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Detecting Drought Conditions in Illinois

by STANLEY A. CHANGNON, JR.

ILLINOIS STATE WATER SURVEY
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CIRCULAR 169

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Reference: Changnon, Stanley A., Jr. Detecting Drought Conditions in Illinois. Illinois State Water Survey, Champaign, Circular 169, 1987.

Indexing Terms: Crop yields, drought, drought initiation, drought severity, drought termination, ground water, hydrologic conditions, Illinois, low flows, precipitation, soil moisture, streamflow, water levels, water shortage.

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Appendices

This report is dedicated to J. Loreena Ivens on the occasion of her retirement, in recognition of her important contributions to many of the author's scientific papers and reports dealing with the weather, climate, and water resources of Illinois.

INTRODUCTION

A major study of Illinois droughts was conducted to develop a basis for quantitative assessments of drought conditions in Illinois (Changnon, 1987). Such information should aid decision making related to local and state actions to ameliorate the effects of future droughts. Those who must deal directly with some aspects of drought, be they farmers, city officials, or staff of state agencies, need to know 1) whether a drought is developing, 2) how severe the drought is at any given time, and 3) how long the drought will last. This report provides information to help address these questions.

In the recent past, Illinois experienced two droughts detrimental to the state's economy and natural resources (Changnon *et al*., 1982; Drought Task Force, 1977). The droughts of 1976-1977 and 1980-1981 were the first periods of major moisture deficiencies since the mid-1950s. During each recent drought, the Governor of Illinois established a Drought Task Force to consider remedial actions. In both instances, it became apparent to local and state officials that better means of assessing the onset, severity, and termination of drought conditions were needed (Changnon and Semonin, 1982). In 1984 the lack of an organized approach to drought problems in Illinois led the Task Force of the Illinois State Water Plan to identify "Drought Contingency Planning" as one of the top 10 water issues needing attention in Illinois (Water Plan Task Force, 1984). The *Illinois State Water Plan* calls for development of a coherent approach to drought management. The Water Survey also prepared a public information document about droughts (Hilberg and Changnon, 1984).

Drought Definitions

One of the obstacles to an objective and reasoned reaction to drought in Illinois is uncertainty over its definition.

What Is Drought? Drought is a complex physical and social phenomenon of widespread significance, and despite all the problems droughts have caused, drought has proven difficult to define. There is no universally accepted definition because: 1) drought, unlike flood, is not a distinct event, and 2) drought is often the result of many complex factors acting on and interacting within the environment (Changnon, 1980). Complicating the problem of drought definition is the fact that drought often has neither a distinct start nor end. It is usually recognizable only after a period of time and, because a drought may be interrupted by short spells of one or more wet months, its termination is difficult to recognize.

Drought is also a temporary feature of the climate of Illinois, and we know it occurs only when less than adequate precipitation exists for an extended period of time. Because of the complex nature of droughts, there are many definitions, often reflecting a specific area of concern of an individual, a city, or a region.

Natural factors commonly assessed to determine drought presence include weather conditions, soil moisture, water table conditions, water quality, and streamflow. Their interactions and the areas of impact caused by drought are illustrated in Figure 1. Some of the impacts affecting people involve water storage systems; the availability of ground water in shallow wells; decreased water use per capita; decreased water services; and a myriad of economic considerations (Changnon et al., 1982). Consequently, the particular criteria used in defining drought may include one or more of the following: precipitation, streamflow, runoff, evapotranspiration, ground water levels, water supply, and water needs.

In essence, the term drought is generally associated with a sustained period of significantly abnormal water or moisture supply. A precise definition of a "sustained" period is not attainable and would vary with drought impacts. For instance, in a humid environment like that of Illinois, where precipitation is normally well distributed throughout the growing season (and where irrigation is not widely practiced), a summer dry period lasting several weeks may constitute a "crop drought." On the other hand, it may take one or more years of deficient precipitation before certain water demand areas, such as those served by urban water supplies, are drought-affected (Changnon, 1980).

The temporal complexity of drought and its impacts on parts of the physical system are revealed in Figure 2. This shows how hypothetical fluctuations in precipitation over a 4-year period are translated, in delayed form, to runoff and then to soil moisture, streamflow, and ground water. Deficiencies in each aspect of the hydrologic cycle develop and end at different times.

The most commonly used drought definitions are based on 1) meteorological and/or climatological conditions, 2) agricultural problems, 3) hydrological conditions, and 4) economic considerations.

Meteorological Drought. This type of drought is often defined by a period of well-below-normal precipitation. The commonly used definition of meteorological drought is attributed to Palmer (1965), who described drought as an interval of time, generally of the order of months or years, during which the actual moisture supply at a given place rather consistently falls short of climatically appropriate moisture supply.

Meteorological droughts relate to deficiencies of water somewhere in the hydrologic cycle. Changnon (1977) showed that within the hydrologic cycle, evaporative processes must be "served." That is, regardless of low precipitation levels that occasionally occur in Illinois, crops and other plants continue to grow (although less than usual, possibly resulting in low crop yields). Hence, the evapotranspiration (ET) demand proceeds at a relatively fixed rate in most years. Jones (1966) calculated annual ET at a point in northern Illinois for 1951-1959 and reported that the highest annual value was 28.2 inches and the lowest was 25.4 inches. This "demand" on moisture in the soil and water bodies must be satisfied before most water for runoff and infiltration is

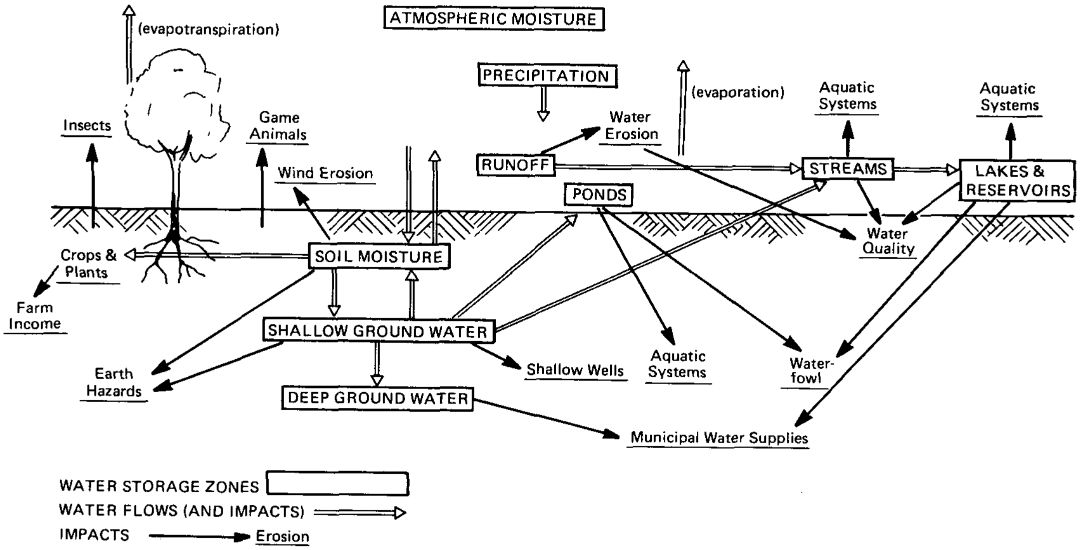


Figure 1. Hydrologic conditions affected by droughts, and related impacts.

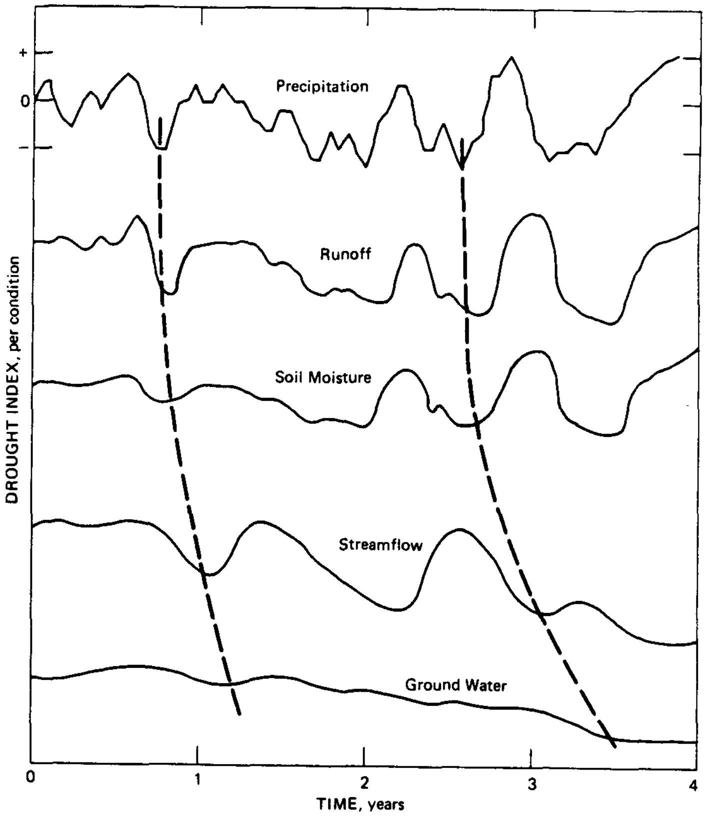


Figure 2. A schematic showing how precipitation deficiencies during a hypothetical 4-year period are translated in delayed fashion, over time, through other components of the hydrologic cycle.

available; hence ET occurs at the expense of runoff and ground water recharge in droughts.

This explains why one finds streamflow values exhibiting much greater departures below normal in a dry period than do the precipitation values. Table 1 illustrates this for the Sangamon River Basin, using the five most severe 30-month dry periods in the 1901-1983 period. ET was treated as a constant in each dry period. Note in Table 1 how well the differences (precipitation minus atmospheric loss) approximate the actual measured streamflows. Also note in the lower portion of Table 1 that the percentage departures of streamflow from normal were much greater than the precipitation departures. When precipitation was 24% below normal in the top-ranked (worst) dry period, streamflow was 79% below normal.

Agricultural Drought. This is a definition often applied to deficiencies in the amount of water needed relative to that available for agricultural requirements. Agriculturists are usually concerned with soil moisture deficiencies as they relate to crop development and yield. Agricultural drought is typically defined as a period when soil moisture is inadequate to meet evapotranspirative demands so as to initiate and sustain crop growth. Another facet of agricultural drought is deficiency of water for livestock or other farming activities.

Hydrologic Drought. This typically refers to periods of below-normal streamflow and/or depleted reservoir storage (Hudson and Roberts, 1955; Changnon, 1981). Depending on the duration of the event, hydrologic drought may include sustained low flows or drought events (Huff and Changnon, 1964). A low-flow event typically refers to a short period of low streamflow occurring on an annual basis; for example, the annual minimum daily streamflow and the 7-day, 10-year minimum (Stall, 1964). If the actual low flow of a natural stream for a selected number of days has a small probability of occurrence, one concludes that a drought in the hydrologic sense is in progress. Closely related to the concept of low flow in defining drought is the use of the number of consecutive months that a streamflow was deficient; that is, within the lowest 50% of record for the monthly record.

Economic Droughts. These droughts are a result of physical processes but concern the areas of human activity affected by drought (Changnon *et al*., 1982). The human effects, including the losses and benefits in the local and regional economy, are often a part of this definition.

Scope

This report draws upon relevant results of in-depth studies of most critical aspects of droughts, including the major components of the hydrologic cycle. These results pertain to drought as reflected in precipitation conditions, soil moisture conditions, shallow ground water levels, and streamflows. Monitoring of these four conditions, coupled with the use of relationships developed in the major drought study mentioned above (Changnon, 1987), allows both the identification of the presence of drought and the quantification of its severity if it does exist. Procedures for such assessments are presented in this report. Routine monitoring of these four conditions serves to detect the onset of droughts in Illinois, and routine state monitoring is advised. Ways to estimate the end of drought are not perfect, but this study offers means by which the termination of drought can be estimated.

Table 1. Assessment of Hydrologic Cycle during 30-Month Droughts in the Sangamon River Basin (1901-1983)

Rank	Precipitation (P) Inches	Water Loss to the Atmosphere (AL) Evapotranspiration and Evaporation. Inches[1]	P minus AL, Inches	Actual Streamflow, Inches
1	68	67	1	5
2	72	67	5	6
3	79	67	12	11
4	82	67	15	13
5	84	67	17	14

Dry Rank	Period Values as Percent of Normal Precipitation	Streamflow	Comparison of Percentage Departures Below Normal Precipitation		Streamflow
1	76%	21%	24%	vs	79%
2	80%	27%	20%	vs	83%
3	89%	46%	11%	vs	54%
4	91%	55%	9%	vs	45%
5	93%	57%	7%	vs	43%

[1] Based on an annual estimate of 26 inches per year, derived from Jones (1966)

Drought Relationships

In our in-depth studies concerning soil moisture, streamflow, and shallow ground water, we related climate variables to available moisture in each part of the hydrologic cycle, Individual relationships between climate variables and 1) soil moisture, 2) streamflow, and 3) shallow ground water were defined (Changnon, 1987). The patterns of these series of relationships (soil moisture, shallow ground water, and streamflow) defined regions on the basis of different yet very specific relationships between weather variables (generally precipitation) and the hydrologic condition under consideration. It is important to appreciate that because of varying geologic factors, soils, and climate conditions in Illinois, various regions of the state have drought conditions that are unique to that region. Presented herein are those patterns of conditions that are believed most useful in interpreting the presence and magnitude of drought at any point in Illinois.

HOW TO DETERMINE IF DROUGHT IS PRESENT

Estimation of Precipitation Drought

"Precipitation drought" can be delineated for periods ranging from 3 months up to 60 months. Dry periods of less than 3 months duration do not equate to drought, except in those unusual circumstances of extremely hot and dry weather in June, July, and/or August, which can affect corn and soybean yields. Studies of past precipitation amounts related to droughts causing measurable physical and socioeconomic impacts during 1901-1983 led us to define criteria indicating droughts 1) at the state scale, and 2) at the local (point, county, basin, etc.) scale.

