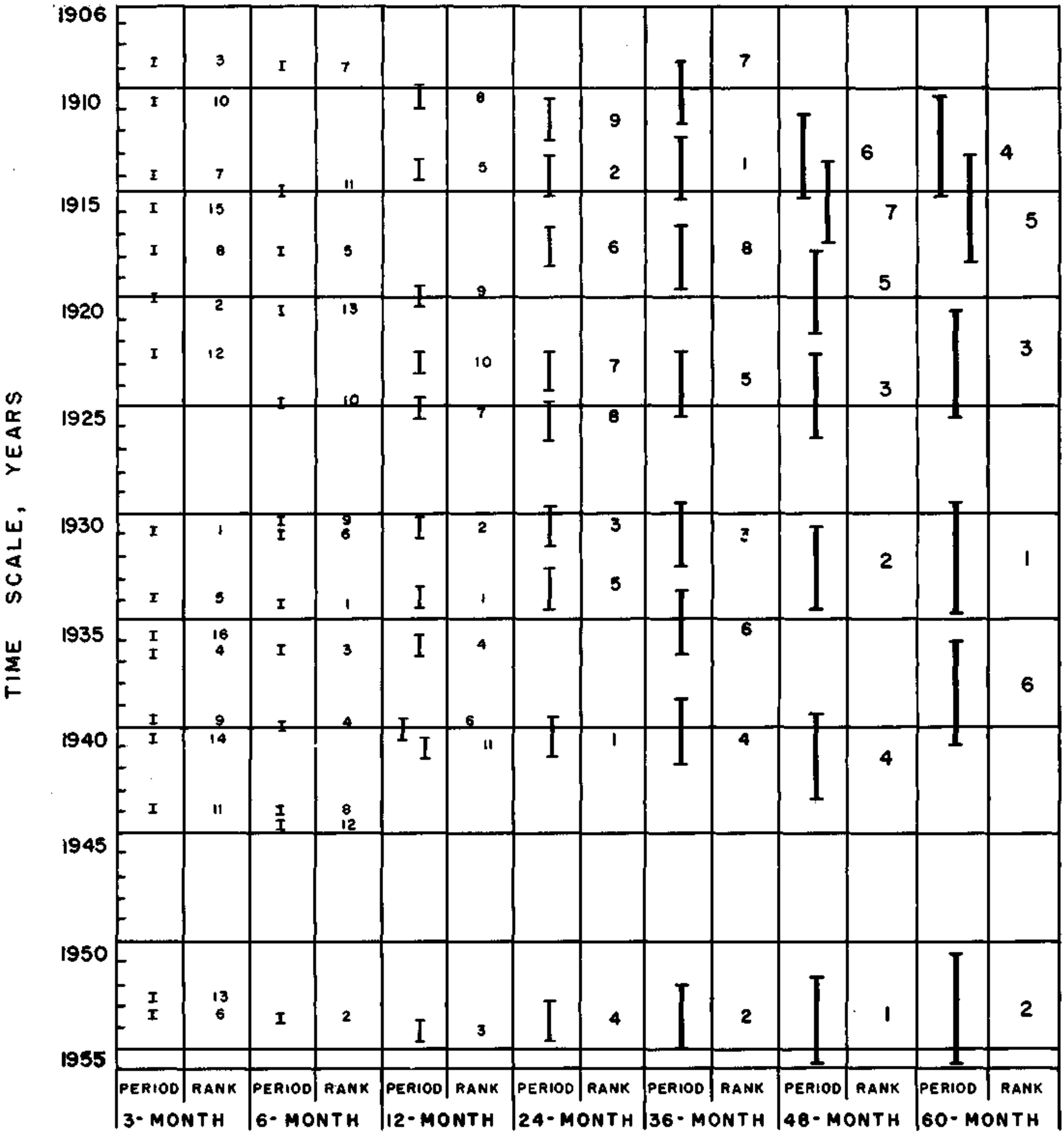


Figure 32. Time scale for peak periods of droughts, 1906-1955

regions of severity did not fall into identifiable geometric shapes. However, most of the severe regions were elongated, and an orientation of the axis of elongation could be determined for many of them. As shown in table 9, most of the regions had either W-E or NW-SE orientations. In the shorter duration droughts the preferred orientations were SW-NE rather than NW-SE.

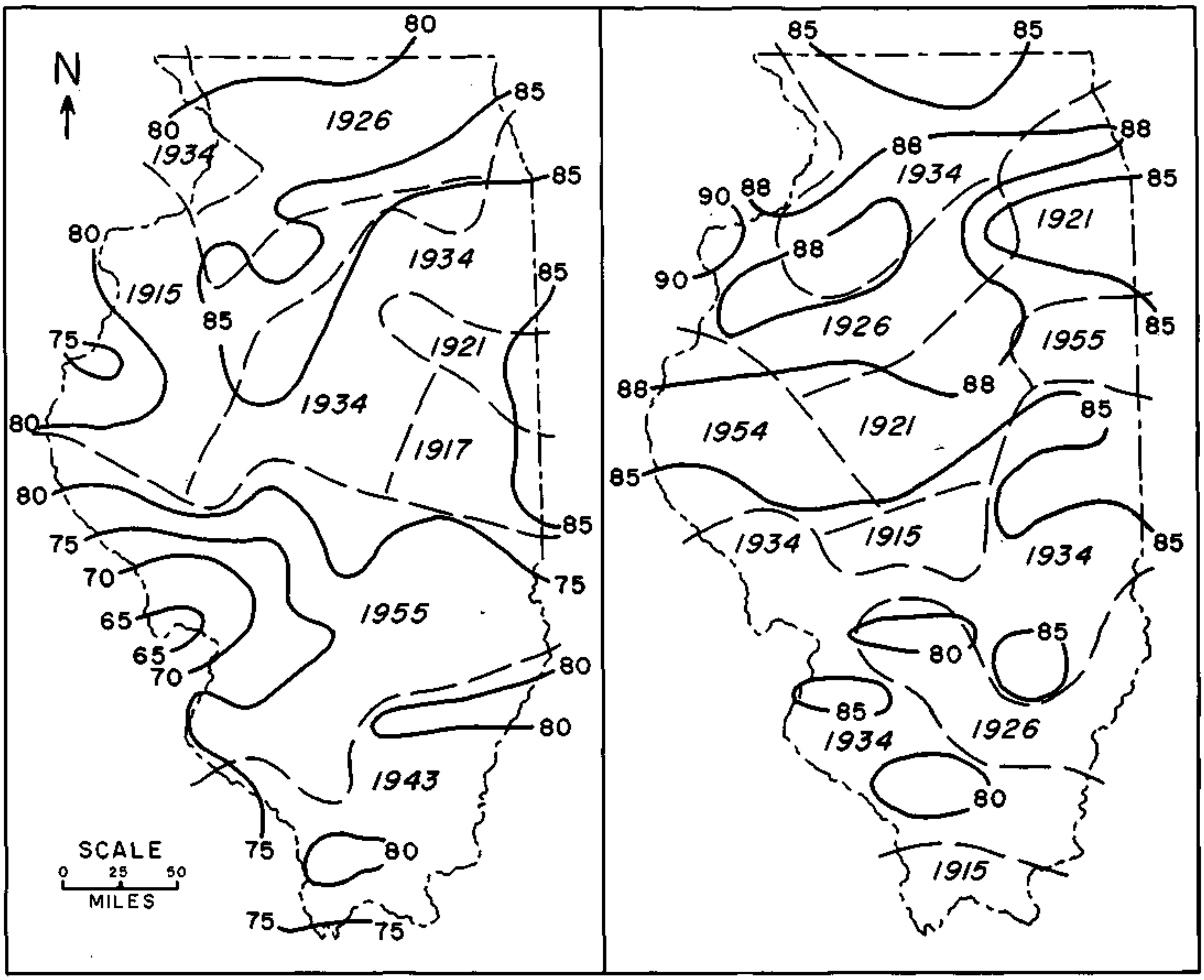
Temporal data for the droughts show that the average drought span of the eight droughts was 54 months. The median duration was 53 months, the longest 68 months, and the shortest 48 months.

Analysis of the months when the peak periods began revealed that five of the droughts began in the August-September period and two began in the May-June period. The summer season beginning preference was in agreement with findings for the 12- and 24-month droughts. Most 36-month droughts encompassed three complete winter periods, two complete summer periods, and only portions of two other summer periods. As with the shorter duration droughts, the dry winter season conditions exerted more influence on time of occurrence for 36-month droughts than did any of the other seasons.

Reference to figure 32 indicates the general time intervals between the eight 36-month droughts. Elapsed time between the peak periods varied from a low of 8 months between the 1911 and 1915 droughts to a high of 135 months between the 1941 and 1954 droughts. With the 50-year period of data no cycle of 36-month droughts was apparent. The average elapsed time between drought peak periods was 39 months and the median value was 24 months.

48-Month Droughts

The regional and temporal patterns for the most severe 48-month droughts in Illinois are depicted in figure 33. The map patterns are based upon station data for the first and second ranked droughts at each of the 62 stations.



a. FIRST RANKED b. SECOND RANKED

Figure 33. Ending dotes and percent of normal precipitation values for first and second ranked 48-month droughts

Table 10. Characteristics of the Seven 48-Month Droughts in the 1906-1955 Period

						Areas of peak severity	
Rank	Drought span	Ending month of peak period	State average percent of normal	Lowest percent	Number of 1-5 ranks	Section location	Pattern orientation
1	1/50-12/55	8/55	88	62	34	WSW,ESE,SW,SE	W-E
2	7/27-10/34	5/34	89	78	40	NW,NE,E, C, WSW;	NNW-SSE
						and SW,SE	Unknown
3	6/20-8/26	5/26	89	79	37	NW,NE;	NW-SE
						and ESE,SE	W-E
4	10/36-8/43	4/43	91	74	30	SW,SE	Unknown
5	9/15-8/21	7/21	92	83	31	WSW;	Unknown
						and NE	NNW-SSE
6	2/10-4/15	4/15	93	74	24	W,NW,WSW	Unknown
7	8/12-3/18	3/17	96	78	17	E,ESE,SE	NNW-SSE

Figure 33a portrays the pattern for the first ranked or worst droughts. There were seven 48-month droughts in the 1906-1955 period, and each of these was ranked first in some portion of the state. Those ending in 1926, 1934, 1943, and 1955 were the most extensive. Comparison of figure 33a with figure 33b reveals that the 1934 drought ranked first or second in much of Illinois. The 1926 drought ranked second in severity in extensive areas.

The isopercentile pattern in figure 33a reveals the great severity of the 48-month drought ending in 1955. The area where this drought achieved first rank has markedly lower percentages of normal than those found elsewhere in Illinois. In fact, the remaining portion of the state has very little variation in percent of normal which indicates that there was very little difference in the first ranked values obtained from the other droughts. The 1915 and 1943 droughts had small areas of moderate severity as revealed in the isopercentile patterns. The isopercentile pattern for the second ranked droughts (figure 33b) has an extremely flat gradient with the lowest values found in southern Illinois and the highest in north-central Illinois. The lowest value for these second ranked station values was 78 percent of normal at DuQuoin and the highest was 90 percent of normal at Aledo (figure 1). In comparison, the extreme values for the first rank category ranged from a low of 62 percent at Grafton to a high of 88 percent of normal at Peoria and Chicago.

Data describing the seven 48-month droughts are listed in table 10. The statewide pattern of the average percent of normal precipitation reveals very little significant difference between most of these droughts. Some portions of the state had above normal precipitation in all of the seven droughts. The 48-month droughts in Illinois are considerably less severe than those of shorter durations.

The frequencies of months with above and below normal temperatures and precipitation values were ascertained for the peak periods of the four severest 48-month droughts. Above normal monthly mean temperatures occurred 63 percent of the time and below normal monthly precipitation values occurred 70 percent of the time in the region of greatest drought severity.

Figure 34 shows isopercentile maps of the four worst droughts. The one ending in August 1955 was the worst or first ranked 48-month drought in Illinois. Although this drought did not have as many stations for which the drought ranked 1 to 5 as did the 1934 and 1926 droughts, it did have the lowest statewide percent of normal and lowest station percentage of any 48-month drought. As with the shorter duration droughts from which it evolved (figure 31), the area of greatest severity in this drought had an E-W axis across south-central Illinois. Positive departure from normal in this drought was greatest at Rockford which had 106 percent of normal precipitation for the period.