The state-scale criteria of drought occurrence included two conditions:

1) the statewide mean precipitation departure; and
2) the areal extent of the precipitation deficiency.

Most relevant to the definition of the presence of precipitation droughts, as defined on a statewide basis, is the statewide average precipitation value. The criteria that discriminate precipitation droughts are as follows:

- A 3-month precipitation drought exists if the state average is ≤60% of the mean value.
- A 6-month precipitation drought exists if the state average is ≤70% of the mean value.
- A 12-month precipitation drought exists if the state average is ≤80% of the mean value.
- A 24-month drought exists if the state average is ≤90% of the mean value.
- A 30-month to 60-month drought exists if the state average is ≤95% of the mean value.

The areal extent of the threshold value (for any duration) should be measured and then expressed as a percent of the total state area. This serves as a second measure of severity. The area of the state experiencing values below the threshold value should equal or exceed 40% of the state for the drought period to truly qualify as a "statewide drought." It should be recognized that in certain circumstances the first criterion (achieving a statewide mean threshold) may be met, but a very small area, covering much less than 40% of the state, may be well below the threshold. This is not to say that there is not a drought in that area. What this approach does say is that in this circumstance, this period does not rank as a statewide drought, only as a small-scale regional drought where the precipitation values fall below the drought threshold. Application of these statewide drought criteria at any given time to determine the presence of precipitation drought is now illustrated.

Drought-Related Calculations. First, from a network of approximately 50 well-distributed weather stations, a statewide average precipitation pattern for a given period (3 months or longer) should be determined. The values should be expressed as a percent of the means given in Figure 3, 4, or 5. This percentage is then compared to the appropriate drought threshold value shown above.

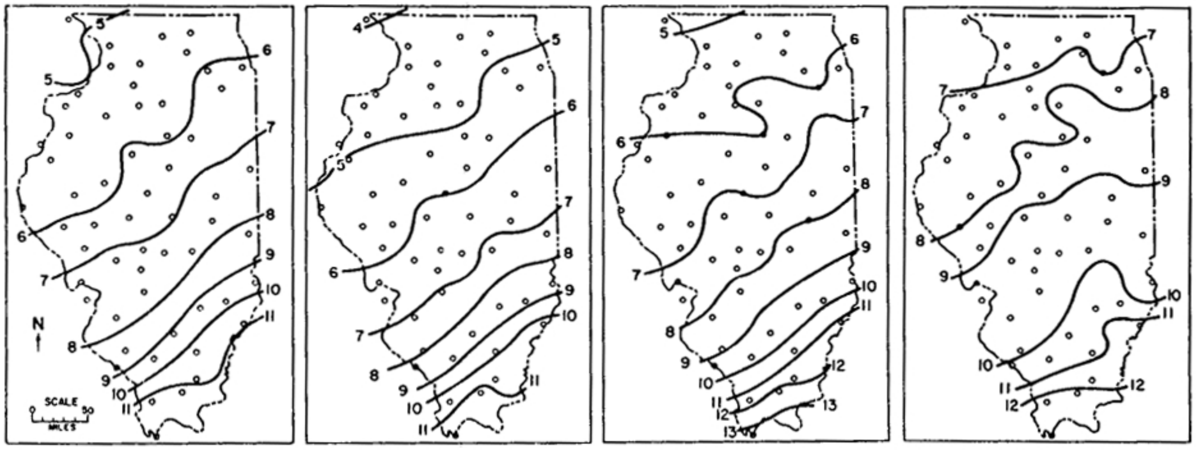
Figures 3, 4, and 5 present mean precipitation patterns to be used in developing departures from mean values needed for periods of varying durations at any given point in the state. For example, if one was concerned about the status of a 6-month precipitation total of 14 inches at the end of July 1992 near Urbana, one would first compare the value with the mean value of 20 inches at Urbana selected from Figure 4. Then, the departure from the mean is calculated (20 - 14 = 6 inches below the mean), and its percentage of normal (14 inches is 70% of the mean) is determined.

If this value makes the period qualify as a statewide precipitation drought, then the second criterion should be investigated; that is, 40% or more of Illinois should meet the departure criteria.

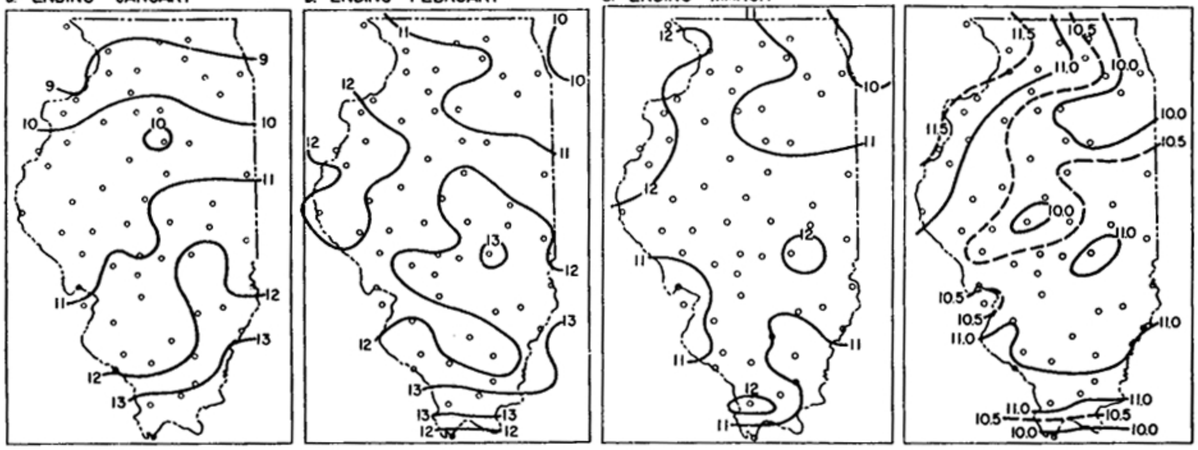
Figure 6 shows average area-depth curves for various drought durations, and these can be utilized to further assess a statewide drought. For example, a given 12-month period suspected of being a drought (based on precipitation deficiency) can be analyzed in the following manner. First, the percentage pattern of precipitation deficiencies for the 12-month period under investigation is plotted (using 5% isolines), and the areal extent of each of the various percentage interval values is calculated (that in 45 to 50%, 50 to 65%, etc.). Use of these values allows the development of an area-depth curve for the specific 12-month period under investigation. The resulting curve can be compared with that shown in Figure 6c (for 12-month droughts) to assess how the specific period under question relates to the past 12-month precipitation droughts in the state.

Precipitation Drought Severity. Guidelines for assessing the severity of statewide precipitation droughts were developed for those with 3- to 24-month durations. The known physical and economic impacts of past droughts were used to develop two categories of precipitation droughts: moderate and severe. This process is illustrated for 12-month droughts in Figure 7 (Changnon, 1980).

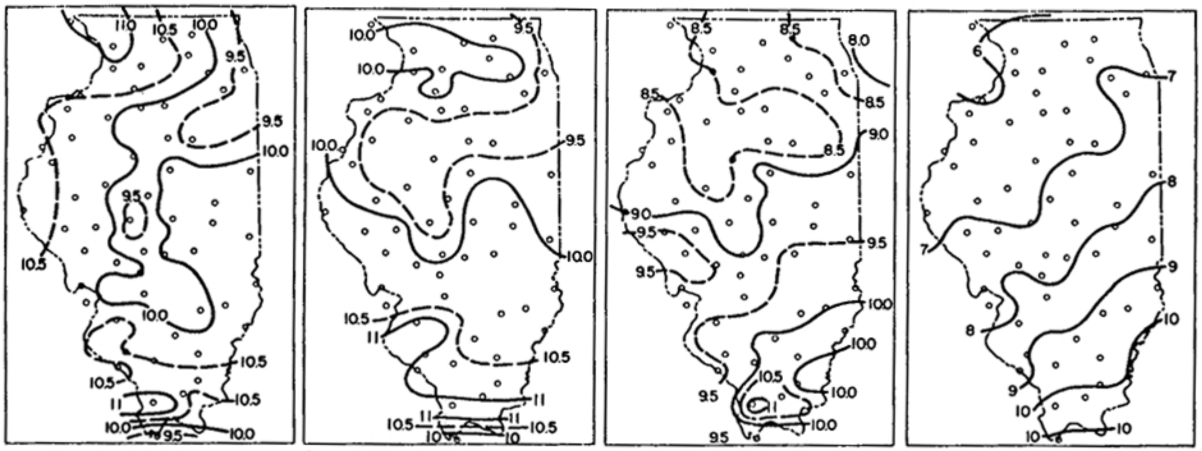
Analysis of droughts revealed that roughly 35-40% of the statewide precipitation droughts in any duration occurred within the "severe" level, and all others were classified as "moderate." The values in Table 2 provide the magnitude of precipitation values (expressed as percent of



a. ENDING JANUARY b. ENDING FEBRUARY c. ENDING MARCH d. ENDING APRIL

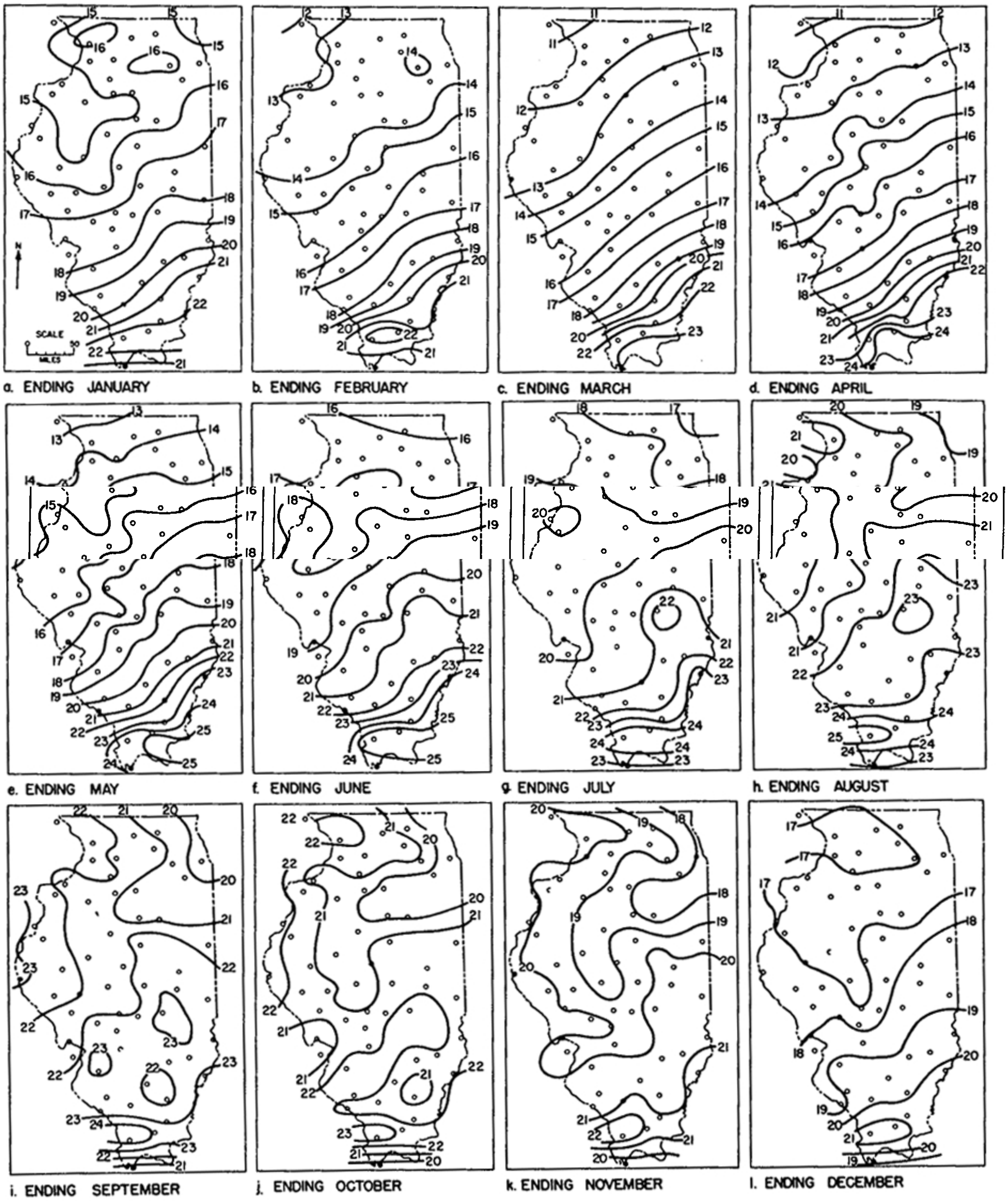


e. ENDING MAY f. ENDING JUNE g. ENDING JULY h. ENDING AUGUST



i. ENDING SEPTEMPER j. ENDING OCTOBER k. ENDING NOVEMBER l. ENDING DECEMBER

Figure 3. Three-month average precipitation ending in month indicated, inches.



a. ENDING JANUARY
b. ENDING FEBRUARY
c. ENDING MARCH
d. ENDING APRIL
e. ENDING MAY
f. ENDING JUNE
g. ENDING JULY
h. ENDING AUGUST
i. ENDING SEPTEMBER
j. ENDING OCTOBER
k. ENDING NOVEMBER
l. ENDING DECEMBER

Figure 4. Six-month average precipitation ending in month indicated, inches.

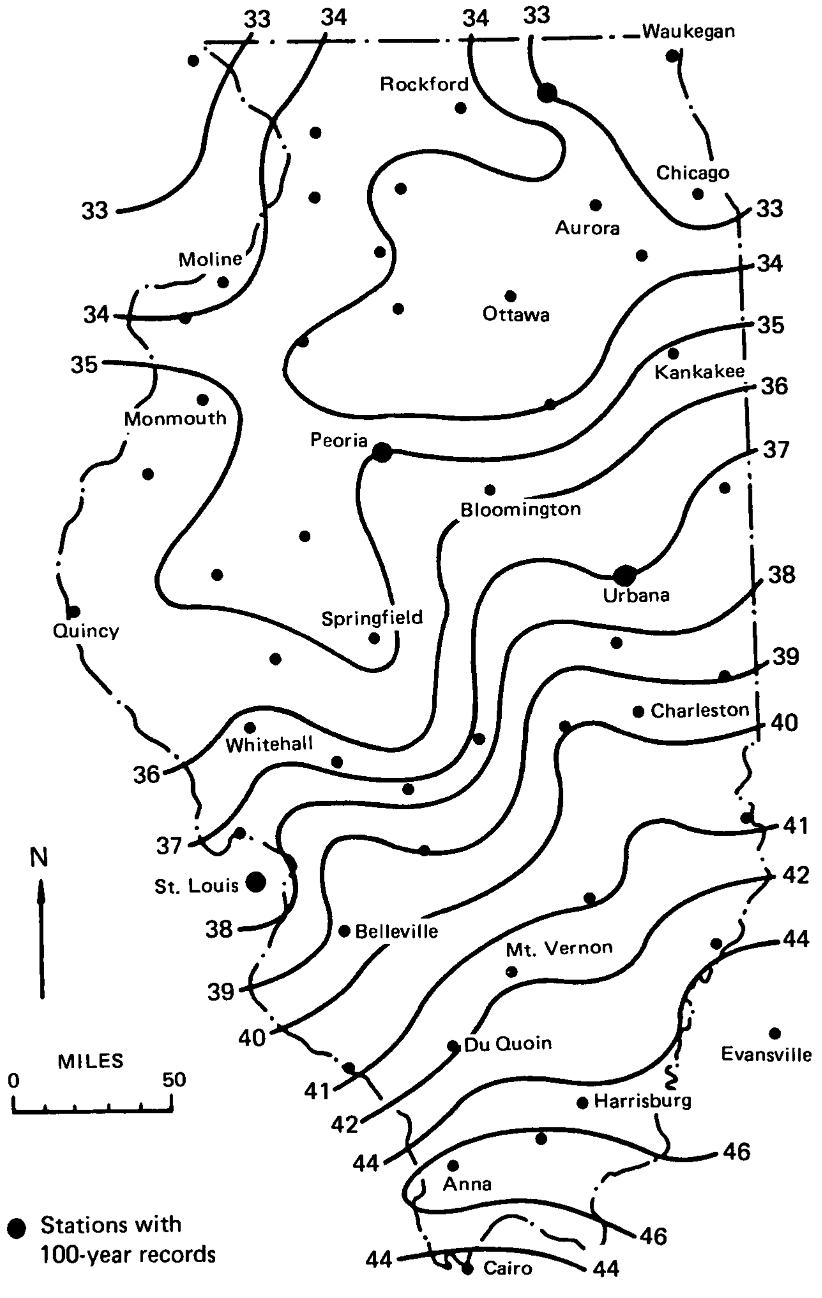


Figure 5. Average (mean) annual precipitation, inches.

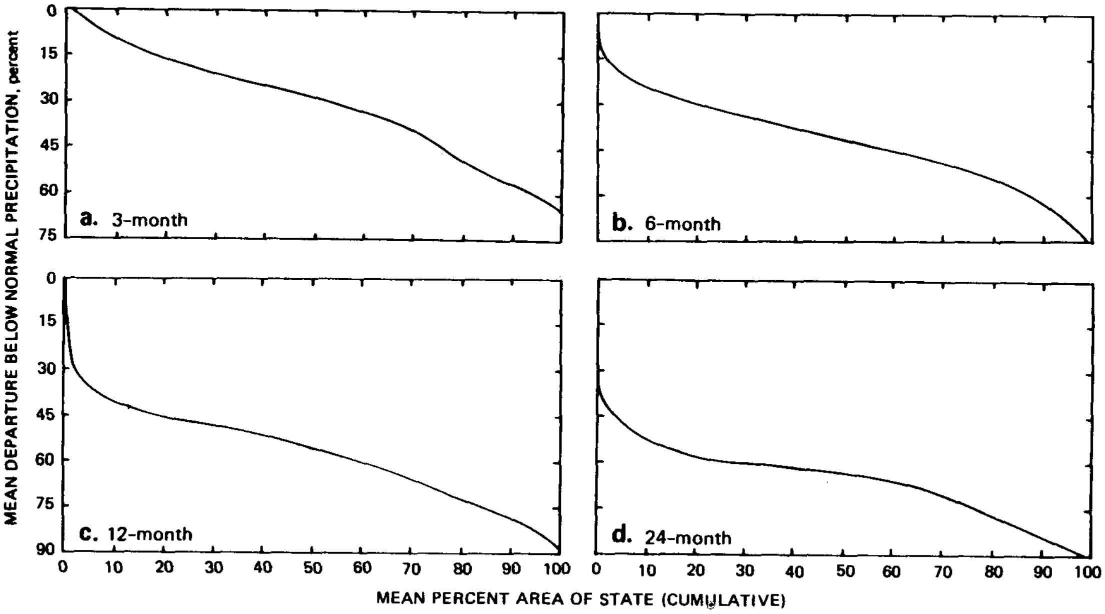


Figure 6. Average area-depth curves based on all droughts of varying durations during 1901-1983.

mean) for classifying a precipitation drought, on a statewide basis, as to severity.

Severity of a precipitation deficiency at any given locale (or point) in Illinois can be assessed in the following way.

Figures 8-12 present precipitation-deficiency patterns for periods of different durations ranging from 12 months to 60 months. The precipitation-deficiency values (in percentages of normal) are expressed for various return intervals of 5-, 10-, 25-, and 50-year frequencies. For example, if one had a 12-month precipitation value for 1955 of 64% of the mean for a point in extreme southern Illinois, comparison of this value with the maps in Figure 8 would show that it ranked as a once-in-10-year event. In this manner, the values shown on Figures 8-12 can be used in making a point. county, or basin assessment of precipitation droughts. (They are also used in the calculations of low flow and ratings of low-flow values, as discussed later.)

Point or basin values that equate to recurrence intervals of 5 years or less are here classed as mild drought.

Those that equal or exceed 5-year values and are less than 20-year interval values are classed as moderate precipitation droughts.

Those values that exceed 20-year recurrence interval levels are here classed as severe droughts.

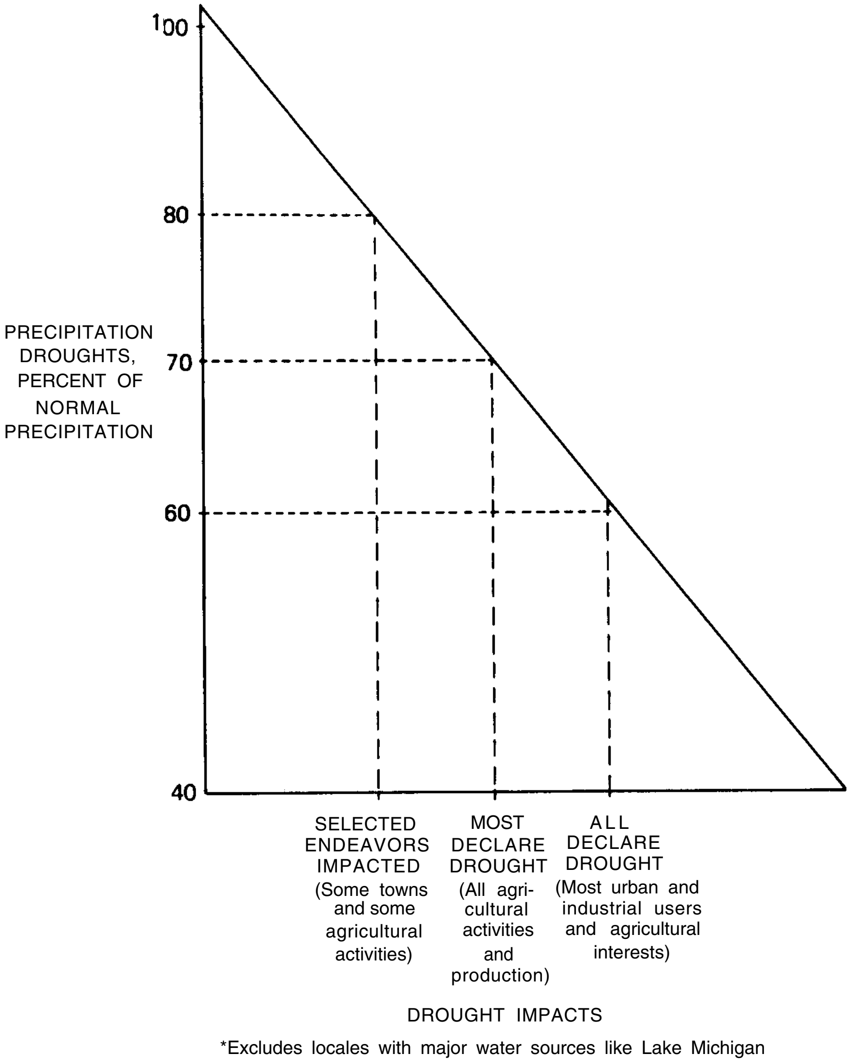
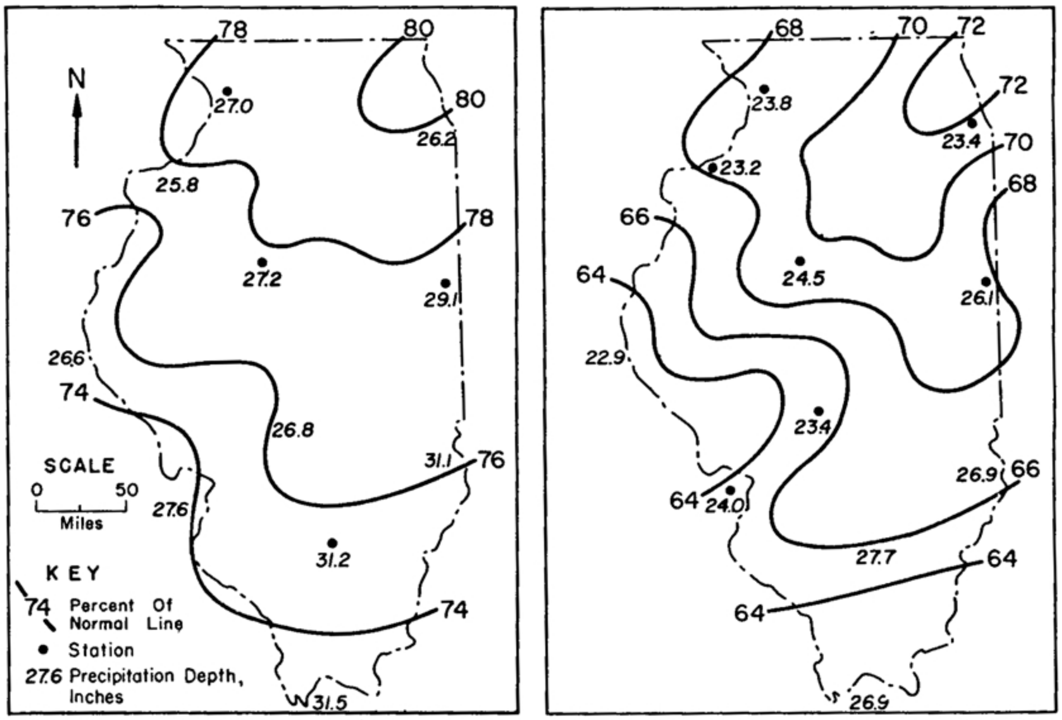


Figure 7. Relationships between 12-month precipitation droughts in Illinois (expressed as a percent of average precipitation) and drought impacts.

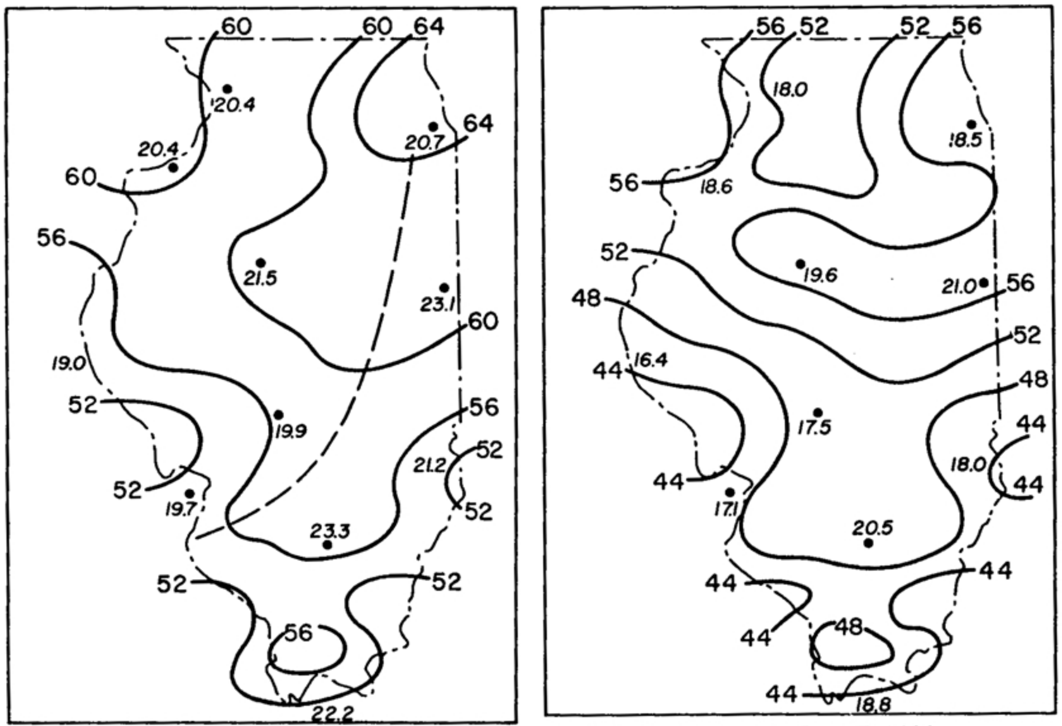
Table 2. Severity of Precipitation Droughts