The second ranked drought (figure 34b) ended in May 1934. This 48-month drought evolved from two rather severe 36-month droughts (figure 31). The regions of lowest percentages occurred along a N-S axis from northern to extreme southern Illinois. The lowest departure was 78 percent of normal in the extreme northwest corner of the state. Areas with above normal precipitation during this drought occurred in western and northeastern Illinois. Aledo with 110 percent of normal had the greatest positive departure. The elongated pattern of severity in this 48-month drought was the result of features found in the two 36-month droughts which combined to form it; that is, the July 1932 drought (figure 31c) was severe in central and southern Illinois and the August 1936 drought (table 9) was severe in northern and southern Illinois. This 48-month drought had a greater number of stations with ranks of 1-5 than any

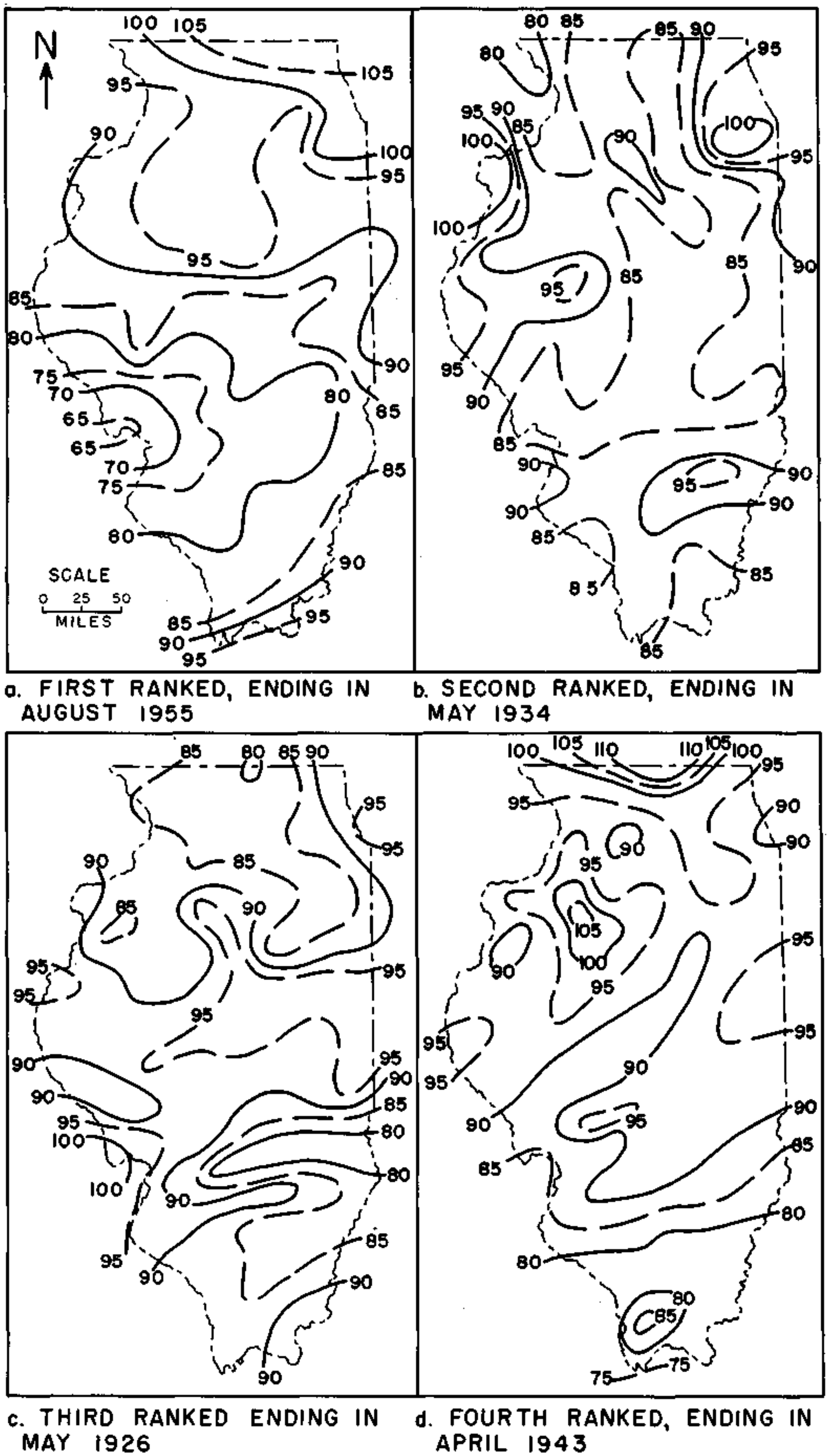


Figure 34. Four highest ranked 48-month droughts

other 48-month drought.

The third ranked drought ended in May 1926. Although the ending month of the peak period was May 1926, portions of the drought area in northwestern Illinois terminated in May 1924. This drought evolved from a slightly less severe 36-month drought which terminated in May 1925 (table 9). The area of lowest percentages occurred in southern Illinois (figure 34c) where Greenville and Palestine both recorded 79 percent of normal precipitation. This drought was also quite extensive in northern Illinois where it ranked first at many stations. Although more severe on a percentage basis in southern Illinois, the drought ranked second in most regions, especially through the area where the 1955 drought was so severe (figure 34a). The highest station percentage in this drought was 102 percent recorded at Grafton (figure 1).

The fourth ranked drought (figure 34d) was concentrated in southern Illinois. This drought ended in April 1943 and resulted primarily from the fourth ranked 36-month drought which ended in August 1941. The lowest station percentage was 74 at Cairo. Large portions of northern Illinois had above normal precipitation in this drought; the statewide high of 120 percent occurred at Rockford.

The sixth and seventh ranked 48-month droughts exhibit an interesting time-space relationship. As shown in table 10, there was a considerable time overlap in their drought spans. These closely aligned periods were separated into two droughts because data for the stations between the two drought zones indicated no gradual time transition; furthermore, many of these intervening stations had above normal precipitation for drought ending dates. The 1915 drought was extremely severe in western Illinois, but stations in central Illinois did not record below normal precipitation. The 1917 drought was concentrated in eastern Illinois, but stations in southern, western, and northern Illinois had above normal precipitation for the period. Stations such as Bloomington and Springfield, located between these two drought areas, did not experience below normal precipitation in either period. Thus, a 48-month drought in Illinois can be very localized.

The descriptions of the regions of greatest severity in the seven droughts are presented in table 10. Three of the droughts had two separate regions of maximum severity. The geographical distribution of the regions were recorded according to the nine areas depicted on figure 1. In five of the seven droughts the Southeastern Section was part of a severe region, and in four cases the West-Southwest Section was in the central portion of the drought. Regions of outstanding severity in the 48-month droughts occurred infrequently in Central and Western Sections. There was a preference for nearly N-S orientations in four of the six regions in which the major axis of the region of maximum severity could be identified.

The average span of time encompassed in a 48-month drought was 73 months and the median value was 72 months. The longest span in any drought was 88 months in the 1934 drought, and shortest span was 60 months in the 1955 drought.

Peak periods of all seven 48-months droughts began in the April-September period with five of these beginning in the April-June period. The preference for the beginning of these droughts in the late spring and summer months is in agreement with the findings for the shorter duration droughts. A general impression of the elapsed time between the peak periods of the 48-month droughts can be gained by examining figure 32. The actual elapsed time between peak periods varied from a low of no months (overlapping 1915-1917 droughts) to a high of 100 months between the 1943 and 1955 droughts.

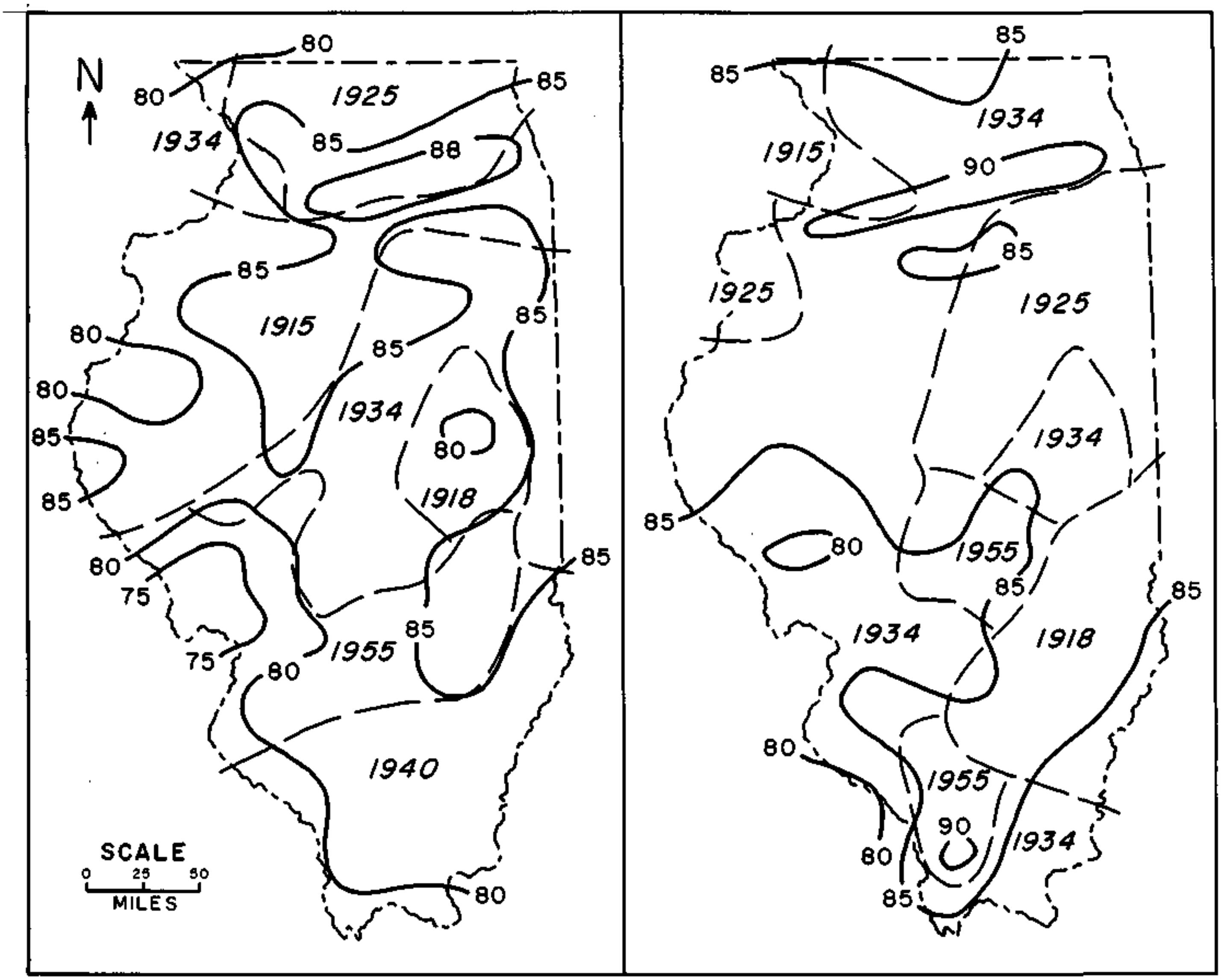
60-Month Droughts

The regional and temporal patterns of the most severe 60-month droughts are portrayed in figure 35 for the first and second ranked droughts listed at each of the 62 stations used in this drought study.

In figure 35a the patterns are based on the first ranked or most severe 60-month droughts in Illinois. Six droughts of 60-month duration occurred in the 1906-1955 period, and each of these ranked first at some stations.

The 1915, 1934, 1940, and 1955 droughts were more extensive than those ending in 1918 and 1925. Comparison of the temporal data in figure 35a with that in figure 35b reveals that the 1934 drought was recorded as the first or second ranked drought over a large area of the state, making this drought the most widespread severe drought.

The isopercentile pattern in figure 35a indicates that the 1955 drought had lower percentages of normal than any other drought. The lowest station value was 70 percent at Grafton, and the highest station value was 90 percent at Aurora recorded in the 1925 drought. In general, the lowest percentages were found in southern, southwestern, and western Illinois, and the highest were located in northern and eastern Illinois. The isopercentile pattern based on the second ranked station values is portrayed in figure 35b. As with the first ranked station values, the lowest percentages occurred in southwestern Illinois and the highest in northern Illinois. The range in values ran from 79 percent at White Hall (figure 1) to 91 percent at Aurora. Interestingly, Anna located in the Shawnee Hills area of southern Illinois had a relatively high second rank value of 90 percent.



a. FIRST RANKED b. SECOND RANKED

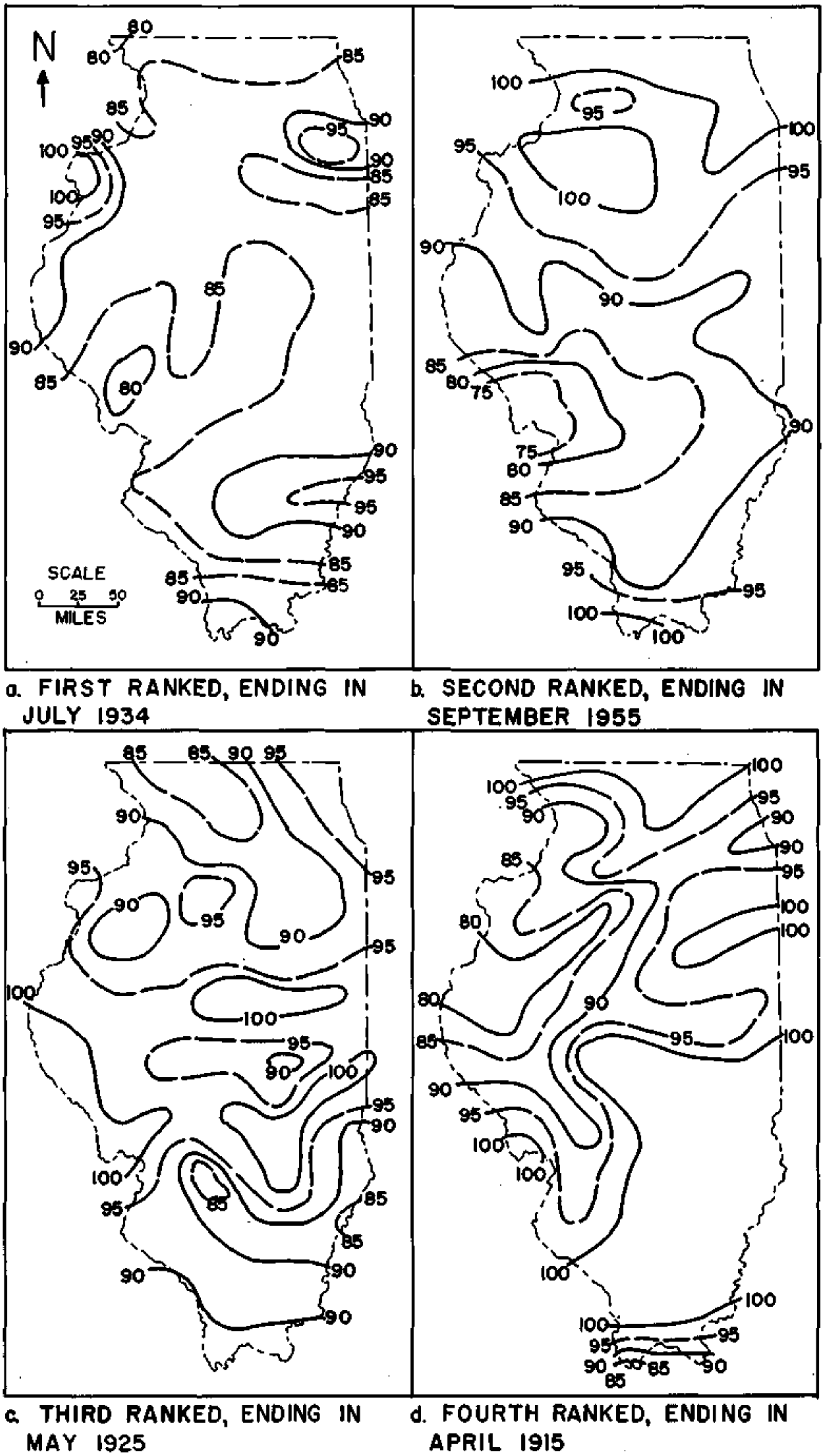
Figure 35. Ending dates and percent of normal precipitation values for first and second ranked 60-month droughts

A frequency analysis of the months with below and above normal precipitation and temperature for the four severest 60-month droughts indicated that months with above normal temperatures occurred 62 percent of the time in the peak periods whereas months with belownormal precipitation prevailed 70 percent of the time.

Descriptions of the six 60-month droughts are presented in table 11. The state average percentages of normal for the six droughts indicates very little difference existed between droughts. In all of the 60-month droughts certain portions of the state recorded above normal precipitation.

The drought ending in July 1934 was classified as the worst 60-month drought. It did not achieve station percentages as low as some in the 1955 and 1915 droughts, but the 1934 drought had the lowest statewide percentage of normal and the greatest number of stations with ranks of 1-5 (table 11). As shown in figure 34, this drought evolved from the second ranked 48-month drought. The lowest station percentage was 79 percent which occurred at Dubuque and at White Hall. The highest station percentage was 109 percent at Aledo. As shown in figure 36a, this drought affected large areas of the state including northern, southwestern, central, and southern Illinois.

The second ranked drought (figure 36b) ended in September 1955 and was extremely severe in south-central Illinois. This drought evolved from extremely severe shorter duration droughts occurring in the 1952-1955 period. Although quite severe in the southern area, this drought had near and above normal precipitation throughout the northern one-third of Illinois. The highest station value was 107 percent of normal at Chicago. Cairo



a. FIRST RANKED, ENDING IN JULY 1934

b. SECOND RANKED, ENDING IN SEPTEMBER 1955

c. THIRD RANKED, ENDING IN MAY 1925

d. FOURTH RANKED, ENDING IN APRIL 1915

Figure 36. Four highest ranked 60-month droughts

Table 11. Characteristics of the Six 60-Month Droughts in the 1906-1955 Period

Rank	Drought span	Ending month of peak period	State average percent of normal	Lowest percent	Number of 1-5 ranks	Areas of peak severity: Section location	Areas of peak severity: Pattern orientation
1	9/27-2/35	7/34	89	79	48	NW,NE;	Unknown
						and WSW,C,SW,SE	SW-NE
2	2/49-12/55	9/55	92	70	34	WSW,SW,ESE	W-E
3	6/19-12/26	5/25	93	81	36	NW,NE,E;	NW-SE
						and SW,SE	W-E
4	1/08-5/15	4/15	94	76	27	W,C;	WSW-ENE
						and SW	Unknown
5	7/12-6/19	3/18	95	79	24	NE,E,ESE,SE	N-S
6	10/35-7/41	11/40	96	82	25	W,WSW;	Unknown
						and SE	Unknown

in extreme southern Illinois had 106 percent of normal precipitation for this drought which indicates the degree to which this drought was confined to the south-central region.

The third ranked drought terminated in May 1925 (figure 36c) and was most severe in northern Illinois where Rockford had 81 percent of normal. A second area of outstanding severity occurred in southern Illinois where Greenville received only 82 percent of its normal 5-year precipitation. These two areas of maximum severity were separated by areas with near normal precipitation. For example, Grafton received 109 percent of its normal precipitation during this drought period.

The fourth ranked drought ended in April 1915 and was most severe in western Illinois. The close time proximity of this drought to the 1918 drought (table 11), which affected eastern Illinois, caused difficulty in deciding whether to separate these two periods into two droughts; however, stations lying between the regions of greatest severity of these two droughts had near normal precipitation and revealed no transition in their ending dates of lowest precipitation between 1915 and 1918. The lowest station percentage in the 1915 drought was 76 percent at LaHarpe.

Brief descriptions of the locations and orientations, if discernible, of the regions of greatest severity in the droughts are presented in table 11. The geographical locations were recorded according to the nine state climatological sections shown in figure 1. This analysis revealed that the areas experiencing regions of maximum severity most frequently were the Southwest, Southeast, West-Southwest, and Northeast Sections. Areas with the least number of occurrences of drought centers included the West, Central, and East Sections. Orientations of the major axis of the elongated regions of severity were determined where possible. The six definable orientations ranged from SW-NE clockwise to N-S with no evidence of a preferred orientation.

The spans of the 60-month droughts ranged from 70 months (1940 drought) to 91 months (1925 drought), and average span was 84 months.

Investigation of the peak periods revealed that all six droughts began in different months; these were April, May, June, August, October, and December. The prevalence of the beginnings in the spring and summer months is in agreement with the findings for droughts of shorter duration. The elapsed time between peak periods of the 60-month droughts varied from none (1915 and 1918 droughts) to 118 months between 1940 and 1955 droughts. No cycles in the occurrence of 60-month droughts were apparent.

Temporal Relationships

The climatological analysis of precipitation droughts indicated the existence of a time relationship between droughts of varying durations. It also indicated some relationship in the degree of severity between droughts related in time. The time position of droughts of varying duration is shown in figure 32 which depicts the calendar position of the peak periods of all droughts.

Examination of the data on figure 32 reveals that time relationships do exist between droughts, especially the higher ranked or more severe droughts. For instance, the high-ranked, long-duration droughts in the 1952-1955 period can be matched with severe short-duration droughts in this same period. The major drought during this period achieved statewide ranks varying from 1 to 4 in all durations except the 3-month duration where two lesser ranked droughts occurred. This particular drought apparently evolved principally from the very severe 6-month drought which ended in 1953.

The relationship between droughts in the 1929-1942 period is more complex than that between the 1952-1955 droughts. The first ranked 60-month drought in Illinois evolved from the second ranked 48-month drought, and these two droughts terminated at almost exactly the same time (late 1934). Interestingly, the 48-month drought ending in 1934 resulted from portions of two 36-month droughts, one of which (ending 1932) was the third ranked 36-month drought. Thus, the second ranked 48-month drought was a composite of portions of two separate dry periods which, when analyzed for 36-month durations, were defined as two droughts.

Figure 32 also reveals that these third and sixth ranked 36-month droughts each resulted primarily from severe 24-month droughts, which in turn had evolved from two 12-month droughts. However, these two droughts were higher ranked at the 12-month level than at the 24-month and 36-month levels. Tracing of these two droughts through the shorter durations reveals that the drought centered in the 1930-1931 period was composed of two moderately severe 6-month droughts but only one very severe 3-month drought. As with the 1952-1955 drought, these two droughts in the 1930-1934 period, which at the 48-month and 60-month durations became one drought, were derived from either severe 3-month or 6-month droughts, or both;

The comparison of the third ranked 60-month drought with the other drought durations in the 1921-1925 period reveals that at the 36-month level this drought was a composite of two moderately severe 24-month droughts. Each of these had derived from moderately severe 12-month droughts, of which one had no preceding 3- or 6-month drought. Thus, in this 1921-1925 period relatively severe 48-month and related 60-month droughts occurred without association with severe droughts of shorter duration.

Detailed examination of figure 32 and related data reveals that all droughts of 24-months and longer evolved from the eleven 12-month droughts during 1906-1955. In most instances, the severity of the 12-month drought was approximated in the related longer droughts. However, this consistency in severity did not occur when two moderately severe 12-month droughts in close succession were grouped to produce a 36-month, 48-month, or 60-month drought. In this situation, a marked change in rank or severity usually occurred as revealed by the 24-month drought in 1941 and the 36-month drought in 1955.

In general, the severest of the 12-month droughts were temporally aligned with 3- and 6-month droughts, but the less severe (ranks 5, 8, 9, 10, and 11) 12-month droughts were dry periods that occurred without any time association with shorter duration droughts. Similarly, five of the thirteen 6-month droughts did not associate with any 3-month droughts, although the eight highest ranked 6-month droughts were time-related to 3-month droughts.

Comparative Study of Droughts

An estimate of the relative severity and the climatological representativeness of the 1906-1955 droughts was obtained by comparing them with droughts in prior years. All stations in and near Illinois with more than 33 years of continuous precipitation records prior to 1906 were utilized in this comparative study. The seven stations are listed in table 12.

Table 12. Comparison of Drought Frequencies Before and After 1906

	Average number of droughts per 5-year periods for various durations													
	3-month		6-month		12-month		24-month		36-month		48-month		60-month	
Stations	B*	A*	B	A	B	A	B	A	B	A	B	A	B	A
Marengo	1.1	0.9	1.0	1.0	1.0	1.0	0.9	1.1	1.0	1.0	0.9	0.6	0.8	0.7
Moline	0.8	1.5	0.8	1.5	1.1	1.2	1.4	1.0	1.3	1.1	0.9	1.1	0.7	0.7
Peoria	1.2	0.8	0.9	1.1	1.2	0.8	1.0	1.0	1.0	1.0	0.9	1.0	0.7	0.6
St. Louis	0.8	1.2	0.8	1.2	0.8	1.2	0.6	1.4	0.9	1.1	0.9	1.0	0.7	0.7
Cairo	1.6	0.9	1.1	1.2	1.0	1.3	1.4	1.0	1.1	1.2	0.7	1.0	0.7	0.6
Chicago	1.3	1.1	1.4	1.0	1.3	1.1	1.0	1.3	1.3	1.1	0.9	1.0	0.7	0.7
Dubuque	0.9	1.2	0.6	1.5	1.1	1.0	1.0	0.9	0.9	0.9	0.9	1.0	0.7	0.7
Northern-4	1.0	1.1	0.9	1.2	1.1	1.1	1.1	1.1	1.1	1.0	0.9	0.9	0.7	0.7
Southern-2	1.2	1.1	0.9	1.2	0.9	1.2	1.0	1.2	1.0	1.2	0.8	1.0	0.7	0.7
State average	1.1	1.1	0.9	1.2	1.1	1.1	1.0	1.1	1.1	1.1	0.9	1.0	0.7	0.7

*B refers to period before 1906; A refers to 1906-1955 period

For drought periods of 3 to 36 months, the 20 lowest station values in each duration were selected and identified by year; for the 48-month and 60-month droughts, the lowest 15 drought values for each duration were similarly identified. The number of droughts in the two periods (before and after 1906) were then counted, and their frequencies compared. Four of the seven stations had records of less than 50 years before 1906; therefore, to permit statistical comparison, the drought occurrences per station for both periods were described as the average number occurring in a 5-year period.

This index of comparison revealed that, for most durations, the average number of statewide severe precipitation droughts in the 1906-1955 period was about equal to the average number of droughts in the period before 1906. Table 12 indicates that on a statewide basis droughts of 6, 24, and 48 months occurred slightly more frequently in the period after 1906 than in the years before 1906.

Since four of the stations (Chicago, Marengo, Dubuque, and Moline, as shown in figure 1) are located in or near northern Illinois, data for these stations were averaged and listed as the Northern-4 in table 12. Similarly, data for St. Louis and Cairo were averaged and listed as the Southern-2 in table 12. In this manner, an attempt was made to detect any generalized regional differences in drought frequencies within the state. In northern Illinois, droughts of 3- and 6-month duration occurred slightly more often in the 1906-1955 period than in the period before 1906, but droughts of 12-month and longer duration showed no difference in frequencies between periods before and after 1906. In southern Illinois, the 3-month droughts were more frequent before 1906 than after; however, all other droughts except the 60-month durations had a higher frequency in the 1906-1955 period.

The foregoing analysis indicates that the 1906-1955 period in Illinois had drought frequencies quite similar to those experienced prior to 1906. Therefore, the drought data for the 1906-1955 period appears to provide a representative sample for determination of the frequency distribution of droughts in the state.

Another expression of the representativeness of the 1906-1955 droughts was obtained by determining the temporal distribution of the severest four droughts of each duration during the 100-year period, 1856-1955. In this analysis, the number in the 50-year period 1906-1955 were compared with the number in 50-year period 1856-1905. The three stations with complete records for the 100-year period were used. These yielded data considered representative for northern Illinois (Marengo), central Illinois (Peoria), and southern Illinois (St. Louis). As shown in table 13, the 1906-1955 period contained slightly more of the severe droughts of short duration on a statewide basis. However, the 1856-1905 period had more of the extremely severe droughts with durations ranging from 24 to 48 months.

Another measure of the time distribution of the severe droughts is shown in table 14. The ending year of the severest droughts on record for all durations is shown for the seven stations used in this portion of the investigation. Neither period, before 1906 or after 1906, had significantly more of the severest droughts in the various durations except for the 12-month droughts which appeared to be concentrated in the 1906-1955 period. The data in tables 12 and 13 indicate that the worst droughts in northern Illinois during the 1906-1955 period may have been somewhat less severe than those that occurred prior to this period. Data in table 14 reveal that the 1895-1898 period contained a drought for all of the seven durations somewhere in Illinois; of the 49 drought years listed, 11 occurred in the 1895-1898 period. The only comparable period of droughts after 1906 was the 1931-1934 period which also had 11 of the drought years listed in table 14.