Drought Duration	Moderate Drought[1]	Severe Drought[1]
3 months	45 to 60%	≤44% of mean
6 months	56 to 70%	≤55% of mean
12 months	70 to 80%	≤69% of mean
24 months	78 to 90%	≤77% of mean

[1] All percentages in relation to mean values

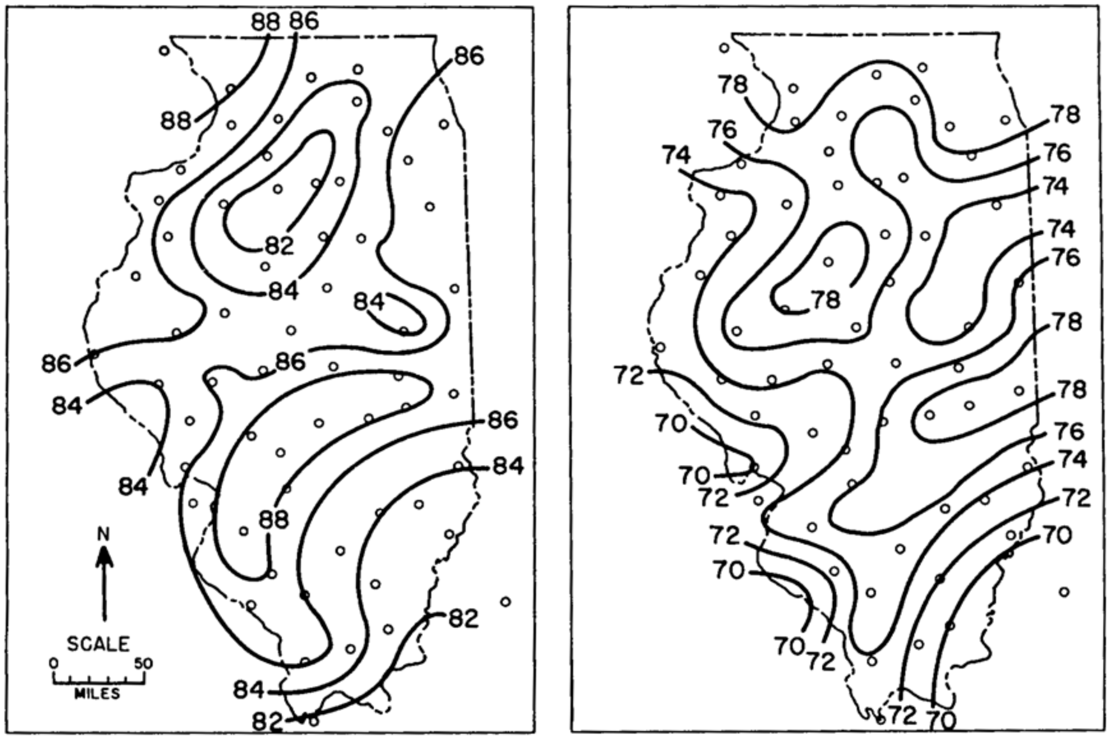


a. 5-YEAR FREQUENCY b. 10-YEAR FREQUENCY

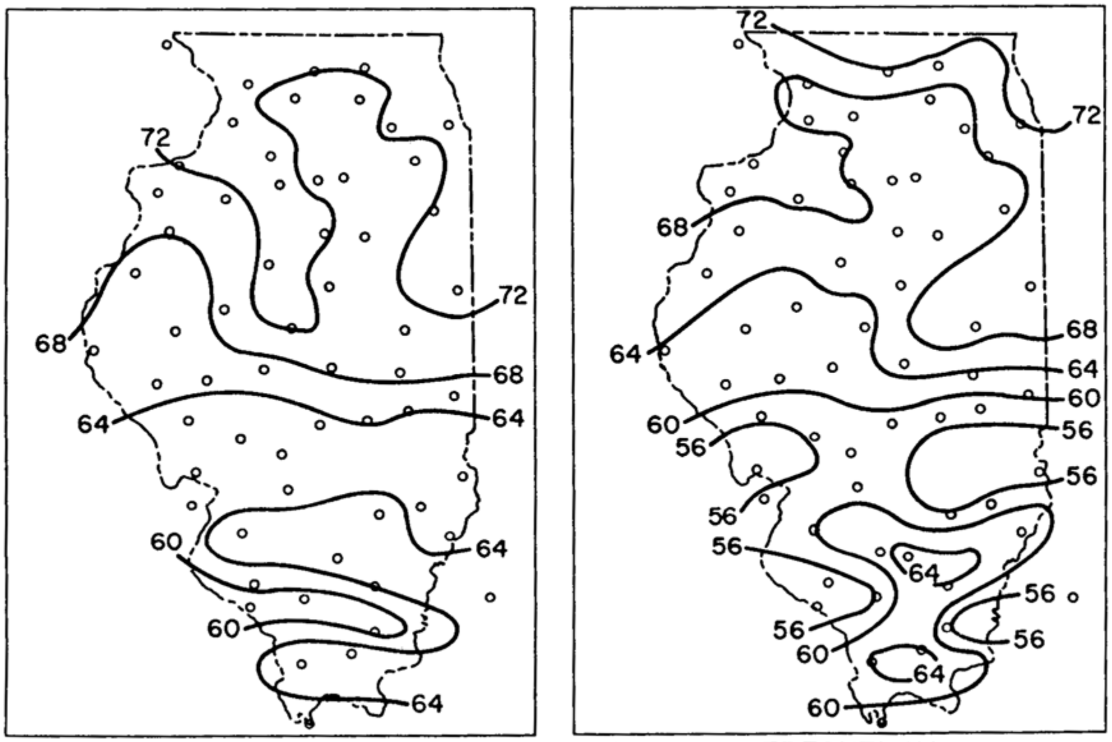


c. 25-YEAR FREQUENCY d. 50-YEAR FREQUENCY

Figure 8. Frequency values of 12-month drought periods, expressed as percent of average 12-month precipitation.

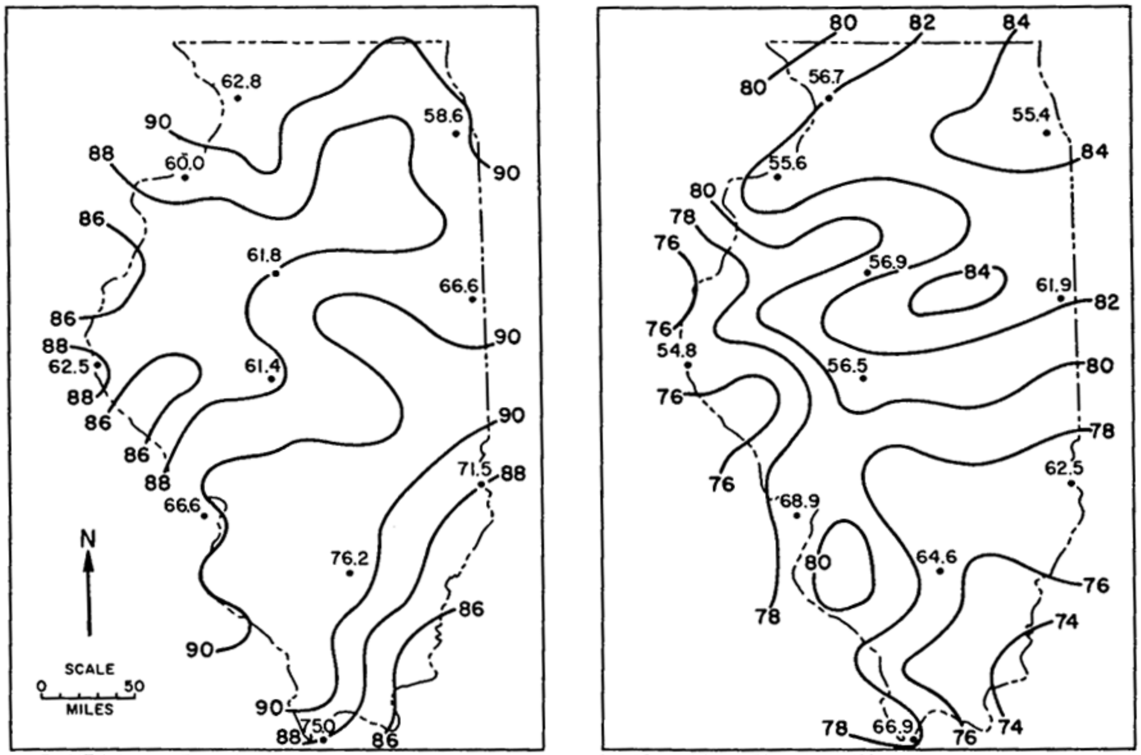


a. 5-YEAR FREQUENCY b. 10-YEAR FREQUENCY



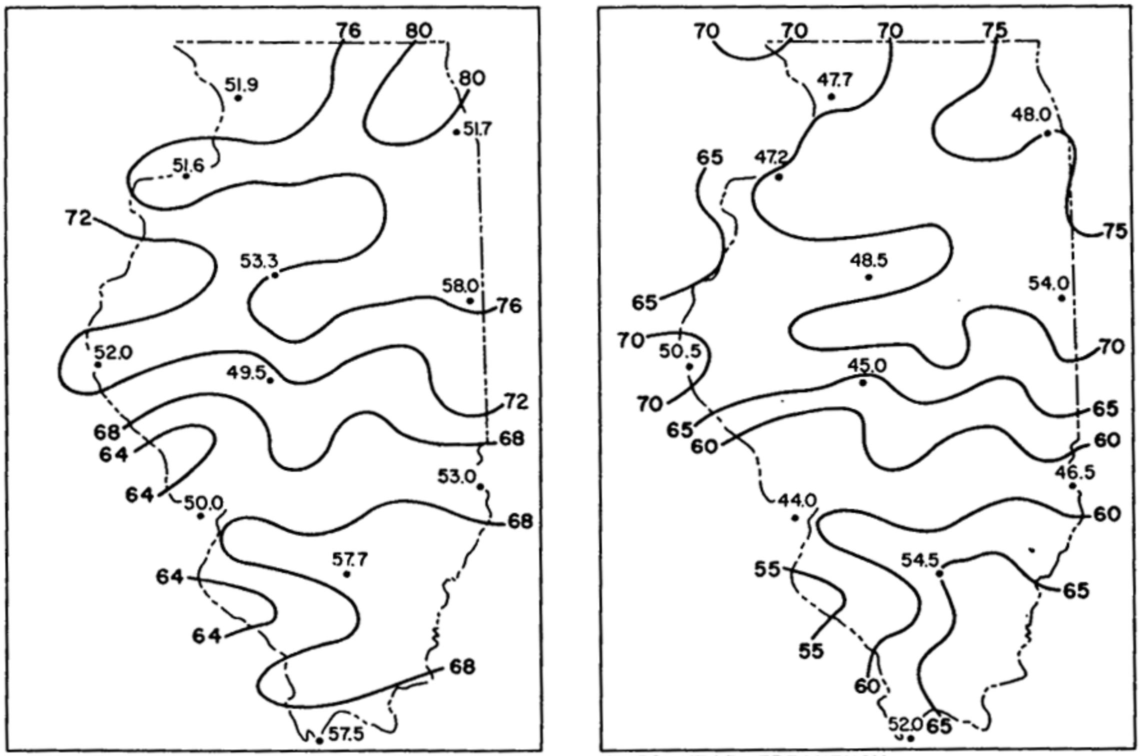
c. 25-YEAR FREQUENCY d. 50-YEAR FREQUENCY

Figure 9. Frequency values of 18-month drought periods, expressed as percent of average 18-month precipitation.



a. 5-YEAR FREQUENCY

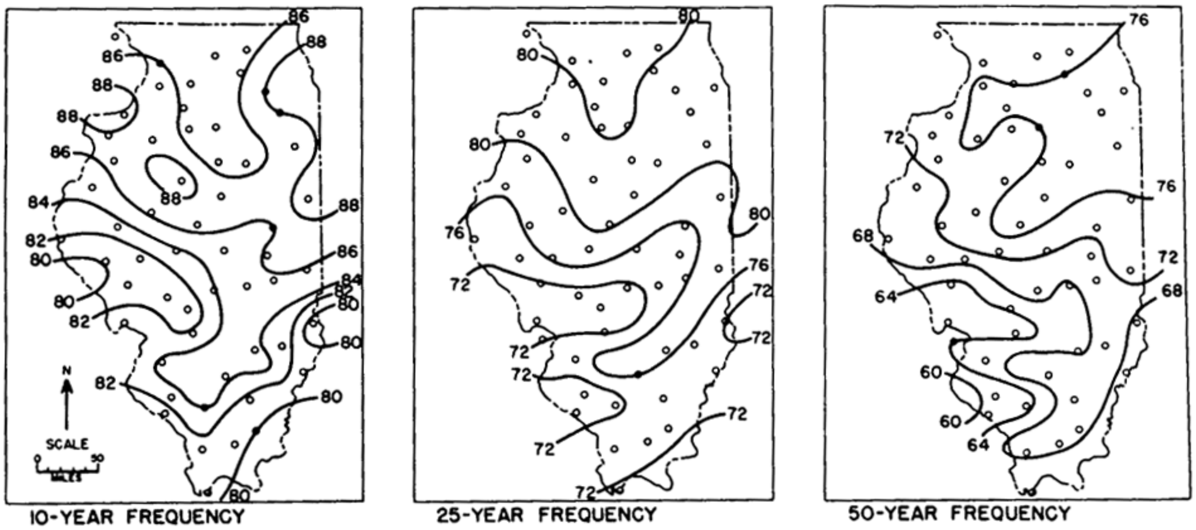
b. 10-YEAR FREQUENCY



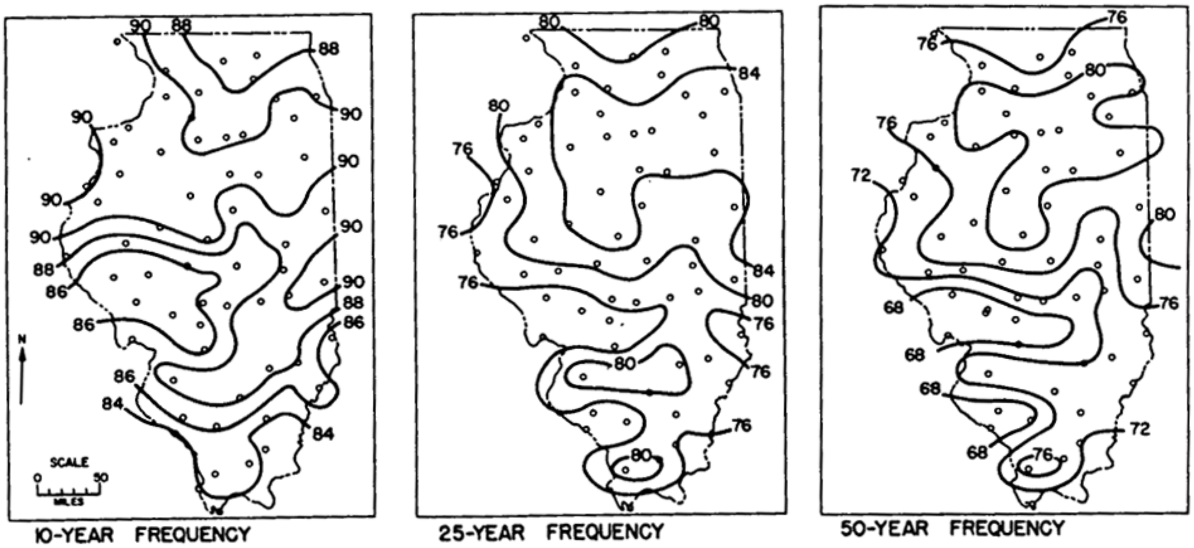
c. 25-YEAR FREQUENCY

d. 50-YEAR FREQUENCY

Figure 10. Frequency values of 24-month drought periods, expressed as percent of average 24-month precipitation.

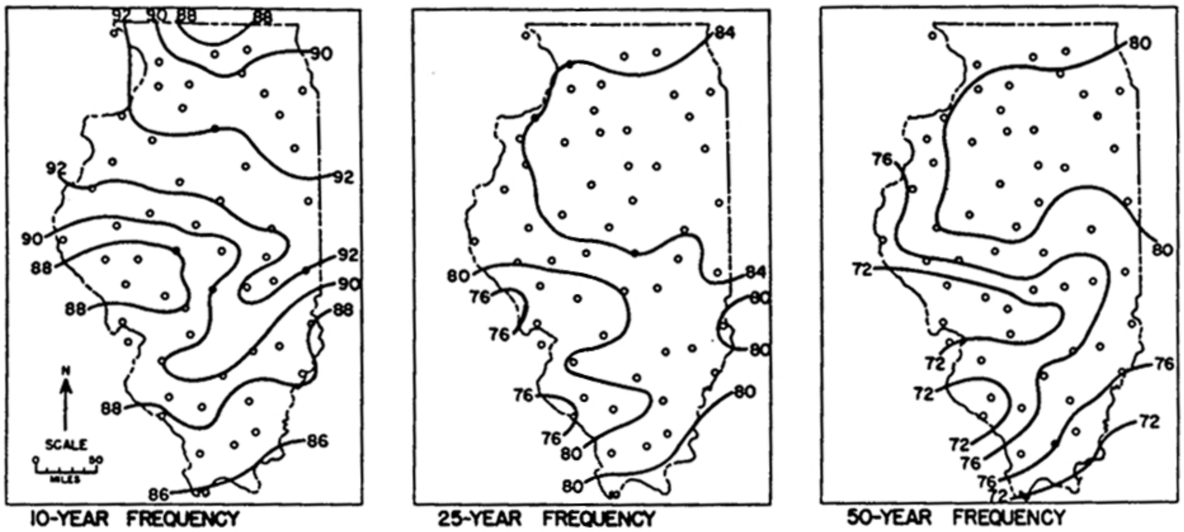


a. 30-month

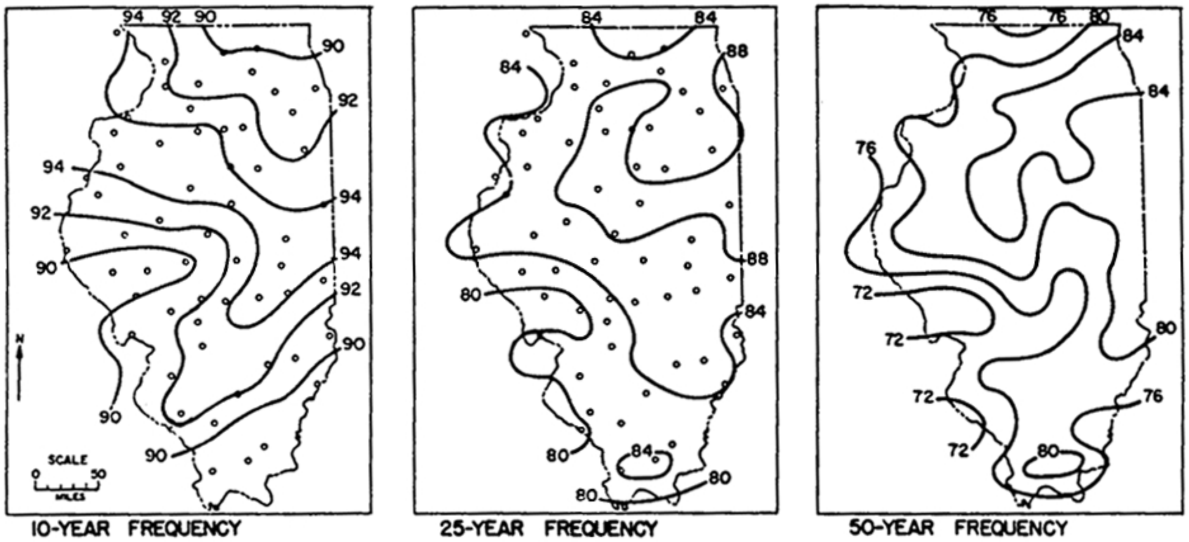


b. 36-month

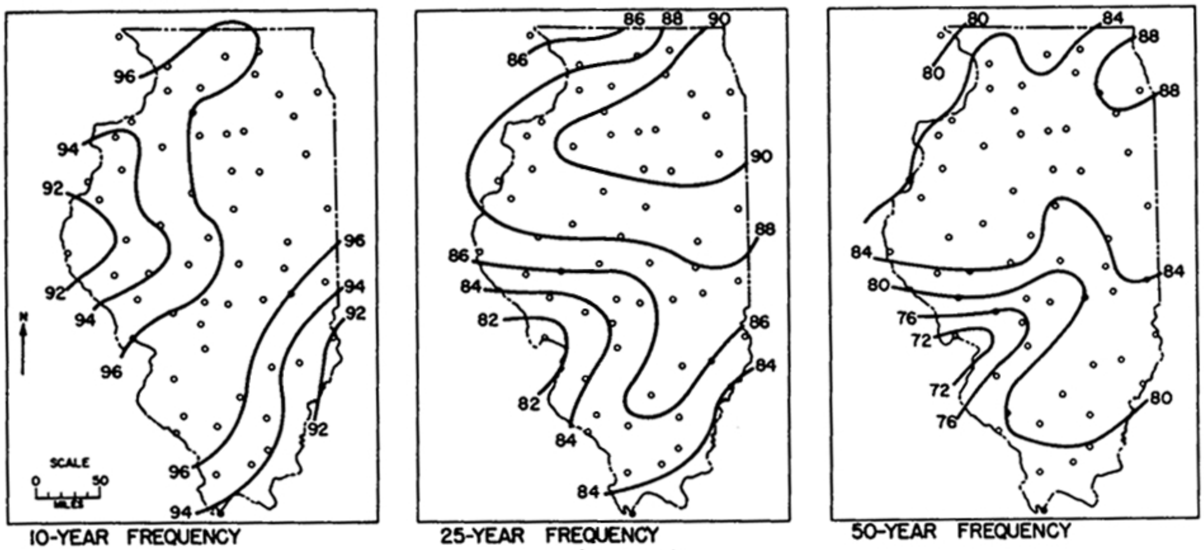
Figure 11. Frequency values of 30-month and 36-month drought periods, expressed as percent of average precipitation.



a. 42-month



b. 48-month



c. 60-month

Figure 12. Frequency values of 42-month, 48-month, and 60-month drought periods, expressed as percent of average precipitation.

Estimation of Soil Moisture and the Severity of Soil Moisture Droughts

Estimates of soil moisture for any given depth and time can be generated by the State Water Survey by using soil moisture models developed for 41 locations in Illinois (Changnon, 1987). Updated weather conditions are fed into the models such that point values of soil moisture for 4 levels (depths) can be generated for 6-day intervals.

If a soil moisture value is desired for a specific locale, we recommend identifying that site's location in one of the eight soil moisture regions. Figure 13 shows these eight areas, defined on the basis of 1) their soil moisture similarities, and 2) soils most susceptible to drought (Figure 14).

In addition to the soil moisture estimates, the Water Survey has a procedure for converting these values to "indices" that are indicative of drought. This delineation of drought severity was based on an analysis of the soil moisture values. Four levels of drought were defined statistically. The four classes of soil moisture drought are weak, moderate, strong, and severe, and are recommended for use in all months except July and August.

Soil moisture values in July and August are assessed on the basis of their direct relationship to major crop yields. This is the approach for estimating the presence of "crop drought" from soil moisture conditions during summer. These established relationships are between the "lowest" soil moisture values reached anytime in July, and corn yield departures. The lowest value better reflects whether the wilting point has been reached than does the monthly average soil moisture value.

This summer relationship was tested at several sites with widely differing soils. The results for Jefferson County, where typical drought-susceptible clay pan soils exist, are illustrated in Figure 15. These soils cover most of southern Illinois (Figure 14) and 21% of the state. The Jefferson County results indicate that when the model-estimated soil moisture value (for the 15-50 cm layer) in July fell below 112 mm, most corn yields fell below their expected value (left of 0 line). The temporal distribution of annual corn yields for 1930-1985 was fitted by a curve considered to represent, in any year, the yield due to current technology acting with average weather, and this was labeled the "expected yield." The years with unusual values (above expected yields but with low soil moisture) are indicated in Figure 15; note that these largely occurred in the 1930s and 1940s when the county yield values are considered suspect, or less accurate than those in recent years.

Assessing Crop Drought Conditions. In assessing soil moisture drought, as defined by reduction in crop yields, it should be realized that there is no single good indicator of crop drought severity.

We recommend the use of the estimated soil moisture values for the 0-15 cm level during the months of March, April, May, June, September, and October, and then their indices of drought severity. The values will be routinely available at the Water Survey.

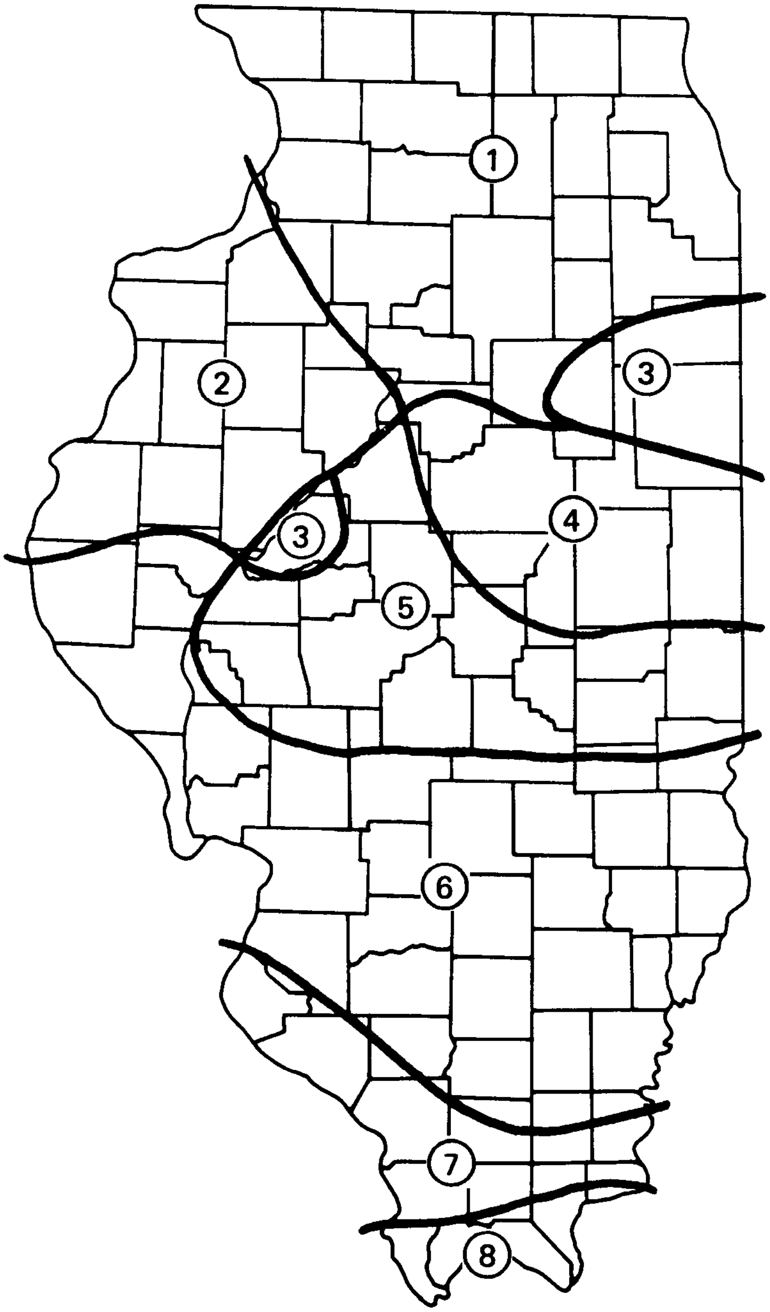


Figure 13. Areas with specific relationships between precipitation and soil moisture.