This investigation of the climatological representativeness of droughts in the 1906-1955 period indicates that the relative number of droughts in this 50-year period was comparable with that in

Table 13. Temporal Comparison of Drought Frequencies Based on Severest Four Droughts on Record

	Number of droughts in each period													
	3-month		6-month		12-month		24-month		36-month		48-month		60-month	
Station	B*	A*	B	A	B	A	B	A	B	A	B	A	B	A
Marengo	1	3	2	2	2	2	3	1	2	2	2	2	2	2
Peoria	2	2	2	2	1	3	3	1	3	1	3	1	2	2
St. Louis	2	2	1	3	2	2	2	2	3	1	2	2	2	2
State totals	5	7	5	7	5	7	8	4	8	4	7	5	6	6

*B refers to period before 1906; A refers to 1906-1955 period

Table 14. Years When Severest Droughts on Record Terminated

Station	3-month	6-month	12-month	24-month	36-month	40-month	60-month
				Years for different drought durations			
Dubuque	1921	1925	1895	1896	1896	1934	1934
Moline	1878	1919	1902	1895	1895	1897	1897
Marengo	1931	1934	1934	1864	1936	1934	1902
Chicago	1931	1873	1934	1895	1895	1902	1902
Peoria	1877	1905	1934	1915	1915	1902	1895
St. Louis	1897	1872	1931	1954	1954	1955	1955
Cairo	1881	1877	1931	1941	1941	1943	1944
				Number of years			
Before 1906	4	4	2	4	3	3	4
After 1906	3	3	5	3	4	4	3

earlier years. However, in northern Illinois slightly more of the extremely severe droughts occurred before 1906 than after, especially for droughts of 24 to 48 months in duration. Conversely, southern Illinois experienced a slightly greater number of droughts and more severe droughts in the 1906-1955 period than it did during the 34 to 50 years before 1906. However, the general conclusion is that the 1906-1955 data for 62 stations provide a close approximation of drought probability in Illinois, despite the occasional dissimilarities brought out in comparing these data with limited data prior to 1906.

CAUSES AND CHARACTERISTICS OF DROUGHTS

Atmospheric Circulation

Tannehill (1947) has presented a plausible theory of the cause of drought in the United States in which he pictures the variations in solar radiation producing changes in ocean temperatures which, in turn, control the continental precipitation. According to Tannehill, the Pacific Ocean largely controls the amount of precipitation over the country with the Atlantic Ocean and Gulf of Mexico controlling the distribution, to some extent, through the behavior of the Azores High. During drought conditions, the flow over the Rocky Mountains is from a Pacific region which is farther south than it is in rainy weather. In dry weather, the upper air flow has an anticyclonic (clockwise) trajectory across the mountains, whereas in wet weather the flow, which originates farther north, is cyclonic. In summer, the relatively cool air and relatively warm continent produce a high-level anticyclone over southwestern United States which expands during droughts to produce dry weather over the central United States. The high-level anticyclone associated with the Midwest droughts was first described by Reed (1933) and has been discussed in considerable detail by Klein (1953) and others.

Klein (1953) has described typical mean circulation patterns associated with droughts over the United States during the warm and cool portions of the year. According to Klein, drought in the warm season is generally found beneath a strong warm high pressure system (high-level anticyclone); and this continental high is accompanied usually by a fast westerly stream in southern Canada, an abnormally strong ridge in the east-central Pacific, an abnormally deep trough along the west coast, and another trough over the east coast. This condition is illustrated in figure 37 which is reproduced from the August 1953 Monthly Weather Review published by the U.S. Weather Bureau. Figure 37 shows the mean circulation at the 700-millibar pressure level (approximately 10,000 ft) in the atmosphere for the 5-day period, August 22-26, 1953. No rain fell in Illinois during this period except for an occasional light air mass shower.

Klein describes the dry weather pattern in the cool season at 700 millibars as featuring northwesterly flow between a high pressure ridge in western United States and a trough in the eastern part of the country. The mean circulation pattern at 700 millibars for September 1953, as presented in the Monthly Weather Review, is shown in figure 38 and reflects the predominance of this condition.

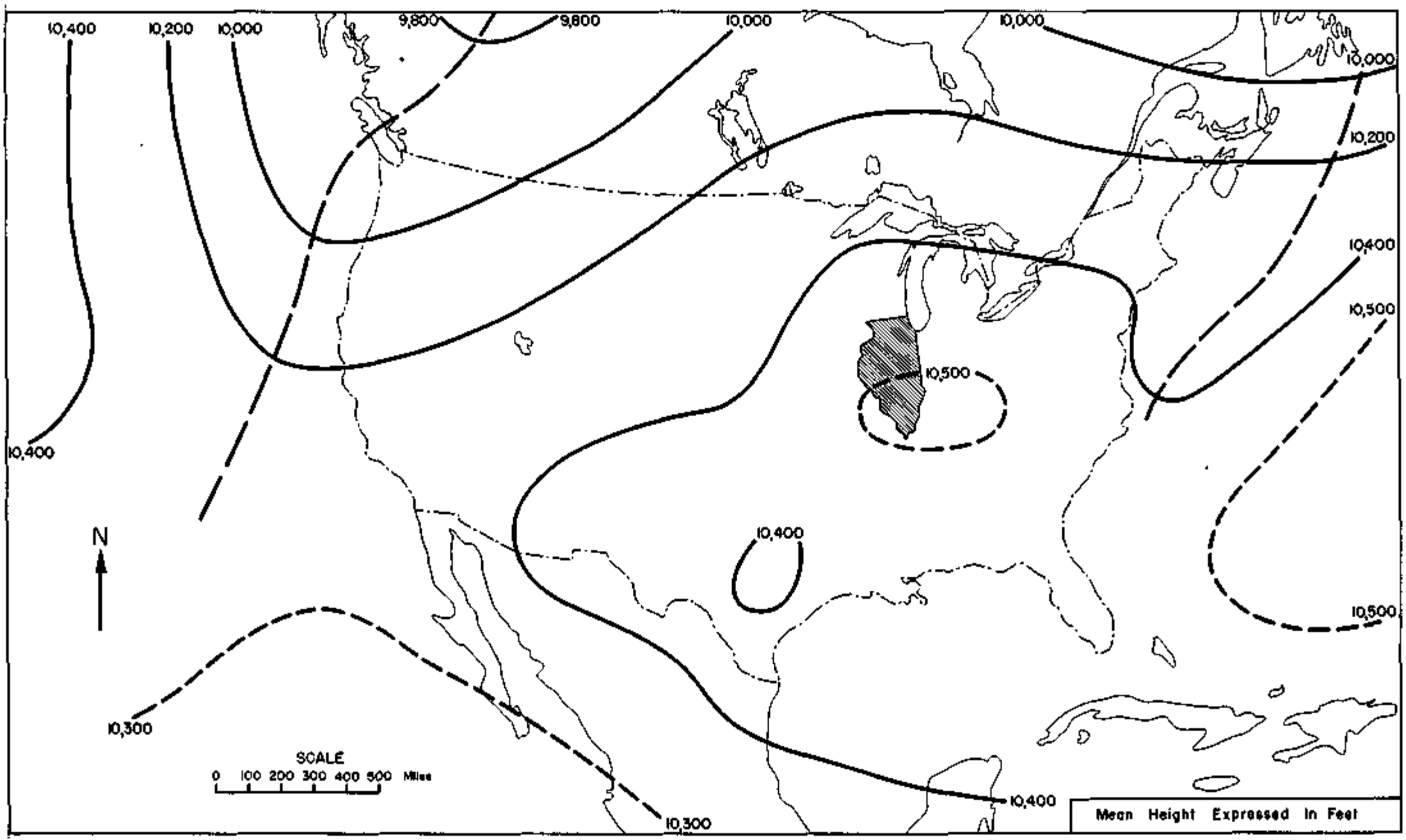


Figure 37. Mean height of 700-millibar pressure surface, August 22-26, 1953

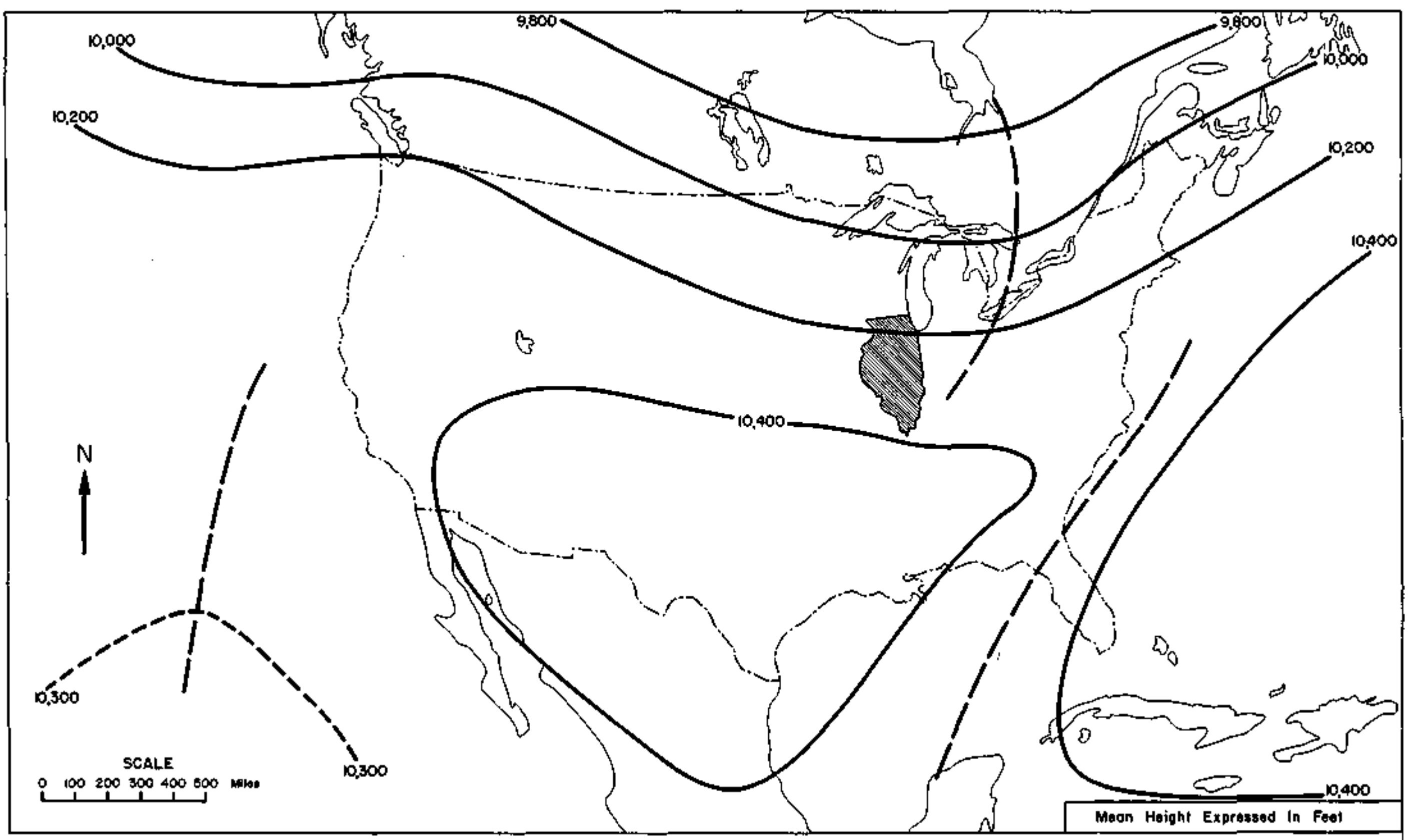


Figure 38. Mean height of 700-millibar pressure surface, September 1-30, 1953

During that month rainfall was only 44 percent of normal in Illinois.

Characteristics of Specific Droughts

Although the large-scale circulation pattern associated with drought throughout or over major portions of the country have been identified adequately, information is quite sparse on the causes of small-scale droughts or large variations in droughts which have been observed over relatively small areas such as Illinois. Detailed studies of meteorological conditions are required to establish the causes of the small-scale variations. It is not possible within the scope of this study to analyze every Illinois drought with respect to existing meteorological conditions during its existence; furthermore, adequate upper air maps, data on frontal frequencies, and other synoptic data have not been available until recent years in sufficient detail to carry out such analyses thoroughly. However, to illustrate conditions prevailing in a severe drought period with a large variation in severity over the state, the 12-month period, August 1953-July 1954, has been selected.

Descriptions of the monthly weather and circulation appearing in the Monthly Weather Review during 1953-1954 indicate that the typical large-scale drought circulation patterns, or slight modification of them, dominated the United States weather throughout most of the period. During this time, the south-central part of Illinois recorded the worst 12-month drought on record in that area (figure 24), while the northern part of the state recorded near normal to slightly above normal precipitation in some areas. With typical drought circulation patterns there is usually a strong band of westerlies in southern Canada or near the United States-Canadian border. As a result, low pressure systems move rapidly across southern Canada and rarely penetrate substantially into the United States. However, trailing cold fronts out of these lows frequently pass across the northern states, and sometimes weak low centers form on these trailing fronts. Analysis of the 50 heaviest rainstorms in Illinois during the 1953-1954 drought showed that 32 of these storms (64 percent) were associated with trailing fronts out of low centers which passed across southern Canada or the northern border states. In these 32 storms, wave formations on the trailing cold fronts intensified the storms over Illinois in 14 cases.

Chiang (1961) made a study of the climatological distribution of fronts in Illinois, based upon the 15-year period 1945-1959. The average frontal frequencies from his study were compared with a tabulation of the number of fronts which passed through Illinois during the 1953-1954 drought period. It was found that the frequency of cold fronts in Illinois during the drought period was 89 percent of the normal frequency established by the Chiang study and that the frequency of all fronts combined (cold, warm, stationary, and occluded) was 98 percent of normal. The frequency of fronts in the most severe drought region was slightly greater than the state average, about 93 percent of normal for cold fronts and 100 percent of normal for all fronts combined. The frontal frequency in northern Illinois, where precipitation was near normal in the drought period, was similar to the general state trend, that is, slightly below normal to near normal. Thus, one must conclude that the severe drought in south-central Illinois and the large variability in drought severity over the state was not produced primarily by a deficiency of frontal passages.

Furthermore, the near normal frequency of fronts in Illinois during this drought period is not surprising. The rapid movement of low pressure centers across southern Canada and the northern border states, typical of this drought period, resulted in the passage of a relatively large number of trailing cold fronts across northern United States, which apparently penetrated Illinois frequently. Huff (1961) in a study of frontal passages at Urbana from 1951 through 1960 found a tendency for an inverse relationship between frontal frequency and annual precipitation. He related this tendency to the prevalence of relatively large, strong, slow-moving storm systems in wet years, in contrast to the fronts which tend to be relatively weak, frequent, and rapidly moving in dry years. Meteorologically, the weak, rapidly moving systems occur in high index situations (weak troughs and ridges aloft), and the strong, slow moving systems are associated with low index conditions (deep troughs and ridges aloft). From the foregoing analysis, it appears that the frontal systems must have been somewhat more active in northern Illinois than in southern Illinois during the 1953-1954 drought, and this is to be expected since the northern part of the state was closer to the storm centers passing across southern Canada and the northern states. Analysis of the frequency of cloud types and daily precipitation amounts in Illinois, discussed in the following paragraph, supports the assumption that the frontal systems tended to be less intense in the severe drought region.

Analysis of climatological conditions in Illinois during the 1953-1954 drought showed that below normal precipitation was recorded in all 12 months in the southern part of the state, 11 out of 12 months in the central part, and only 6 out of 12 months in the northern regions. Temperatures averaged about 2.5°F above normal throughout the state. The frequency of days with measurable precipitation was below normal throughout the state, but was least in the south. However, heavy daily rainfalls, classified as those exceeding 0.5

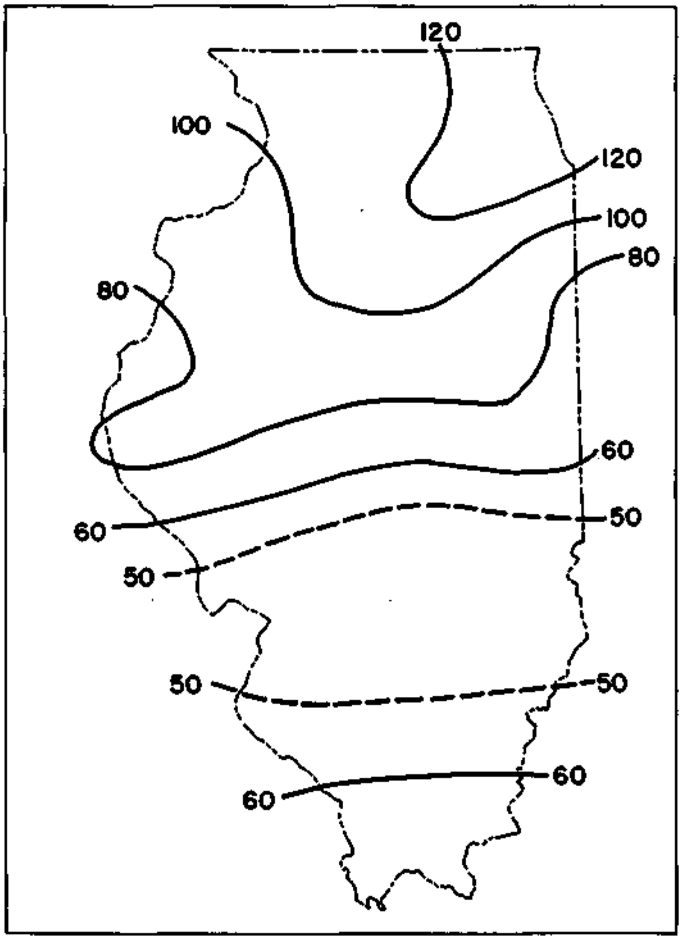


Figure 39. Percent of normal number of days with precipitation **of 0.5** inch **or** more, **August 1953 - July 1954**

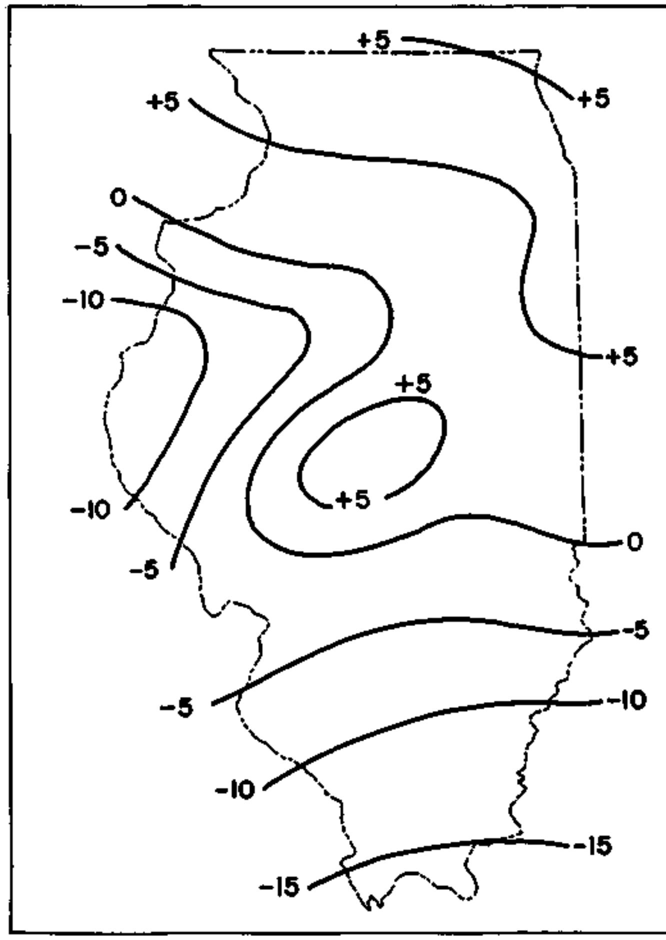


Figure 40. Departure from normal number of thunderstorm days, August 1953 - July 1954

inch per day, were most deficient in the worst drought area, and this lack was responsible for a major portion of the precipitation deficiency. The pattern of percent of normal for days with precipitation of 0.5 inch or greater is shown in figure 39. The frequencies of thunderstorms (figure 40) and convective-type clouds (figure 41) were below normal, especially in the southern and western parts of the state. Average depth of precipitable water in the atmosphere was found to be slightly below normal with near normal vertical stratification. In the worst drought area, the precipitable water was approximately 87 percent of normal during the 1.2-month period. Semonin (1960) in a study of dry periods of five days or longer in Illinois has found that both the total amount and vertical stratification of atmospheric moisture is near normal during such dry periods. While the moisture supply is frequently adequate during drought conditions, the atmosphere is abnormally warm so that the humidity is low even with normal atmospheric moisture content. Furthermore, the atmosphere is so abnormally stable that vertical development of clouds and subsequent precipitation initiation, except on a very localized basis, is impossible most of the time.

Hourly Precipitation in Drought And Nondrought Periods

One of the worst droughts on record occurred in southern Illinois from 1952 through 1954, particularly in the south-central portion, and as shown in the previous section, produced the worst 12-month drought on record in the south-central region. As part of an investigation to define the characteristics of precipitation during such severe drought periods, analysis of hourly precipitation for the 10-year period 1948-1957 was made for six selected stations in the region. The period was divided into two parts, the severe drought years 1952-1954, and the nondrought years 1948-1951 and 1955-1957.

First, a seasonal and annual comparison was made of the frequency of hours with measurable precipitation (0.01 inch or more) in the drought and nondrought years. Results are summarized in table 15, which shows the mean number of seasonal and annual occurrences for each of the six stations, the average of all stations combined, the difference in frequency between drought and nondrought years, the ratio of the average frequency in drought years to the average frequency in non-

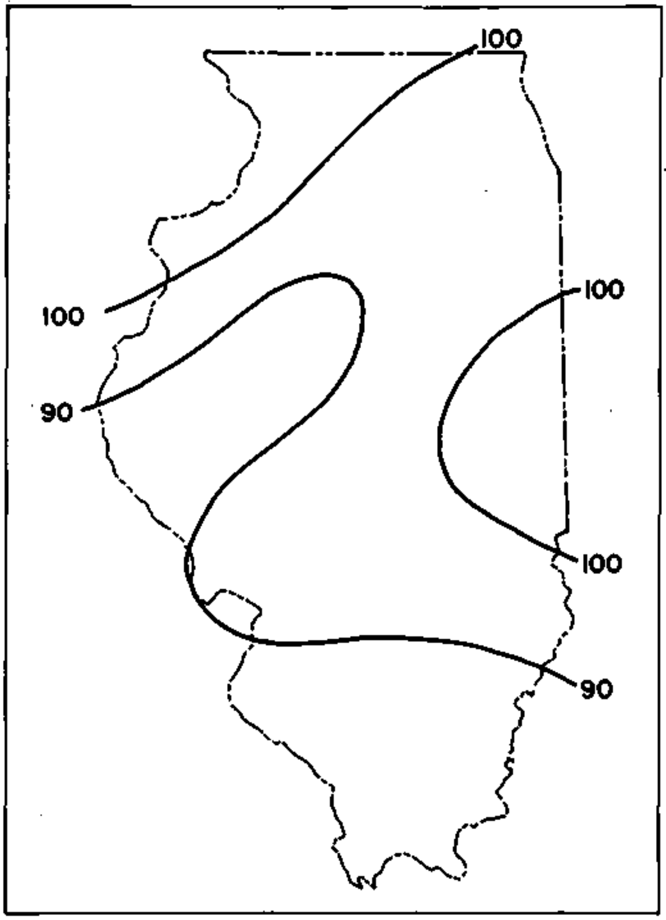


Figure 41. Percent of normal convective clouds, August 1953 - July 1954

drought years, and annual ratios for the individual stations.

Table 15 shows that the number of hours with measurable precipitation in the severe drought years was only about one-third the number in the nondrought years, as indicated by the average annual ratio of 0.34 for all stations combined. Individually, the annual ratios ranged from 0.24 at Greenfield to 0.41 at Hutsonville. Seasonally, the drought severity, as portrayed by the drought to nondrought ratios, appears to have been greatest in fall and winter and least severe in spring.

Table 16 is similar to table 15 except that the comparison is based upon the frequency of hours with precipitation in excess of 0.10 inch. The purpose here was to determine whether the departure from normal of the frequency of relatively heavy hourly rainfall amounts was greater than that of relatively light amounts. Comparison of the two tables shows a slight trend for the heavier rainfalls to be more scarce than lighter rainfalls in drought periods, the annual average ratio dropping from 0.34 for all measurable amounts to 0.30 for amounts exceeding 0.10 inch. The trend is pronounced only in winter, however, when the ratio decreased from 0.30 to 0.19.

Table 17 compares hourly mean precipitation rates in drought and nondrought years on a seasonal basis. In general, there is a trend for rainfall rates to be lighter during drought periods, but the trend is not pronounced except in winter.

Table 15. Comparison of Frequency of Hours with Measurable Precipitation in Drought and Nondrought Periods

	Drought 1952-54					Nondrought 1948-51, 1955-57					Annual ratio, drought to nondrought years
	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Annual	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Annual	
	Mean number of cases per year per given interval										
St. Louis	104	138	75	74	391	350	324	85	239	998	0.39
Greenfield	76	109	31	35	251	290	283	226	232	1031	0.24
Vandalia	93	121	62	73	349	297	246	197	242	982	0.36
Sullivan	103	133	79	70	385	292	274	247	245	1058	0.36
Louisville	47	82	59	80	268	248	301	162	252	963	0.28
Hutsonville	132	139	42	78	391	351	285	130	193	959	0.41
Average frequency	93	120	58	68	339	305	285	174	234	998	
Average difference	212	165	116	166	659						
Average ratio, drought to nondrought years	0.30	0.42	0.33	0.29	0.34						

Table 16. Comparison of Frequency of Hours with 0.11 Inch or More Precipitation in Drought and Nondrought Years

	Drought 1952-54					Nondrought 1948-51, 1955-57					Annual ratio, drought to nondrought years
	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Annual	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Annual	
	Mean number of cases per year per given interval										
St. Louis	9	20	17	14	60	45	54	24	52	175	0.34
Greenfield	5	18	10	6	39	46	43	53	38	180	0.22
Vandalia	7	28	18	12	65	55	52	59	60	226	0.29
Sullivan	9	23	19	12	63	35	36	62	51	184	0.34
Louisville	5	15	16	15	51	45	55	41	56	197	0.26
Hutsonville	16	28	11	15	70	62	48	35	42	187	0.37
Average frequency	9	22	15	12	58	48	48	46	50	192	
Average difference	39	26	31	38	134						
Average ratio, drought to nondrought years	0.19	0.46	0.33	0.24	0.30						

Table 17. Seasonal Comparison of Hourly Mean Precipitation Rates in Drought and Nondrought Periods

	Drought 1952-54				Nondrought 1948-51, 1955-57			
	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
	Mean hourly rainfall rate (in/hr)							
St. Louis	0.040	0.057	0.106	0.065	0.053	0.071	0.120	0.073
Greenfield	0.041	0.066	0.143	0.078	0.051	0.060	0.110	0.071
Vandalia	0.047	0.081	0.134	0.087	0.072	0.086	0.141	0.086
Sullivan	0.045	0.075	0.079	0.064	0.070	0.066	0.118	0.086
Louisville	0.051	0.072	0.089	0.086	0.084	0.076	0.109	0.081
Hutsonville	0.050	0.077	0.091	0.065	0.068	0.074	0.123	0.087
Average rate	0.046	0.071	0.107	0.074	0.066	0.072	0.120	0.081
Average difference	0.020	0.001	0.013	0.007				
Average ratio, drought to nondrought years	0.70	0.99	0.89	0.91				

In the December-February period, the drought to nondrought ratio is 0.70; that is, the average hourly-rate during drought periods is 70 percent of that in nondrought periods. Spring shows no significant difference between rates, and the differences are relatively small in summer and fall, with ratios of 0.89 and 0.91, respectively.

From the data in the three tables, it appears that drought periods are more closely related to frequency of precipitation than to precipitation rate. On a percentage basis, the greatest difference in both frequency and rate between drought and nondrought periods occurs during winter and the least difference during spring. Table 15 shows that the actual decrease in number of occurrences of measurable rainfall is greatest in winter and least in summer. Table 17 shows that the actual rate decrease from nondrought to drought periods maximizes in winter and minimizes in spring.

Other Meteorological Factors

To obtain pertinent information regarding the causes and distribution of droughts in Illinois and areas of similar climate and topography, an investigation was made of the relation between the spatial distribution of drought and the climatic distribution of other meteorological elements such as mean precipitation, thunder storms, hail, severe rainstorms, and atmospheric moisture content. Since the frequency distributions of droughts of various durations showed the same general patterns and the climatological analyses indicated strong interrelationship of droughts of various length, this phase of the study was restricted to 12-month droughts, which are considered representative of the drought regime in Illinois.