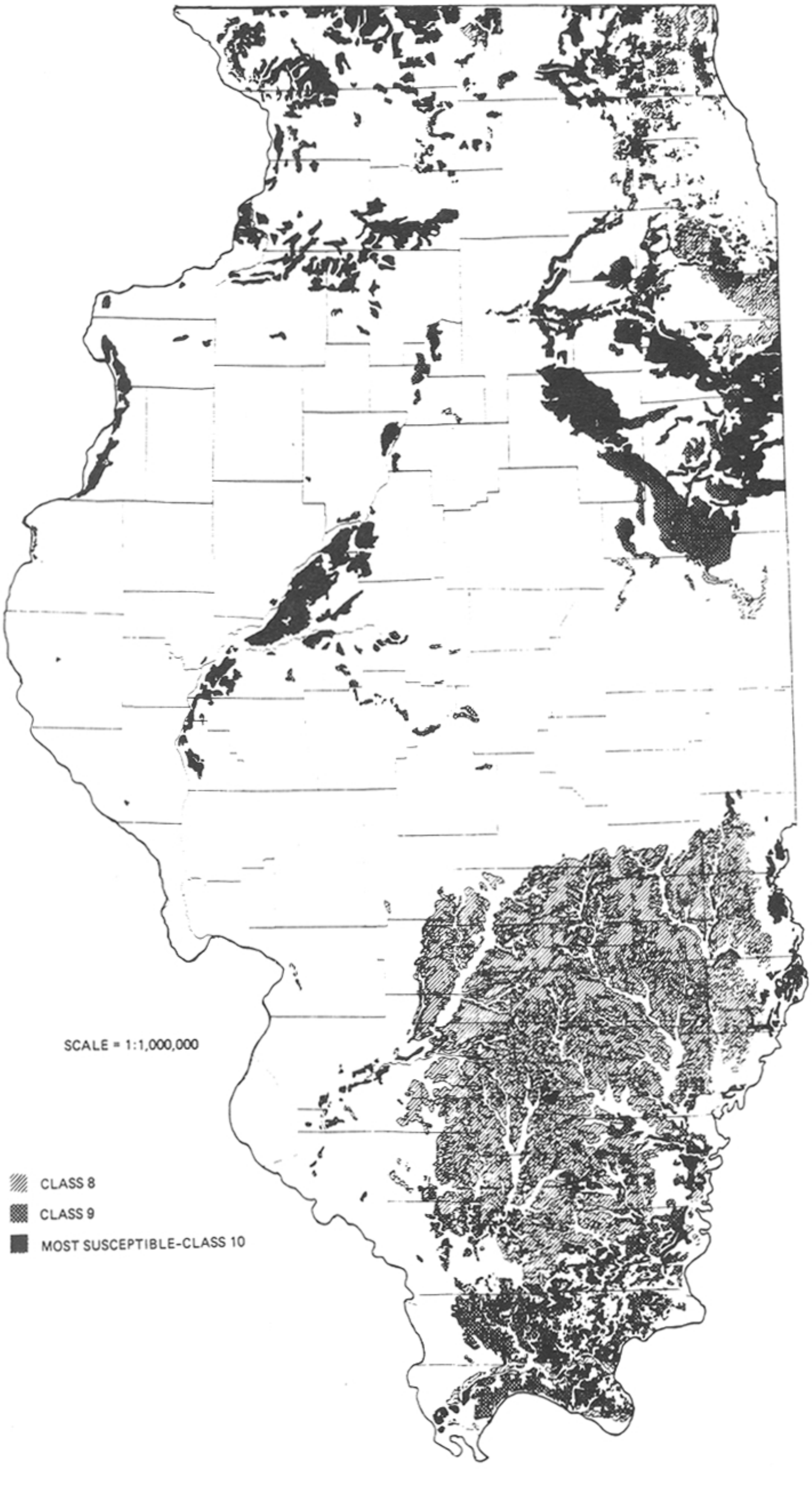


Figure 14. Areas with the three soil classes most susceptible to drought.

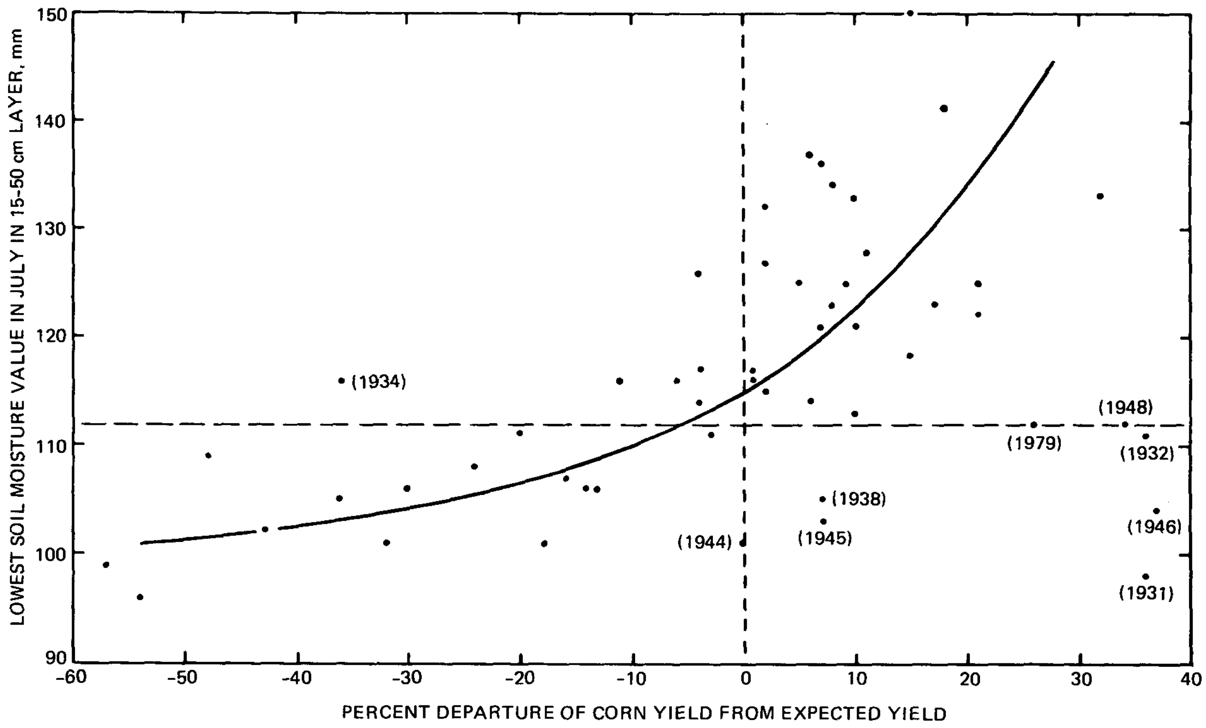


Figure 15. Relationship between the lowest soil moisture value during each July (15 to 50 cm depth) and annual corn yield departures (from expected levels) in Jefferson County during 1930-1985.

During July and August, we recommend the use of the soil moisture values for the 15-50 cm layer and the following ratings:

1. For areas with soil types 1, 2, 3, and 4 (see Figure 16), use soil moisture values ≤90 mm as indicative of "crop drought."
2. For areas with soil types 5, 6, and 7 (Figure 16), use soil moisture values ≤110 mm as indicative of crop drought.
3. For areas with soil types 8, 9, and 10 (Figure 16), use values ≤115 mm as indicative of crop drought.

For November - February we recommend use of the soil moisture values for the 0-100 cm depth and the indices of drought. These values will be available at the Water Survey.

Estimation of Low Flows and the Severity of Streamflow Droughts

Low streamflow values for any Illinois basin can be computed for potential drought periods of 12 months or longer and for precipitation

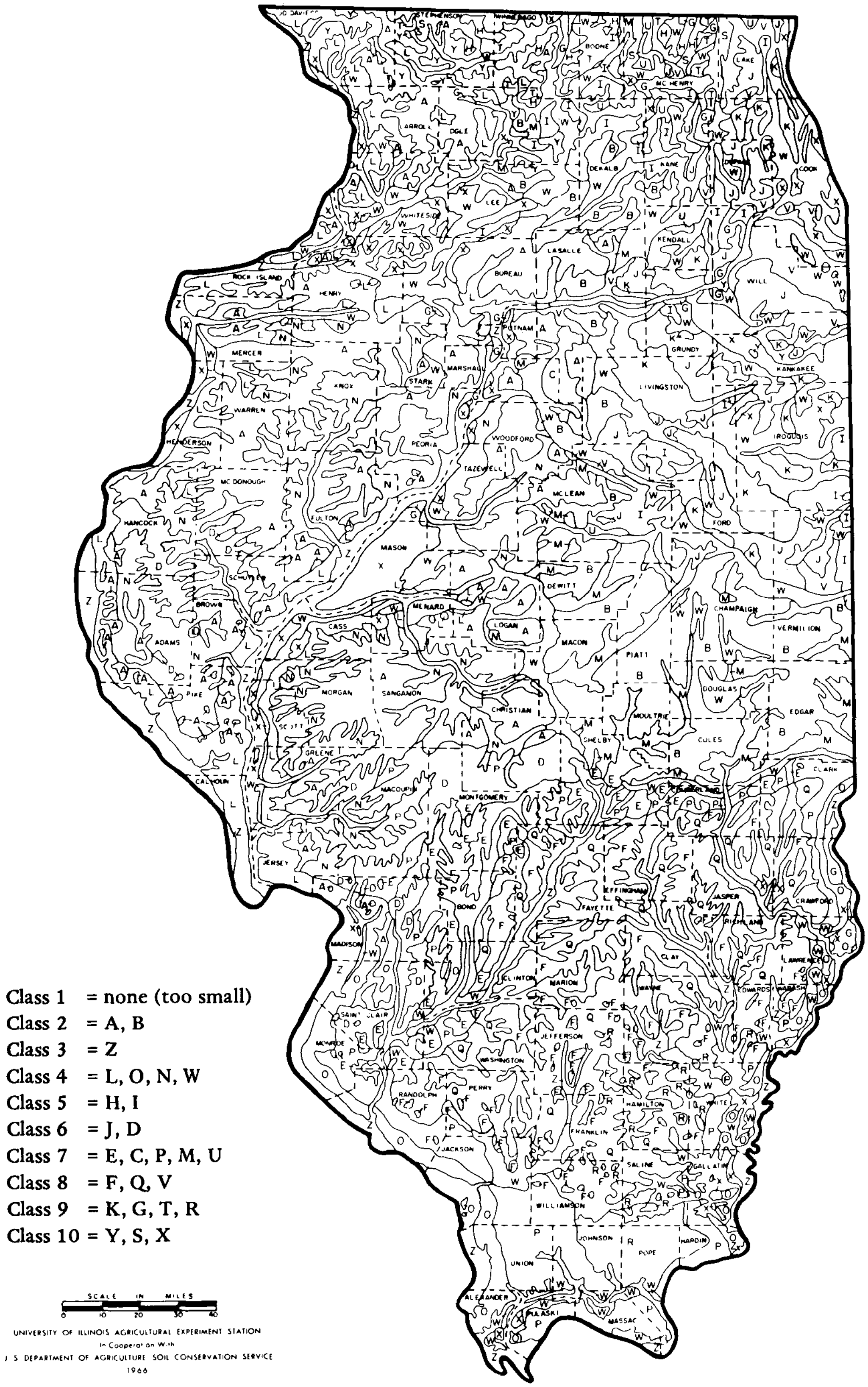


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Figure 16. Soil types of Illinois grouped into ten classes.

and low-flow recurrence intervals of 5 years or longer. The values in Table 1 (lower portion) reveal the percentage relationships between precipitation and streamflow departures; note that the below-normal values for streamflow are much lower than those for precipitation.

The relationship in the predictive equation is:

Runoff (R) = Precipitation (P) x the Geomorphic index (G) of the basin

That is:

$$[R = P \bullet G]$$

The first step in the process of defining the low-flow value and its severity involves selection of the basin area mean precipitation value for the "period of interest" (12 months or longer). This value, in inches, is the "P value" for use in the equation above.

This value is then converted to a percent of normal by comparison with the mean values on Figure 5. (Figure 4 values will also be needed to compute percentages for periods of 18, 30, or 42 months' duration.)

This basin mean departure from normal value is then interpreted as to its return frequency, using the appropriate duration maps selected from Figures 8 through 12. If the precipitation percentage departures for the basin (and the period of interest) fall between the 5-, 10-, 25-, 50-year values, then interpolation of their frequency will be needed.

Once the frequency of the precipitation value is known, appropriate G-values for the frequency and the type of basin area can be selected from Table 3, based on the locale of the basin and its geomorphic type (use Figure 17). If the basin in question is located in two geomorphic areas, interpolation of the appropriate G-value can be made by using values in Table 3. Interpolation is computed on the basis of the percent of total basin area in each geomorphic area. Then multiplying the appropriate G-value by the appropriate precipitation (P) value provides the estimate of the low-flow value.

The prediction process for determining the low-flow values and their frequencies for a given basin in Illinois is illustrated in the following example. For this purpose, let us select the Vermilion River Basin north of Danville in central Illinois. It is located in the "Glacial Plain - 2 stages," as determined by comparing the basin location with the geomorphic areas on Figure 17. In this example of drought assessment and severity, let us assume that evaluation of a 12-month flow value was desired.