First, the frequency patterns of 12-month droughts (figure 9) were compared with the mean annual precipitation (figure 2). This revealed evidence of an inverse relationship between patterns. Whereas the drought pattern indicates a minimum severity in northeastern Illinois and maxima in the southeastern, southern, and southwestern portions of the state, the precipitation pattern shows regions of low precipitation in the northeast and high precipitation in the southeast and south. The relation does not hold too well in the southwestern region where relatively high drought severity occurs in a region of moderate precipitation.

Comparison of the coefficient of variation of annual precipitation (figure 42) with the drought patterns of figure 9 reveals a rather striking similarity. Relatively low coefficients in the northeast and east occur in conjunction with relatively low drought severity, whereas high coefficients in the southeast, south, and southwest correspond with peaks in the drought pattern. High relative variability of annual precipitation appears to be correlated closely with 12-month drought severity; that is, droughts are more severe where the year-to-year variability of rainfall is greatest, despite the fact that average precipitation is considerably greater in most of the severe drought areas.

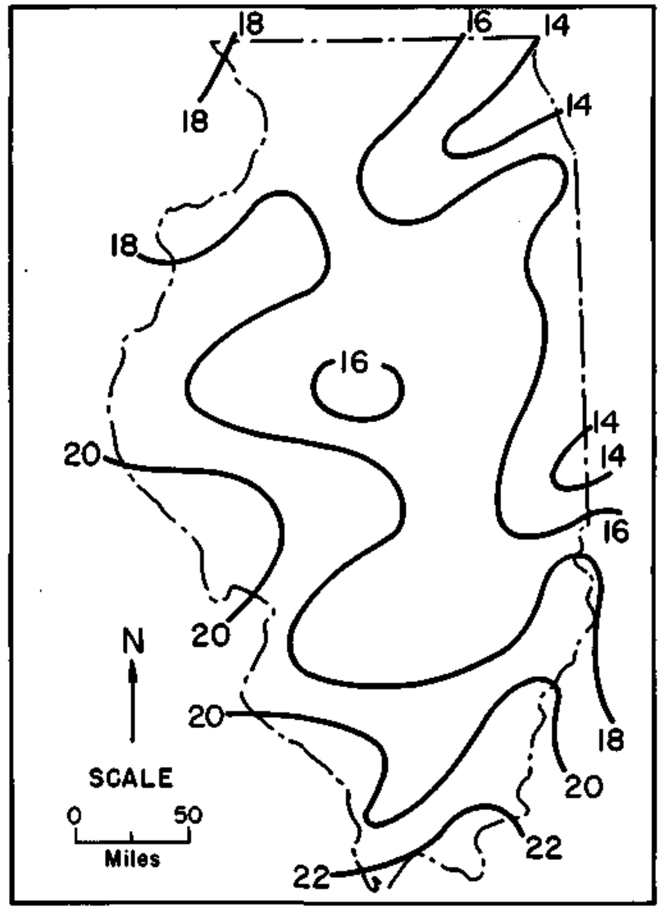


Figure 42. Coefficient of variation of mean annual precipitation

Results of the above comparisons suggest that a strong association might exist between drought severity and the distribution of thunderstorms, which are primarily responsible for the great variability of rainfall common to the central United States. Reference to figures 9 and 43 indicates that a strong association does exist. A trough in the thunderstorm pattern extends southward and then southwestward corresponding closely with a ridge in the drought pattern. Thunderstorm frequency is at a minimum in the northeast in the region of lowest drought severity and maximizes in the south and southwest where drought severity maximizes. Changnon (1957) has found that thunderstorms account for 50 percent of the annual mean precipitation in southwestern Illinois compared with 35 to 40 percent in the northeastern part of the state. Thus, the drought severity increases as the dependence on convective activity for precipitation becomes more pro-

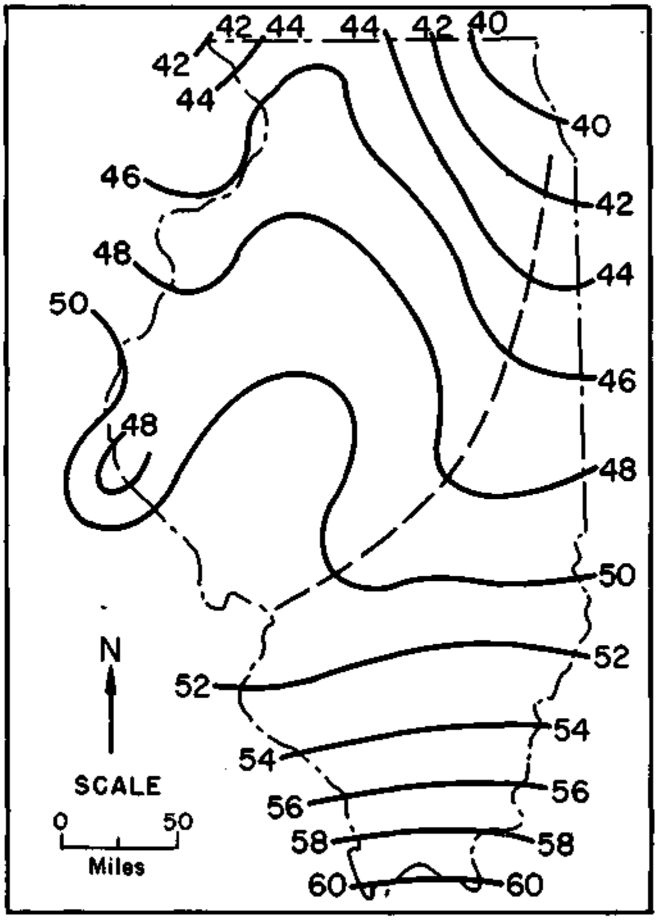


Figure 43. Annual thunderstorm frequency

nounced. This is borne out also by cloud studies in Illinois made by Changnon and Huff (1957). Convective-type clouds, cumulus and cumulonimbus, occur with minimum frequency in northeastern and eastern Illinois, whereas the stable-type cloud, stratocumulus, maximizes in these regions.

A study of severe rainstorms in Illinois for the period 1914-1957 has shown that the frequency of these storms is greatest in southwestern and southeastern Illinois, with the extreme value in the region east of St. Louis (Stout and Huff, 1962). These two rainstorm maxima correspond closely with 12-month drought maxima in southeastern and southwestern Illinois on the 25-year and 50-year frequency maps of figure 9.

Clirnatological maps of hail for Illinois (Huff and Changnon, 1959) show that the region of maximum hail frequency in the state is also within the region of drought severity in southwestern Illinois, and that a hail minimum is present in eastern Illinois in the region of low drought severity. Elsewhere the association is not so pronounced.

Particularly outstanding from a climatological standpoint is the southwestern region of the state which is an area of weather extremes, including relatively severe droughts and high frequencies of thunderstorms, hail, tornadoes, and intense rainstorms. The development of these extreme weather events in this region appears to be related to both synoptic weather and topographic features. As shown by Chiang (1961), southwestern Illinois is a region of high frequency of fronts with respect to the rest of the state, particularly quasi-stationary fronts. These stationary fronts are often accompanied by wave action and, subsequently, intensification of the front. With respect to topography, the Ozarks, a breeding ground of convective clouds, lie less than 100 miles to the south and southwest, in the prevailing direction of flow or moist air off the Gulf of Mexico in the lower layers of the atmosphere.

Correlation of drought severity with the frequency of rainy days was investigated, but no outstanding features were apparent since the frequency decreases gradually from east to west across the state. Similarly, the atmospheric moisture content, as portrayed by depth of precipitable water, does not appear to correlate well with drought severity. On an annual basis, the mean depth of precipitable water from the surface to eight kilometers decreases gradually from south to north throughout the state (U. S. Weather Bureau, 1949).

Summarizing, the coefficient of variation of mean annual precipitation and the frequency of thunderstorms showed the best association with the 12-month drought patterns. Other meteorological factors, including mean annual precipitation, cloud types, severe rainstorms, and hail, correlated well with certain features of the drought pattern. This phase of the study suggests that decreased convective activity during droughts is the major cause of the differences in severity found in Illinois, since the regions of greatest severity are more dominated by convective-type precipitation than are the regions of minimum severity.

Monthly Temperature and Precipitation

A study was made of the characteristics of monthly mean temperature and precipitation during the four worst droughts in Illinois during 1906-1955. The results are summarized for each drought duration in tables 18 and 19 on a seasonal and annual basis. In these tables, winter includes December through February; spring, March through May; summer, June through August; and fall, September through November.

Combining all months, table 18 shows a general decrease in the frequency of months with above normal temperatures with increasing drought duration, although above normal temperatures dominate all durations. Above normal temperatures occurred in 75 percent of all months included in the 3-month droughts, and the percent-

Table 18. Frequency of Months with Above Normal Temperature During Peak Periods of Severe Droughts

Drought duration, months	Percent of total months above normal: Winter	Spring	Summer	Fall	All months
3	67	100	84	89	75
6	62	58	91	85	72
12	63	59	90	71	71
24	74	45	82	68	68
36	76	52	76	71	69
48	71	49	69	63	63
60	71	57	64	60	62

Table 19. Frequency of Months with Below Normal Temperature During Peak Periods of Severe Droughts

Drought duration, months	Percent of total months below normal: Winter	Spring	Summer	Fall	All months
3	100	100	100	100	100
6	98	98	100	100	99
12	98	98	98	83	94
24	73	86	90	75	81
36	68	80	78	73	75
48	73	71	70	68	70
60	71	70	70	65	70

age decreased to 62 percent with 60-month droughts. Except for winter, the same general trend is shown in the seasonal distributions.

Table 19 shows the percentage of months with below normal precipitation in severe drought periods. As expected, both the seasonal and total monthly data show a gradual decrease in the percent of months with below normal precipitation as the drought duration increases; that is, drought severity decreases with increasing duration of dry periods. The combined months in tables 18 and 19 show a greater frequency of months with below normal precipitation than with above normal temperatures for all drought durations, but especially for durations of 3, to 12 months.

PRECIPITATION DROUGHT AND LOW STREAMFLOW

In Illinois, as in most regions of the United States, long-period records of precipitation far outnumber those of streamflow. As of 1960, there were 62 stations in Illinois with precipitation records of 55 years or longer, whereas there were only 12 stream gages with records of 45 years or longer. Consequently, the time and space distribution of low flow could be defined considerably better if a satisfactory method of relating precipitation drought to low flow were developed. Since the basic source of streamflow replenishment is precipitation, a physical relationship should exist between the frequency distribution of low flow and the frequency distribution of precipitation. However, the relationship is complicated by the influences of other factors upon precipitation before a portion of it finally reaches a stream as runoff.

For drought periods with durations of 12 to 60 months and recurrence intervals exceeding 5 years, a successful method has been developed for defining low flow frequency throughout most of Illinois by relating the frequency distribution of low flow to the frequency distribution of precipitation drought within similar geomorphic regions. This method was employed to obtain the frequency distribution of low flow for periods of 12 to 60 months, but the following discussion of the development of the method is restricted mainly to 12-month periods. Results obtained for the longer durations also are presented, along with examples of application of the method.

Correlation Between Precipitation Drought and Low Flow

Schneider (1961) has shown that annual runoff correlations between basins were significantly improved by using annual precipitation values of basins. In order to further demonstrate a basis for the method, the authors determined the degree of correlation between ranked low flows and their time-associated precipitation drought data. For this correlation phase, the rainfall-runoff data were not for exact matching periods, since for example, the lowest 12-month low flow period associated with a precipitation drought normally terminated from 1 to 4 months after the end of the precipitation drought. Allowance for lag was a reasonable adjustment in view of expected geophysical relations between streamflow and precipitation for periods of 12 months and longer.

Table 20. Correlation Coefficients Between Low Precipitation and Streamflow for Eight Basins

Basin	Length of record, years	Basin size, square miles	Number of raingages for basin	Average lag, months, drought end to low flow	Correlation coefficient
Spoon River	41	1600	5	3.3	+0.91
Sangamon River	41	550	2	3.0	+0.88
Kaskaskia River	45	1980	5	2.8	+0.91
Embarrass River	44	1540	4	2.5	+0.95
Macoupin Creek	35	875	2	1.5	+0.92
Little Wabash River	41	1130	2	1.5	+0.90
Big Muddy River	45	753	2	1.8	+0.98
Cache River	33	242	2	1.9	+0.85

To perform the correlative testing, precipitation and streamflow data for 12- and 24-month durations were used from eight gaged basins ranging in size from 242 to 1980 square miles (table 20). Each basin had long streamflow records, each had adequate precipitation data, and their locations were dispersed so as to sample most of the various geomorphic regions in Illinois. All periods of streamflow were independent periods as defined by Hudson and Roberts (1955). In essence, the low flow periods were selected in a manner that eliminated the possibility of any month being included in different droughts of the same duration. The time-associated average basin precipitation with appropriate lag was determined from all raingage stations located within and relatively near the eight basins. These averages were expressed as a percentage of normal, as were the low flow values, and correlation coefficients were computed from these percentages for the 15 lowest-ranked runoff values and their time-associated precipitation percentages.

As shown in table 20, relatively high coefficients were obtained in all cases. For 12-month periods, the coefficients varied from 0.98 to 0.85 with a median of 0.91. The correlation coefficients for 24-month periods varied from 0.99 to 0.88 with a median of 0.93. The coefficients for these periods indicated that the precipitation data explained more than 70 percent of the variation exhibited in the 15 low flows of the eight basins.

Methodology

From consideration of the physical factors involved and the results of the correlation analysis, it appeared that the low flow frequency distribution for recurrence intervals for 5 years or longer and for durations of 12 months or longer could be expressed as

$$R = f(P,G) \tag{1}$$

where R is runoff for a given mean recurrence interval, P is the basin precipitation for that recurrence interval, and G is the effect of geomorphology. For the above durations and recurrence intervals, the effects of such factors as land use, season of the year, and watershed size are minor.