Results of the illustrated computations are summarized in Table 4, which provides the various recurrence interval values for 5 to 50 years. Basin normal precipitation (column 2 of Table 4) was obtained by using the basin placement and then interpolating values from Figure 5. The P - values (column 3 of Table 4), expressed as the percent of normal

Table 3. Frequency Distribution of G-Values in Geomorphic Regions of Illinois

G-Values for Given Precipitation Droughts of 12-, 24-, 36-, 48-, and 60-Month Durations

	Glaciofluvial Plain				
Recurrence Interval - Years	12	24	36	48	60
5	.17	.22	--	--	--
10	.13	.17	.21	.22	.23
25	.09	.13	.15	.18	.18
50	.06	.10	.13	.14	.15

	Glaciofluvial Plain				
Recurrence Interval - Years	12	24	36	48	60
5	.17	.22	--	--	--
10	.14	.19	.22	.24	.24
25	.11	.15	.17	.19	.19
50	.09	.13	.14	.16	.16

	Glacial Plain - 1 Stage				
Recurrence Interval - Years	12	24	36	48	60
5	.14	.24	--	--	--
10	.08	.18	.22	.24	.26
25	.04	.12	.15	.17	.18
50	.02	.09	.11	.13	.13

	Glacial Plain - 1 Stage				
Recurrence Interval - Years	12	24	36	48	60
5	.16	.24	--	--	--
10	.11	.18	.22	.24	.26
25	.06	.12	.15	.17	.18
50	.02	.09	.11	.13	.13

Table 3. Concluded

Recurrence Interval - Years	Interior Plateau				
	12	24	36	48	60
5	.23	.26	--	--	--
10	.21	.24	.24	.28	.28
25	.19	.22	.22	.26	.26
50	.18	.20	.20	.25	.25

Recurrence Interval - Years	Dome Uplift				
	12	24	36	48	60
5	.19	.31	--	--	--
10	.13	.22	.28	.34	.34
25	.08	.15	.19	.21	.21
50	.05	.12	.15	.147	.17

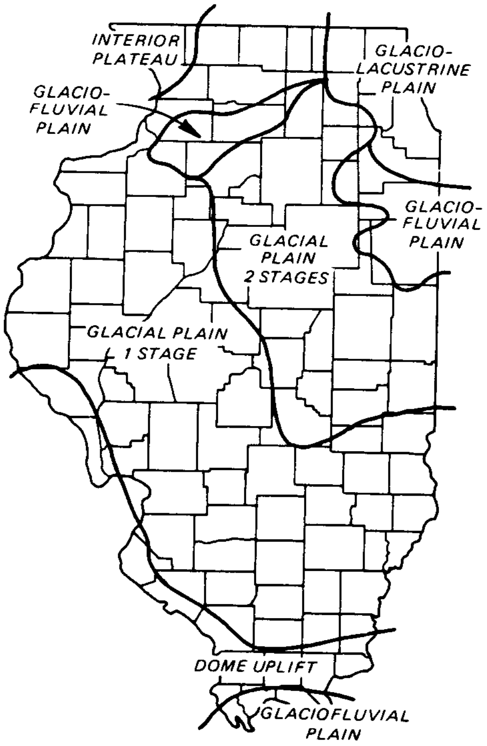

Figure 17. Geomorphic areas used in estimating low streamflow.

Table 4. Calculated Flow Relations in 12-Month Droughts on the Vermilion River Basin north of Danville

Recurrence Interval, Years	Normal Precipitation, Inches	P-Values, Percent of Normal	G-Values	Calculated Runoff, Inches	R-Values, Percent of Normal
5	36.5	78	0.16	4.6	50
10	36.5	68	0.11	2.7	29
25	36.5	60	0.06	1.3	14
50	36.6	55	0.02	0.8	1

precipitation for the specific 12-month period under assessment, were obtained from Figure 8. The recurrence interval G-values shown in column 4 were identified for the Glacial Plain - 2 stages from Table 3. In this example, let us assume that the 12-month precipitation value (P) for the period of interest was 68% of normal. The runoff (column 5 of Table 4) was calculated using the P-value as 2.7 inches. This represented 29% of the average annual runoff for the Vermilion River at this point, or approximately 9 inches.

Drought Conditions. Severity of low flows in Illinois rivers and streams is normally assessed according to their return frequencies based on statistical analyses. This study of droughts and low flows has shown that these low-flow frequency values can be calculated directly using: 1) the precipitation values under question and their return frequencies, and 2) the geomorphic indices based on the location of the basin.

For measuring "drought severity" on the basis of low streamflow conditions, the classification is based on the return frequencies. Low-flow drought was defined as occurring when 12-month or longer periods had flows equaling or less than 5-year return intervals.

- Moderate droughts included those low-flow values rated as 5- up to 20-year return values.
- Severe droughts were those achieving 20-year or longer return frequencies for 12-month or longer periods.

Estimation of Shallow Ground Water Levels and Drought Conditions

Study of the relationship between shallow ground water levels and precipitation amounts indicated that the physical factors best defining the spatial relationships between precipitation and ground water were those based on the parent soil materials: outwash, alluvium, till, thin (<2.1 meters) loess, and thick (≥2.1 meters) loess (Changnon, 1987). Figure 18 presents the pattern of these regions, identified for use in estimating the major precipitation-ground water level at any place and

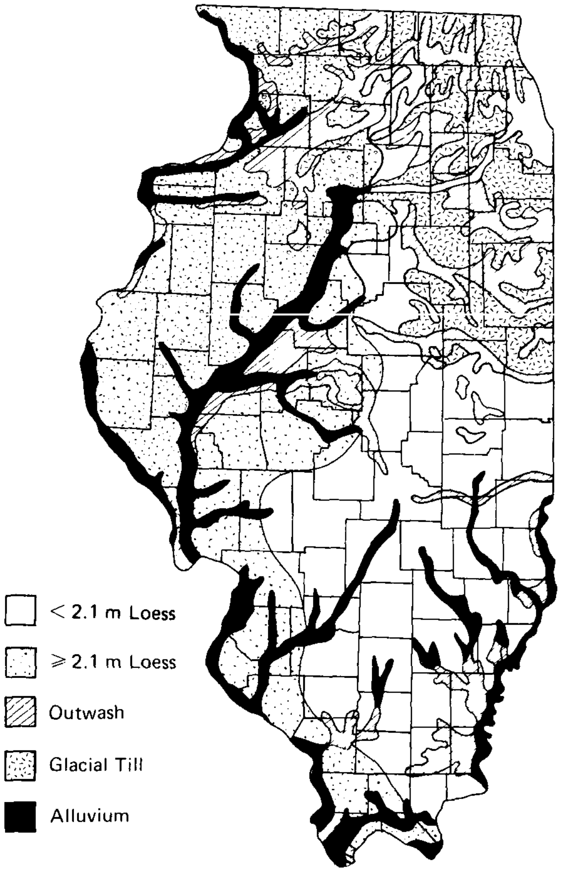

Figure 18. Areas with different parent soil materials, for use in identifying shallow ground water levels to ascertain drought presence and magnitude.

time. This value for an area of interest can then be related to values (depths) indicative of drought conditions.

The process of using the precipitation-ground water equations to estimate the ground water level at any locale of interest is complicated. The State Water Survey has these equations and the data for input into them, and can operate them on a routine monthly basis. For each month, the Survey can produce a) the estimated water level for these five types of areas, b) its departure from normal, and c) the departure as a percent of the long-term average for each of the five areas based on the parent soils. These departures from average are used to calculate drought presence.

<u>Drought Conditions</u>. The process of determining whether shallow ground water levels (and the departures below average) are in a drought

situation is now described. The historical records of the levels for all shallow wells in the Water Survey's monitoring network, available for 1951-1985 or portions thereof, were analyzed for conditions (levels) during known past droughts. We learned that when three or more consecutive months had water levels more than 30% below average, there was a notable drought, both locally and over larger areas, causing problems in water supplies dependent on shallow wells. When values were less than 30% below normal, the dry periods were short-lived and were not identified in the socioeconomic assessments as droughts. Second, the severe drought years of the 1950s were associated with shallow ground water levels that were 55% or more below the average monthly levels for periods of 10 months or longer. These various results provide the basis for defining drought in shallow ground water levels.

Moderate drought is when levels are more than 30% below the average for 3 months or more.

Severe drought is when levels are 55% or more below normal for more than 12 months.

Estimation of Drought Effects on Major Crop Yields

A method is offered for estimating how drought conditions during a growing season can decrease crop yields. The method involves use of regression equations for determining corn or soybean yields in any one of 13 areas of Illinois (Figure 19), using weather data. The 19-term equation is in the form:

$\text{Yield}_{(\text{corn or beans})}$ = a$\cdot$ Technology + b$\cdot$ $(\text{Tech})^2$ + c$\cdot$ $(\text{Tech})^3$ + d$\cdot$ Preseason precipitation (in.) + e$\cdot$ May temp (°F) + f$\cdot$ June temp + g$\cdot$ July temp + h$\cdot$ Aug. temp + i$\cdot$ June precip (in.) + j$\cdot$ July precip (in.) + k$\cdot$ Aug. precip (in.) + ------ A series of 4 precip^2 variables +------ A series of 3 variables of precip $\cdot$ temp $\cdot$ technology.

These equations can be used at any time <u>during a growing season</u> to estimate yields based on use of 1) the actual weather conditions up to that time, and 2) the expected weather conditions (good, bad, or average) in the remaining portion of the growing season.

To estimate the effect of drought-period weather conditions on crop yields at any time, the equation for each of the regions can be solved. This involves using the regression equation parameters for corn (Appendix 1) or for soybeans (Appendix 2). The process of calculation involves identifying the existing weather conditions (at the time of interest) and the technology level.

For these types of applications, the corn technology level value for 1985 should be set at 50 (that for beans at 28), and for each future

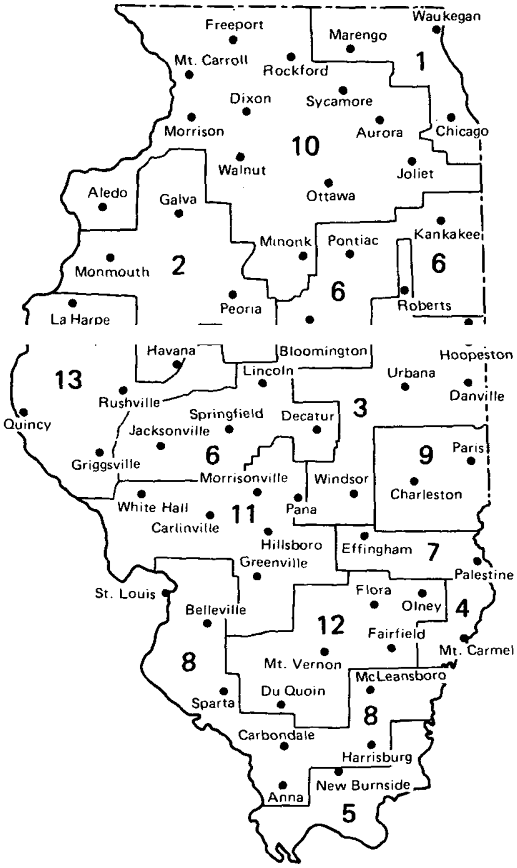

Figure 19. Regions of similar weather-crop yield relations.

year, a value of 1 should be added for corn and 0.5 for soybeans. Thus, if one were estimating drought effects in 1990, the technology value inserted into the corn equation for any of the regions would be "55." However, this value should be assessed again by 1990 to learn if a more appropriate technology value exists.

If one were in the middle of a drought with part of the growing season completed, one could estimate future yield outcomes by using the equations in the following manner. In this example, let us say that we are at the end of June 1990, and we know the regional preseason precipitation (September 1989 - May 1990) and the June 1990 temperature and rainfall values. These are inserted in the corn equation. Then one can choose various July and August temperature and precipitation "scenario" values, and with these different choices, can estimate the different yields apt to result.

Solving the equation for region 3 and corn yields (Appendix 1), with all weather conditions set at average values, produces an estimate of 164 bushels per acre with July having an average temperature of 75°F and rainfall of 4 inches (and August values at normal). If the rainfall for July is set at 1.5 inches and the mean temperature at 85°F (typical of a summer drought condition), and August values are kept at normal, the predicted yield becomes 126 bushels per acre, a 38-bushel decrease. In this manner, yields due to specific drought conditions in the immediate future can be estimated. It should be recognized, however, that these are approximations based on historical data relationships and assumed technological increases averaging 1 bushel per acre per year.

PREDICTING THE INITIATION AND TERMINATION OF DROUGHTS IN ILLINOIS

The prior sections either showed how critical components of the hydrologic cycle (soil moisture deficiencies, low streamflows, and lowered ground water levels) could be related to precipitation to estimate current conditions, or indicated that the Water Survey would provide conditions for areas that in turn can be used to assess point values. For all three hydrologic cycle aspects, values indicative of drought (yes/no) occurrence and drought severity were provided. These are guidelines for indicating the presence and severity of drought.

In addition, the way in which precipitation deficiencies (for periods of 3 to 60 months) relate to drought conditions was described. This information allows the user to estimate which portions of Illinois are experiencing drought conditions, as well as the severity, as measured by precipitation alone. A fifth measurement of drought presence, particularly relevant to growing season droughts, was the inclusion of a method for using current weather data to estimate crop yields.

This section addresses two other fundamental drought-related questions asked by decision makers: 1) those relating to the initiation of drought ("has drought begun?"), and 2) those relating to the termination of drought ("has the drought ended?" or "when will the drought end?").

Answers to these questions are extremely valuable in making key decisions. For example, at the initiation of a drought one begins to consider local/regional remedial actions such as conserving supplies or seeking other water supplies. Answering the question about the ending of drought affects other types of actions relating to conserving existing water supplies or importing water.

Thus two fundamental scientific questions arise: how well can the initiation of drought be detected, and how well can the end of a drought be predicted? These are not simple questions. Since droughts begin and end on the basis of precipitation, these questions are primary issues for atmospheric scientists. Regardless, the questions must also be addressed in a socioeconomic and environmental context. That is, droughts are a mixture of physical impacts on various segments of our society and environment.