According to the discussion in the previous paragraph, it is reasonable to assume that the geomorphology of a basin, to a considerable extent, determines the portion of rainfall that becomes runoff as measured by a stream gage. Furthermore, in accordance with the results of the correlative testing in the previous section, it is reasonable to assume that geomorphology affects the frequency distribution of the fraction of the precipitation that becomes runoff during drought conditions. With this assumption in mind, the operator f in expression (1) can take on the specific operation of multiplication, i.e., multiplication of P times G, and the general expression (1) can be written as an equation

$$R = P\,G \tag{2}$$

Solving the equation for G gives

$$R/P = G \tag{3}$$

which equates geomorphology to the ratio of runoff to precipitation for the particular geomorphic unit. G is a dimensionless quantity as a result of expressing R and P, in the same units, as depth of water over a watershed. In equation (3), R represents a low flow series and P represents a minimum precipitation series. Both series represent independent periods as defined by Hudson and

Table 21. G-Values Corresponding To Selected Recurrence Intervals of 12-Month Precipitation for 13 Basins

River basin	Streamgage station	Recurrence interval, years 5	10	25	50	Basin location by geomorphic unit
Green	Geneseo	.16	.12	.08	.06	Fluvial-Lacustrine-Deltaic Plain
Iroquois	Chebanse	.17	.13	.09	.06	Fluvial-Lacustrine-Deltaic Plain
Fox	Algonquin	.17	.14	.11	.09	Fluvial-Lacustrine-Deltaic Plain
Big Muddy	Plumfield	.12	.07	.03	.02	Glacial Plain
Skillet Fork	Wayne City	.13	.07	.03	.02	Glacial Plain
Embarrass	Ste. Marie	.14	.07	.03	.02	Glacial Plain
Spoon	Seville	.15	.09	.05	.04	Glacial Plain
LaMoine	Ripley	.14	.08	.04	.02	Glacial Plain
Little Wabash	Wilcox	.14	.08	.04	.02	Glacial Plain
Sangamon	Monticello	.15	.10	.06	.04	Glacial Plain
Kaskaskia	Vandalia	.17	.12	.06	.04	Glacial Plain
Pecatonica	Freeport	.23	.21	.19	.18	Interior Plateau
Cache	Forman	.19	.13	.08	.05	Dome Uplift

Roberts (1955). The ratios of R/P, where R and P are for the same mean recurrence interval in their respective series, provide a geomorphic factor, G, for various mean recurrence intervals. The G-factors and a minimum precipitation series can be inserted in equation (2) for predicting R for various recurrence intervals for an ungaged watershed.

In expression (1), P can be determined with a high degree of accuracy for water sheds anywhere in Illinois for precipitation droughts of 12 to 60 months. Figures 2 and 9 can be used to illustrate the determination of P. In figure 2, the mean annual precipitation pattern in Illinois is shown, based upon records for the 50-year period, 1906-1955, at 62 stations. Figure 9 shows the space distribution of 12-month droughts expressed as a percent of normal for selected recurrence intervals, derived from the same 50-year record at the 62 stations. A smoothed frequency distribution curve of precipitation drought was determined for each station by a logarithmic plotting of the data for use in preparing figure 9. P in centimeters can be obtained for a given basin and recurrence interval by multiplying the appropriate percentage from figure 9 by the mean precipitation for the basin from figure 2.

G is a complex parameter which is largely dependent upon the integration of the surface and subsurface geological factors, which are here referred to as the basin geomorphology (von Englen, 1942). This geomorphology includes all those geophysical characteristics that act together to effect the low flow characteristics of a basin. Cross (1949) has shown that four geologic factors determine drought-period runoff to a large extent in Ohio, which has many geomorphic features similar to those in Illinois (Fenneman, 1928). Factors listed by Cross included the amount of water storage in the underlying aquifer, the permeability of the layer between the aquifer and the surface, the horizontal transmissibility of the aquifer, and horizontal gradients of the surface toward the stream. G in expression (1) includes these factors and other pertinent physical factors as an integrated empirical value.

The G-value was determined from the comparison of R and P for the few basins in Illinois where these two parameters could be calculated. The success of the prediction method depended on whether similar G-values were obtained for those basins within similar geomorphic regions. If so, then it appeared safe and reasonable that these G-values could be used to calculate the R values for ungaged basins throughout a geomorphic region. Computed G-values, or R/P ratios, are shown in table 21 for 12-month periods at 13 basins.

The geomorphology of the 13 basins listed in table 21 is indicated by reference to major geomorphic units or classifications set forth by von Englen (1942). The location of these 13 basins and the five geomorphic units found in Illinois are shown in figure 44. No stream with adequate records was available to develop G-values for use in the small area occupied by the Coastal Plain Unit in extreme southern Illinois (figure 44). However, an estimate of the G-values for this particular geomorphic unit could be obtained if similar research were performed for streams located in this Coastal Plain Unit beyond the boundary of southern Illinois.

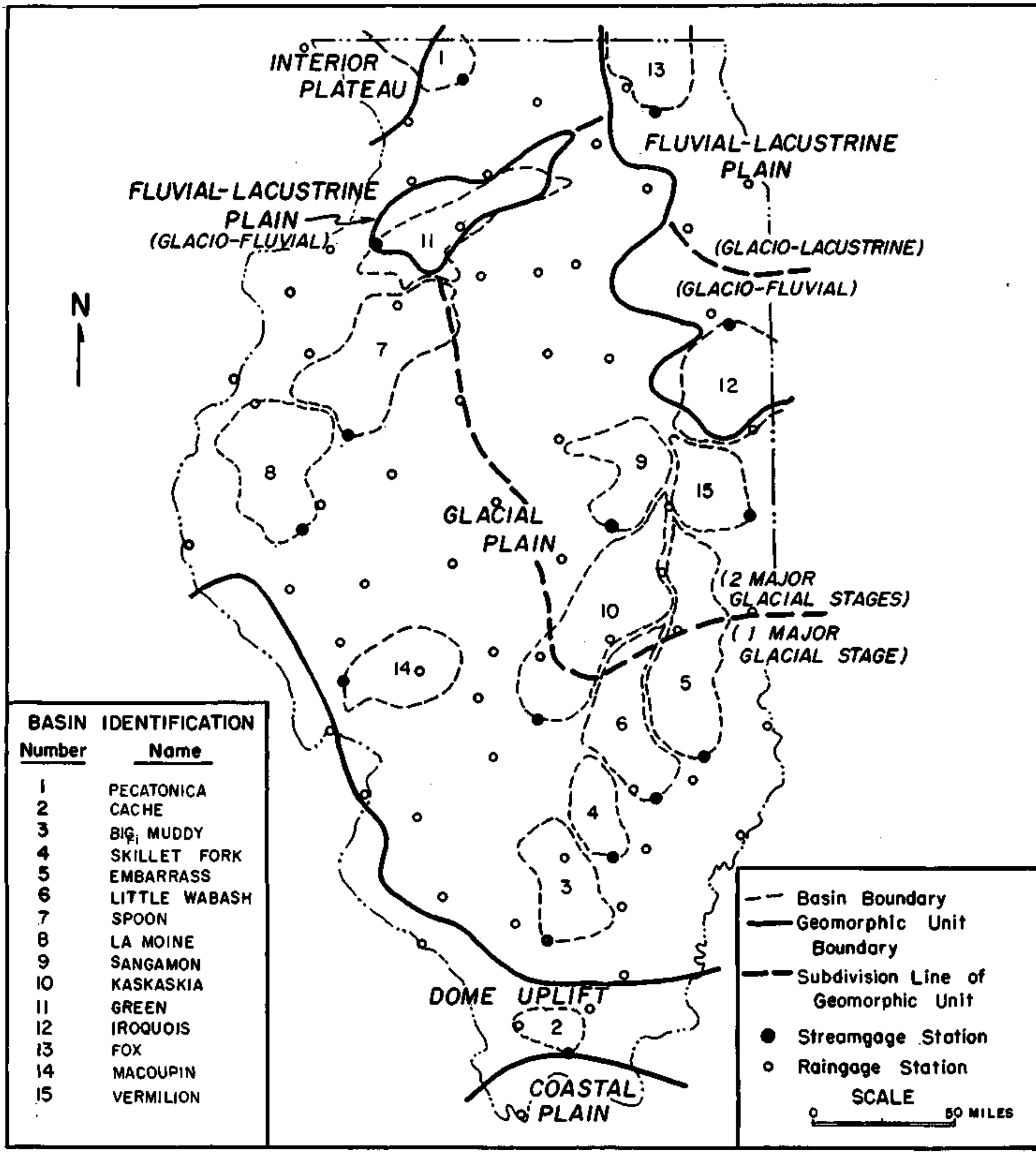


Figure 44. Select basins and geomorphic units in Illinois

Similar G-values shown in table 21 were grouped, and six classifications or groups of values resulted. Each of these groups was identified and further justified according to the four sampled geomorphic units and the major subdivisions within two of them. These six groups of G-values for 12-month periods and associated geomorphic regions are shown in table 22.

Table 22. G-Values Corresponding to Selected Recurrence Intervals of 12-Month Precipitation in the Geomorphic Regions in Illinois

Geomorphic region	Recurrence intervals, years 5	10	25	50	100
Fluvial-Lacustrine-Deltaic Plain -- glaciofluvial	.17	.13	.09	.06	.05
Fluvial-Lacustrine-Deltaic Plain -- glaciolacustrine	.17	.14	.11	.09	.07
Glacial Plain-1 (One major glacial stage)	.14	.08	.04	.02	.01
Glacial Plain-2 (Two major glacial stages)	.16	.11	.06	.04	.03
Interior Plateau	.23	.21	.19	.18	.16
Dome Uplift	.19	.13	.08	.05	.03

The geomorphic unit labeled as Fluvial-Lacustrine-Deltaic Plains by von Englen (1942) is present in two areas of northern Illinois (figure 44). However, as shown in table 21, G-values from one of the three basins in this unit differed considerably from those of the other two basins. This difference suggested a possible subdivision of the unit. The Iroquois River and Green River basins largely occupy regions classified as glaciofluvial aggradational geomorphic areas (Leighton and others, 1948). The G-values for these two basins were quite similar (table 21), and average G-values (table 22) were determined from these two basins for application to ungaged streams in any of the glaciofluvial areas of the state. The Fox River basin had higher ratios than the other two basins in this particular geomorphic unit (table 21). The Fox River basin lies in a glaciolacustrine plain (figure 44) rather than a glaciofluvial plain (Leighton and others, 1948). The G-values for this basin are the glaciolacustrine values used in Illinois (table 22).

The northwestern corner of the state is in a geomorphic unit described as an Interior Plateau. It is an unglaciated uplands, or modified structural plain (Horberg, 1950), which has been maturely dissected. As shown in table 21, the G-values for the one basin in this plateau area were considerably different than all others. The G-values for the Pecatonica River basin were those selected for use in determining the R-values for any streams in the Interior Plateau geomorphic unit.

The G-values. for the Cache River were unlike those of the other basins (table 21). As shown in figure 44, this basin is the only basin located in the Dome Uplift Unit. This uplands area is an unglaciated, cuesta-form region determined structurally by the Ozark Dome with associated complex faulting and folding which accompanied basic intrusions (Horberg, 1950). The G-values denoted for the Dome Uplift region in table 22 were derived from those shown for the Cache River in table 21. As shown in figure 45, this bedrock area, along

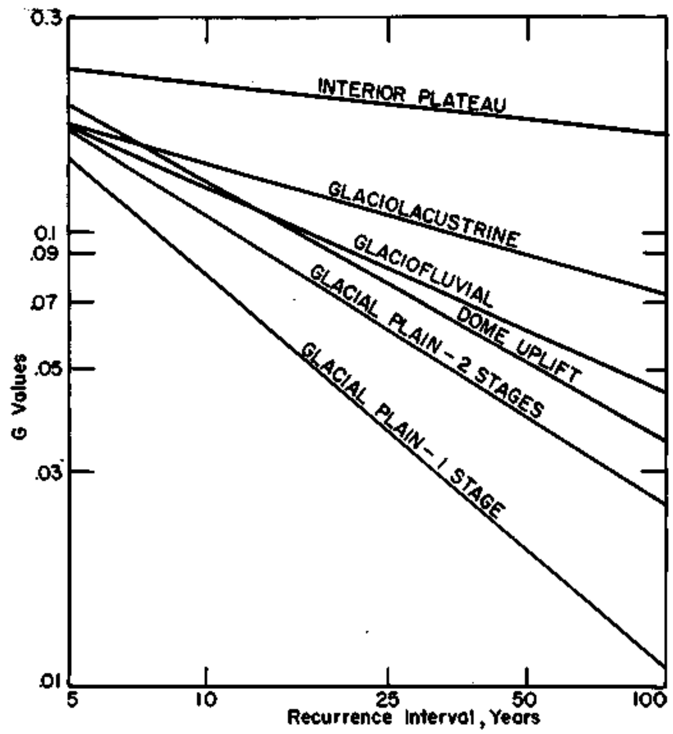


Figure 45. Curves based on G-values for different geomorphic regions for 12-month periods

with the one in northwestern Illinois, produced the two highest G-values for the 5-year recurrence interval. Recharge of the streamflow from stream-intercepted bedrock aquifers may account for these relatively greater 5-year flows in the two geomorphic units with bedrock surfaces.

As shown in table 21, the Kaskasia River and Sangamon River basins in the Glacial Plain Unit had similar G-values, but these were higher than those of the remaining six basins located in this unit. The geomorphology in the Glacial Plain differed to a sufficient extent to suggest a divisioning of the unit.

A physiographic divisioning of the Glacial Plain area of Illinois by Leighton and others (1948) indicated that the Sangamon and Kaskaskia basins were located in areas that had experienced two major glacial stages, the Hlinoian and Wisconsinan, whereas the remaining portion of the Glacial Plain Unit had largely experienced only one major glacial stage (Illinoian). Portions of both regions had experienced the Nebraskan and Kansan stages of the Pleistocene Period (Horberg, 1950). The line separating these two different physiographic areas is shown on figure 44. The differential morphology associated with the northeasternmost of these two portions of the Glacial Plain Unit apparently created runoff characteristics of streams in this area which are significantly different from those in the remaining portion of the Glacial Plain. Horberg (1950) describes the northeasternmost region, which has the Wisconsinan stage surface, as a till plain in an early stage of stream dissection with large areas without important valleys, whereas in the area with no Wisconsinan stage, stream erosion has cut deeply into the Illinoian drift surface bringing extensive modifications to the glacial surface. Thus, the Glacial Plain geomorphic unit was subdivided, based on major differences reflected in the two stages of the geomorphic cycle found in this unit. The G-values for the area experiencing two major glacial stages is the average of the Kaskaskia basin and Sangamon basin values in table 21, whereas the G-values for the area of one major glacial stage are the averages of those from the six other basins in the Glacial Plain Unit listed in table 21.

The similarity in the G-values for the different sized basins in the same geomorphic regions indicated that basin size did not influence the G-values. For example, the Kaskaskia basin is almost four times larger than the Sangamon basin and both had comparable G-values.

Frequency curves based on the G-values shown in table 22 are presented in figure 45. The different slopes represented by these curves are indicative of the varying effects on low flow exerted by the geomorphology of each region.

Application of Prediction Method

The method of predicting low-flow frequency distributions from precipitation frequency distributions and geomorphic indices was applied to data for drought periods of 6 to 60 months. For periods of 6, 24, 36, 48, and 60 months, analysis similar to that performed for the 12-month periods was accomplished. P-values for these five other periods were derived from 50-year records of precipitation at 62 raingage stations, and the R-values were determined for the 13 basins listed in table 21. For each period, G-values were computed for recurrence intervals of 2, 5, 10, 25, and 50 years for each basin. These G-values were grouped into the six geomorphic regions determined from the 12-month analysis (table 22). An example of the G-values for one of the six geomorphic regions is shown in figure 46. G-values for each of the drought durations in excess of 12 months are listed in table 23 for application by interested users.

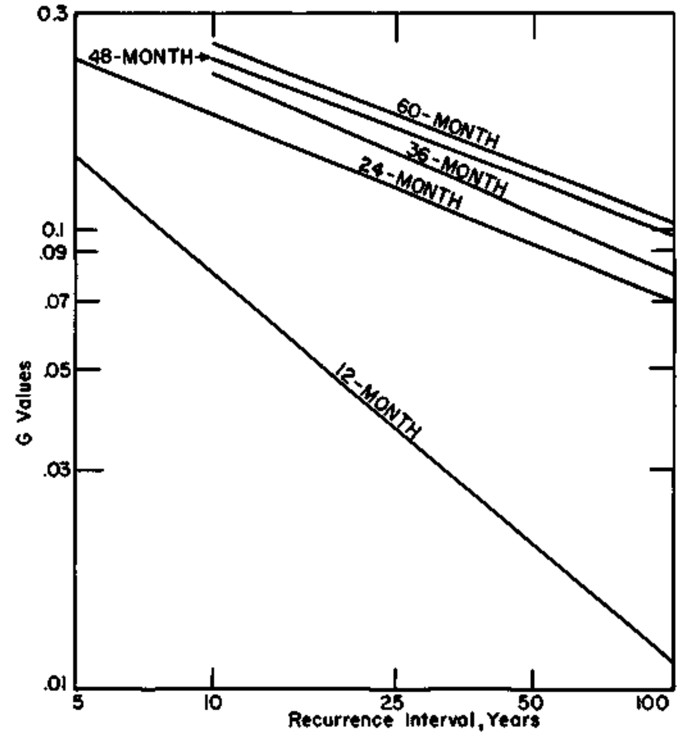


Figure 46. Distribution of G-values for 12- to 60-month periods in the Glacial Plain-1 geomorphic region

The method of predicting low flow was attempted for 6-month periods. However, the frequency distributions for this shorter period could not be determined as accurately or as simply as those for the longer periods, principally because of the complexities created by the effect of antecedent precipitation and by seasonal variations in the P-values and G-values. Similarly the method did not yield accurate estimates for any recurrence interval shorter than 5 years. This is attributed to the effect of other factors, such as land use and basin size, as well as season.

Application of the prediction method to determine the low flow frequencies for a given basin in Illinois is quite simple, as illustrated by the following example. For this purpose, the Vermilion River basin located in the Glacial Plain-2 region was selected (figure 44). This basin had 16 years of streamflow records through 1955. The frequency calculations performed for 12-month periods on this basin are shown in table 24. For each recurrence interval, the basin P-value (expressed as a percentage of normal) was multiplied by the normal basin precipitation and the result multiplied by the G-value to obtain the runoff value in inches. The P-values and the normal precipitation for the basin area were computed from figures 2 and 9.

Table 23. Frequency Distribution of G-Values for Selected Durations by Geomorphic Region

Geomorphic region	5-year 24	10-year 24	10-year 36	10-year 48	10-year 60	25-year 24	25-year 36	25-year 48	25-year 60	50-year 24	50-year 36	50-year 48	50-year 60	100-year 24	100-year 36	100-year 48	100-year 60
Glaciofluvial Plain	.22	.17	.21	.22	.23	.13	.15	.18	.18	.10	.13	.14	.15	.08	.10	.12	.12
Glaciolacustrine Plain	.22	.19	.22	.24	.24	.15	.17	.19	.19	.13	.14	.16	.16	.11	.12	.13	.13
Glacial Plain-1	.24	.18	.22	.24	.26	.12	.15	.17	.18	.09	.11	.13	.13	.07	.08	.10	.10
Glacial Plain-2	.26	.20	.22	.24	.25	.13	.16	.18	.20	.10	.13	.15	.16	.08	.10	.12	.13
Interior Plateau	.26	.24	.24	.28	.28	.22	.22	.26	.26	.20	.20	.25	.25	.18	.18	.24	.24
Dome Uplift	.31	.22	.28	.34	.34	.15	.19	.21	.21	.12	.15	.17	.17	.09	.13	.14	.14

Recurrence intervals and drought durations (months)

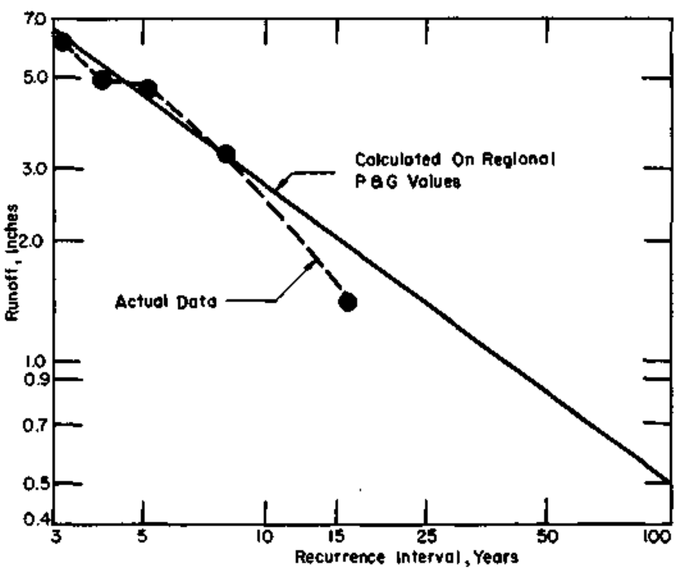


Figure 47. Frequency distribution of low flows for 12-month periods at Vermilion River Basin (Catlin)

Figure 47 shows a curve fitted to the predicted R-values in table 24 along with the frequency values determined from the actual data for the period of record of the Vermilion River at Catlin. The error which can be introduced into frequency distributions of low flows for basins with records of 25 years or less is illustrated by differences in these frequency distributions for this basin (figure 47). The 16-year value determined from the actual data is considerably less than the 16-year predicted value. Examination of figure 47 reveals that the actual low flow value of 1.4 inches given as the 16-year value, is the calculated 25-year value. The calculated frequency curve indicates that the 16-year runoff value is almost 2.0 inches rather than the 1.4 inches indicated by the actual data.

Table 24. Calculated Low Flows for 12-Month Periods on the Vermilion River at Catlin

Recurrence interval, years	Normal precipitation, inches	P-values, percent of normal	G-values	Calculated runoff, inches
5	36.5	78	.16	4.6
10	36.5	68	.11	2.7
25	36.5	60	.06	1.3
50	36.5	55	.04	0.8
100	36.5	48	.03	.05

The 1.4-inch low flow was for the 12-month period ending in December 1954; and according to long-period precipitation records in the basin area, a 12-month period ending in the summer of 1954 was the second worst precipitation drought in the area in over 50 years. Thus, moderately short streamflow records can easily lead to erroneous low flow frequency distributions especially if extremely severe precipitation droughts have occurred during the sampling period. Other examples of the errors introduced by short-period streamflow records were found in the Illinois study.

Macoupin Basin Abnormality

A further illustration of the use and application of the prediction method is revealed by analysis performed for the Macoupin basin which lies in the Glacial Plain-1 region (figure 44). The actual frequency curve of low flow, based upon 35 years of record from 1920 through 1955, indicates abnormally low flows for a given recurrence interval compared with the other six basins with long records in the same geomorphic region. In fact, the Macoupin basin has experienced much lower flows than any of the 13 basins with long records. Consequently, data from the Macoupin basin were not used in the calculation of the G-values for this region because these data were considered nonrepresentative.

Subsequently, an effort was made to determine why the Macoupin low flow distribution departs so radically from that of other basins in its region and from that predicted through use of the R/P relationship for the geomorphic region. It was found that, to a large extent, the departure resulted from an abnormal frequency of severe precipitation droughts on the Macoupin basin during the 35-year runoff sampling period.

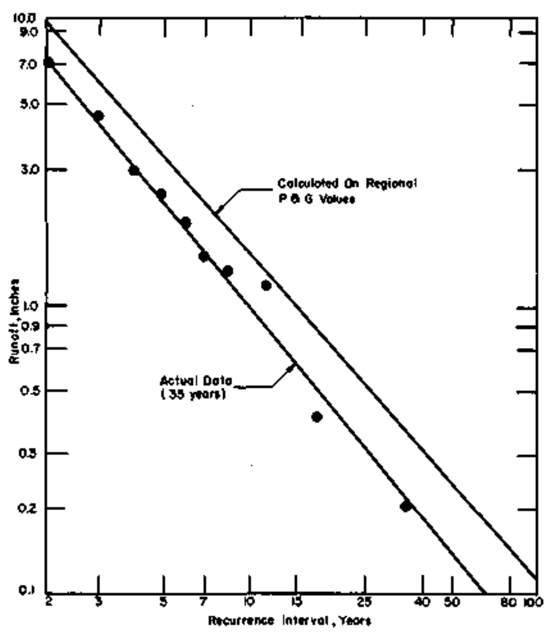


Figure 48. Frequency distribution of low flow for 12-month periods at Macoupin Creek Basin

Figure 48 shows the frequency curve of low flow for Macoupin, based upon actual data, along with a predicted curve which has obtained from the use of the G-values for this geomorphic region in conjunction with the P-values for the Macoupin basin. The difference between these two curves for 12-month periods has been summarized in table 25. This table shows that the relative difference between the two curves increases with increasing recurrence interval. For example, the 2-year low flow from the 35-year curve is equivalent to the 2.7-year low flow on the calculated curve, whereas the 50-year value obtained from

Table 25. Comparison of Actual Data and Predicted Low Flow Values from Frequency Curves for Macoupin Creek

Actual data recurrence interval, years	Predicted recurrence interval, years
2	2.7
5	7
10	15
25	40
50	80

the Macoupin curve is equivalent to the 80-year value on the calculated curve.

These comparisons suggested that the sectional nonrepresentativeness of the Macoupin low flow may have resulted from an unusual number of severe precipitation droughts. The study of precipitation drought has shown that the 1953-1954 precipitation drought was centered near the Macoupin basin, and this drought was the worst in the 1901-1955 sampling period in this region. Further, the 1930-1931 precipitation drought, which was the most extensive of the severe droughts in Illinois, was also centered near the Macoupin basin. These occurrences indicated that the 35-year Macoupin runoff sample probably reflected a low flow distribution which is too severe, especially for the longer recurrence intervals.

Partial verification of this assumption was obtained from a study of the 100-year precipitation record at St. Louis, about 45 miles southwest of the Macoupin basin. This record indicated that the above two droughts were the worst in the 100-year sampling period. Assuming 1) a 100-year sample is representative of the population distribution (true distribution) of drought and low flow and 2) the St. Louis precipitation distribution is approximately representative of the Macoupin basin distribution during the 100 years with respect to departures from normality, the 1931-1932 and 1953-1954 low flow values would be expected to approximate the 50- and 100-year recurrences. In obtaining the actual data curve (figure 48), however, these two low flow values were assigned frequencies of 35 and 17.5 years. This would cause the derived frequency curve to predict runoff amounts that are too low for a given recurrence interval, particularly for the longer recurrence intervals.

Next, it was assumed that the two lowest flows in the 35-year Macoupin sample represented 50-year and 100-year average occurrences, but that the rest of the ranked flows were representative of their ranked positions; that is, it was assumed that the third-ranked low flow represented the minimum flow to be expected once in about 12 years, the fourth-ranked value represented a once in 9-year occurrence, etc. Then, from this modified ranking, a modified low flow frequency curve was determined for the Macoupin basin. Runoff values obtained with the actual, calculated, and modified frequency curves are shown in table 26 for selected recurrence intervals of 5 to 100 years. The amounts obtained from the modified curve compare favorably with those calculated from P values, especially for recurrence intervals of 25 to 100 years. Even the 5-year modified value is within 12 percent and 0.4 inch of the calculated flow value. That the curve based on actual data gives runoff amounts that are much lower than the calculated values, at least on a percentage basis, is clearly shown.

The findings indicate that relatively large differences in the low flow characteristics between the Macoupin basin and the other six basins with similar geomorphology (table 21) resulted to a large extent from the vagaries of sampling. The results stress the importance of utilizing all available meteorological data and knowledge in conjunction with runoff data in the analyses of low flow frequency distributions. The results vividly illustrate how even a relatively long sampling period can also lead to erroneous conclusions unless all factors are considered.

Table 26. Comparison of Low Flows Derived from Macoupin Creek Actual Data, from Modified Data, and from Predicted Frequency Curve

Recurrence interval, years	Low flow, inches: Actual data	Modified	Predicted
5	2.4	3.0	3.4
10	1.0	1.3	1.5
25	0.32	0.52	0.54
50	0.14	0.27	0.25
100	0.006	0.13	0.11

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