Initiation of Droughts

The detection of drought initiation, in its simplest form, requires two activities:

1) a routine, month-to-month continuous monitoring of precipitation conditions in Illinois at up to 40 locations; and

2) a continuing operation of the models provided in this report for estimating soil moisture, shallow ground water levels, and low flow values.

A single agency with access to water and weather information (such as the Illinois State Water Survey) should routinely monitor statewide precipitation conditions. Then at the end of each month, relevant recent values of weather conditions should be used in the various hydrologic models to estimate 1) current soil moisture values, 2) streamflow tables, and 3) shallow ground water conditions. Further, these estimates for any locale should be compared with the "yes/no" drought criteria presented in this report to detect the initiation of a drought period of any type. In this manner, the initiation of drought, as defined in any sector of the hydrologic cycle, can be ascertained within 30 days of its beginning. Mechanisms involving the Illinois Water Plan Task Force are available to distribute this information to appropriate state agencies and to local communities and areas apt to be affected.

Termination of Droughts

Once a drought of any duration is in progress, a continuing and fundamental question concerns the termination of the drought. The problem is difficult because even in the most severe Illinois droughts there are periods (typically weeks or a month or two) that achieve normal or above-normal rainfall and which are again followed by extended periods of below-normal precipitation.

Research has identified certain helpful clues relating to estimating the termination of drought. First, most soil moisture droughts appear to be ending when the mid-winter soil moisture values reach average or above-average levels. Hence, monitoring of soil moisture, which is normally recharged by fall and winter precipitation, is one measure that should be followed as an indicator of the possible ending of droughts, at least as defined by soil moisture conditions.

Climatological studies of precipitation droughts have examined the conditions typically found at the end of Illinois droughts of varying durations. These showed that most Illinois droughts of 3- to 24-month durations are terminated by at least one month of very excessive precipitation. That is, values exceeding 125% of normal are frequently (8% of the time) indicative of the end of a 12-month drought, and values of >138% of normal indicate the end of 24-month droughts in 90% of the cases. This "drought ending" month is frequently followed by a month of slightly below-normal precipitation (typically 90% of normal). Thus, the magnitude and sequence of monthly precipitation departures can serve as an indicator of the possible ending of a drought.

The third potential source of information relates to the existing techniques developed by the Illinois State Water Survey to estimate trends in future monthly and seasonal precipitation at three levels (above normal, near normal, or below normal) for each crop district. These predictions have been found useful in making decisions in earlier drought situations in southern Illinois (Changnon and Vonnahme, 1986), and in addressing the summer droughts of 1980 and 1983 (Changnon and Hsu, 1985). The seasonal outlooks are not highly accurate, but they do have utility beyond normal chance (they are correct 55% of the time, with chance being 33%). The techniques are available and require only the input of historical data. The National Weather Service also issues 30-day and 90-day predictions of precipitation each month, and this information should also be considered.

It is <u>recommended</u> that once a drought has begun in any area of Illinois, these monthly and seasonal outlooks of precipitation be generated by the Illinois State Water Survey. These can be utilized to help estimate the potential conclusion of droughts.

ACKNOWLEDGMENTS

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Many others were helpful in the review and preparation of this report, including Peter J. Lamb. John W. Brother, Jr., and Linda J. Riggin assisted in the preparation of the illustrations.

REFERENCES

Changnon, S. A., 1977: Climatic Change and Potential Impacts on Water Resources. Living with Climatic Change, Phase II, Mitre Corp., McLean, VA, 85-93.

Changnon, S. A., 1980: Removing the Confusion over Droughts and Floods: The Interface Between Scientists and Policy Makers. Water International, 5:10-18.

Changnon, S. A., 1981: The 1980-1981 Drought at Eldorado: A Precursor of Future Water Problems. Ill. Municipal Review, 10-11.

Changnon, S. A., assembler, 1987: Droughts in Illinois: Their Physical and Social Dimensions. (Contributors: J. Angel, S. Changnon, M. Demissie, W. Easterling, K. Hendrie, C.-F. Hsu, F. Huff, R. Raman, G. Ramamurthy, D. Schnepper, K. Singh, V. Tsihrintzis, C. Collinson, L. Smith, C. Helm, L. Iverson, M. Kogan, and H. Sadeghi.) Ill. State Water Survey, 369 pp.

Changnon, S. A., G. Achtemeier, S. Hilberg, V. Knapp. R. Olson. W. Roberts, and P. Vinzani, 1982: The 1980-1981 Drought in Illinois: Causes, Dimensions, and Impacts. Rept. of Investigation 102, Ill. State Water Survey, 113 pp.

Changnon, S. A., and C.-F. Hsu, 1985: Assessment of Operationally-Issued Long-Range Precipitation Outlooks for Illinois. J. Clim. and Appl. Meteorol., 24:253-265.

Changnon, S. A., and R. G. Semonin, 1982: Atmospheric Issues Identified in State Water Planning. Bull. Amer. Meteorol. Soc., 63:399-406.

Changnon, S. A., and D. Vonnahme, 1986: Use of Climate Predictions to Decide a Water Management Problem. Water Resources Bulletin, 22:649-652.

Drought Task Force, 1977: Drought in Illinois. Emergency Services and Disaster Agency, Springfield, 47 pp.

Hilberg, S. D., and S. A. Changnon, 1984: Drought. Public Information Brochure 9, Ill. State Water Survey, 12 pp.

Hudson, H. E., and W. J. Roberts, 1955: 1952-1955 Illinois Drought with Special Reference to Impounding Reservoir Design. Bull. 43, Ill. State Water Survey, 52 pp.

Huff, F. A., and S. A. Changnon, 1963: Drought Climatology of Illinois. Bulletin 50, Ill. State Water Survey, 80 pp.

Huff, F. A., and S. A. Changnon, 1964: Relation Between Precipitation Deficiency and Low Streamflow. J. of Geophys. Res., 69:605-613.

Jones, D. M. A., 1966: Variability of Evanotranspiration in Illinois. Circular 89, Ill. State Water Survey, 13 pp.

Palmer, W., 1965: Meteorological Drought. U.S. Weather Bureau Research Paper 45, 58 pp.

Stall, J. B., 1964: Low Flows of Illinois Streams for Impounding Reservoir Design. Bull. 51, Ill. State Water Survey, 395 pp.

Water Plan Task Force, 1984: The Illinois State Water Plan. Illinois Division of Water Resources, Springfield, 48 pp.

Appendix 1. Regression Equation Parameters for Corn Based on 1931-1980 Data

Independent Variable[1]	Regional Regression Coefficents												
	1	2	3	4	5	6	7	8	9	10	11	12	13
T	3.9291	.2234	-.1474	.7249	1.9870	-1.3035	-2.1741	.6652	-2.6667	3.2666	.9082	.7579	2.2857
T^2	-.1480	.0299	.0387	-.1052	-.0764	.0557	.0520	-.0869	.0635	-.2025	-.1248	-.1041	-.0897
T^3	.0027	-	-	-.0024	.0018	-	-	.0021	-	.0037	.0031	.0026	.0021
PP	-1.1889	1.3120	-.1366	1.1442	.3235	-2.1256	1.3170	.7626	3.9856	2.5265	7.2136	.4318	1.7233
MT	.4428	.2280	·0864	.1792	.3187	.4589	.0850	.4282	.3114	-4353	-.0034	-.0397	.0114
JT	-6.7190	-3.5175	-3.8610	-4023	-.6159	-4.0638	-.9752	-1.9829	-2.5714	-1.8570	-1.7796	-2.3277	-1.2109
JyT	-5.6027	-1.3937	-3.4992	-.1639	-.6356	-1.8179	-3.2792	-1.6616	-4.8045	.2374	-2.9916	-.4500	-2.4100
AT	-6.1106	.5331	1.7064	-2.3404	-1.5058	3.4014	-3.4380	-2.4237	3.6262	-2.8775	-1.6916	-1.7079	1.4234
JP	-116.3584	-55.9539	-61.7813	10.4894	-4.8922	-53.9111	-13.6351	-28.4117	-42.9604	-25.1943	-33.5755	-31.3487	-19.1111
JyP	86.1277	-13.8083	-33.7339	53.7529	18.9569	25.3648	-40.5092	-3.7875	-79.7597	38.4662	-16.7250	29.9981	-17.3763
AP	-108.9538	23.7780	64.8089	-8.1556	-9.1906	-119.9663	-42.1087	-33.0857	-42.5107	-49.4304	-25.3900	-15.6588	37.3831
PP^2	.0201	-.0211	.0006	-.0229	-.0082	.0411	-.0238	-.0122	-.0787	-.0466	-.1525	-.0077	-.0345
JP^2	.0219	-.0771	.0392	-.3851	-.0662	-.7078	-.2374	.1276	-.0138	-.8441	-.0384	-.1168	-.4282
JyP^2	-1.8149	.3883	.1933	-.7275	-.1758	.0643	-.5315	-.5366	.3821	-1.4712	-.4097	-.4949	-.1500
AP^2	-.4810	-.3790	-.0716	-.5022	-.0528	-1.8077	.5186	.2838	1.0119	-.2212	.5297	.3971	-.3054
JTXJP	1.7058	.8035	.8491	-.1369	.0843	.8188	.2070	.3589	.5725	.5038	.4678	.4076	.3222
JyTJyP	1.3884	.1592	.4364	-.5738	-.2046	-.3086	.5545	.0711	.9558	-.4091	.2575	-.3247	.2705
ATXAP	1.5677	-.2850	-.8747	.1454	.1528	-1.4655	.4677	.4065	.4068	.6884	.2453	.1719	-.4554
T(JT)(JP)	-.0026	-.0008	-.0008	.0013	-.0008	-.0001	-.0000	.0001	-.0000	-.0026	.0000	.0014	-.0008
T(JyT)(JyP)	-.0011	.0002	.0006	.0002	-.0003	-.0004	.0020	.0028	.0028	.0041	.0013	.0008	-.0001
T(AT) (AP)	.0006	.0002	.0004	.0010	-.0014	.0015	.0025	-.0004	.0028	.0515	.0013	-.0000	-.0002
Dependent variable intercept	1296.960	336.8610	464.2698	222.4286	199.2334	205.7121	619.8166	463.8703	862.4585	314.9183	457.5496	363.4600	153.4449

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[1] T = technology; PP = preseason precipitation; MT, JT, JyT, AT = May, June, July, and August temperatures; JP, JyP, AP = June, July, and August precipitation.

Appendix 2. Regression Equation Parameters for Soybeans Based on 1931-1980 Data

Independent Variable[1]	RegionalregressionCoefficents												
	1	2	3	4	5	6	7	8	9	10	11	12	13
T	.5193	.7996	.5923	.0288	.5292	.2370	.0298	.2314	.0622	.3797	.1575	.0931	.3727
PP	-.8164	1.1105	.9618	.7463	.0250	1.6862	.8591	.8306	1.0523	.5005	2.8651	.8055	.7848
MT	.0216	-.0466	-.1039	-.0664	.0605	-.0790	.0011	.1007	-.0523	-.0582	-.1352	-.1128	-.0015
JT	-1.7540	1.0903	-.2752	-.5793	-.5042	.1464	-.2641	-.7504	-.8105	-.6590	.2226	-.2862	.0906
JyT	-1.3278	1.0099	-.2036	.2479	.2688	.1815	-.3522	-.3429	-.4413	.1509	-.0887	.1358	-.1842
AT	-1.4634	.9297	.8641	-.1033	-.1767	.2716	-.4465	.2489	-.6505	-.0754	-.2019	.2316	.0965
JP	-31.7659	13.9843	-8.6045	-11.0905	-8.5614	2.6556	-1.9035	-15.4743	-14.5205	-13.2880	1.7911	-4.6796	2.4664
JyP	-18.7787	26.8434	6.2331	18.5166	19.5059	13.2500	-.8173	4.3725	-5.0454	7.1158	6.2869	21.1041	-2.4398
AP	-33.0749	29.5681	25.4756	1.8088	-.3827	12.0366	-1.7571	11.3550	-14.9235	3.7836	1.3375	13.8372	9.4343
Pp^2	.0158	-.0216	-.0183	-.0114	-.0007	-.0335	-.0139	-.0136	-.0239	-.0105	-.0544	-.0121	-.0171
JP^2	-.0677	-.3801	.0573	.0059	.0378	-.1679	-.0398	.2111	-.0111	.0180	-.0814	-.0930	-.0808
JyP^2	.0833	.2017	-.2348	-.1180	.0902	-.1715	-.1414	-.1324	-.0582	-.0055	-.1393	-.1287	-.1034
AP^2	-.8541	-.3340	-.1891	-.1361	.0463	-.5701	-.2260	-.1189	.1444	-.3663	-.0574	-.1701	.1644
JTXJP	.4812	-.1253	.1100	-.1311	.1115	-.0239	.0197	.1799	.1937	.1938	-.0116	.0663	-.0239
JyTXJyP	.2765	-.3541	-.3025	-.2137	-.2510	-.1304	.0188	-.0373	.0629	-.0859	-.0637	-.2409	.0523
ATXAP	.4670	-.3731	-.3022	-.0056	.0146	-.1098	.0479	-.1269	.1917	-.0184	-.0131	-.1636	-.1029
T(JT) (JP)	-.0008	-.0009	-.0001	.0006	-.0001	-.0003	.0002	-.0001	.0002	-.0004	-.0001	.0001	-.0000
T(JyT) (JyP)	-.0007	-.0009	.0004	-.0000	.0000	-.0005	.0008	.0005	.0008	-.0002	.0002	-.0002	-.0000
T(AT) (AP)	.0004	-.0005	.0007	.0003	-.0005	.0006	.0001	.0000	.0003	.0005	.0004	.0007	-.0001
Dependent variable intercept	339.4935	-236.0778	-30.3515	35.7830	33.0594	-56.5100	79.4985	53.8719	144.4485	48.3927	-11.5911	-8.5421	-.4062

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[1] T = technology; PP = preseason precipitation; MT, JT, JyT, AT = May, June, July, and August temperatures; JP, JyP, AP = June, July, and August precipitation.