Thomas Eugene Pond. AN ANALYSIS OF DROUGHT COMPONENTS IN THE EASTERN UNITED STATES. (Under the direction of Richard A. Stephenson, Department of Geography and Planning, November, 1986).

The purpose of this research is to study drought components in the climatic regions of the United States east of the Mississippi River. It is hypothesized that drought associated with temperature variation exhibits unique spatial patterns. This investigation adds a different spatial dimension related to drought phenomenon. The areal association of temperature as an altering factor upon environmental moisture status is evaluated.

Research related to drought analysis has traditionally focused upon negative departures from precipitation normals. Only in recent years has temperature variation as an aspect of drought and its intensity been considered. These studies incorporated temperature-induced evapotranspiration demands as an element significant to either intensifying or ameliorating an area's moisture status, but failed to separate the moisture supply and moisture demand parameters as component elements.

This study shows that there is an areal differentiation regarding the impact of above normal temperatures on the phenomenon of drought.

# AN ANALYSIS OF DROUGHT COMPONENTS
# IN THE EASTERN UNITED STATES

A Thesis Presented to
the Faculty of the Department of Geography and Planning
East Carolina University

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts in Geography

by
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# CHAPTER I

# DROUGHT: CONCEPTS AND MEASUREMENT TECHNIQUES

## Introduction

Moisture has long been recognized as being extremely important to man as a necessary resource. Because it is a necessary resource, major departures in the amount of available water from that normally expected have often proved disastrous to man and his environment. The measurement and prediction of these departures have been of keen interest to researchers for decades.

Much effort has gone into the examination of positive moisture anomalies, yet there exists only meager research regarding the negative aspect of drought. No doubt the positive deviations are more dramatic in terms of swift response, for example, the fluctuations of stream head. Yet, the deviation caused by the lack of moisture, such as damaging and destroying property, crop, and livestock should be considered of major significance. Of all insured crop claims in the United States, drought accounts for 39 percent of indemnities paid (Annual Report, Federal Crop Insurance Corp., 1963).

Departures from the normal precipitation for any location or area for any period of time are expected. Seldom do average climatic data express persistent conditions over extensive time periods. If a particular moisture departure does not significantly deviate from the mean moisture conditions, the physical environment may well accommodate that departure without deleterious affects, but deviations that reach the stress limits of the physical environment are of major consequence to man (Wang, 1963).

While drought or a negative moisture departure has widespread geographic ramifications, the subject, with few exceptions, has not been investigated in geographic detail. The topic has received some attention in terms of cultural perception and agricultural impacts; but the actual identification of its onset, termination, degree of intensity, and magnitude has been almost solely limited to the hydrologists, agriculturists, meteorologists, and foresters (Saarinen, 1966; Hewes, 1963; and Visher, 1943). Rarely have the investigations been applicable or utilized for broadscale areal characterization of drought patterns. However Shear and Steila (1971), utilizing the Thornthwaite Water-Budget technique, have combined certain Thornthwaite indices and arrived at an index of drought. The Shear-Steila method has been applied throughout the southeastern United States as well as Arizona and has proven to function quite well in the recognition of drought and its intensity.

Clearly the identification of drought is of significance, but also of importance is the impact of the individual components of drought upon moisture status departures and intensities. The impact of a moisture deficiency was vividly demonstrated during the dust-bowl era, and since then dry periods have been a threat to the forests and food supplies. The Shear-Steila Index will be used in this study in the recognition of drought's areal patterns, intensity, and components.

## Drought Definitions

Drought is a phenomenon of widespread significance. The use of the term in both professional and non-professional literature is extremely varied. The following comments and definitions demonstrate a lack of agreement regarding terminology and an absence of reference to above normal temperatures being a contributor to drought.

(1) Drought (common usage) reflects the relative disparity of mankind in the face of natural phenomenon that he does not understand thoroughly and for which, therefore, he has not devised adequate protective measure (Thomas, 1963).

(2) . . . a spell of dry weather (Tannehill, 1947).

(3) A period of ten days with a total rainfall not exceeding a fifth of an inch of rain (Tannehill, 1947).

(4) A valley of rain deficiency in the broad sweep of time and weather (Tannehill, 1947).

(5) . . . 15 days with no rain (Coble, 1933).

(6) . . . period of thirty days or more with deficient rainfall and not in excess of a fourth of an inch in any 24 hours (Tannehill, 1947).

(7) An "absolute" drought . . . a period of 14 consecutive days without a hundredth of an inch in any one day (Tannehill, 1947).

(8) drought . . . a meteorological phenomenon which occurs during a period when precipitation is significantly less than the long term average and when this deficiency is great enough and continues long enough to affect mankind (Thomas, 1963).

(9) Drought . . . a relatively temporary departure of the climate from the normal or average toward aridity (Palmer, 1957).

(10) When precipitation is insufficient to meet the needs of established human activities, drought conditions may be said to prevail (Hoyt, 1938).

(11) drought . . . is considered to be a period when pasture growth is so far below normal that it affects adversely the animals grazing in particular areas (Everist and Moule, 1952).

(12) Any period in which tree growth was reduced for five or more years has been considered to be a drought period (Weakly, no date).

(13) drought . . . refers to a specific period of time during which the total amount of rainfall recorded at a station is deficient to the extent that, more often than not, the corn yield falls below normal for the county in which the station is located (Barger and Thom, 1949).

(14) . . . a period of deficient rainfall that is seriously injurious to vegetation (Tannehill, 1947).

(15) a period of 21 days or more with rainfall 30 percent or more below the normal (Tannehill, 1947).

(16) A droughty condition is created if, in the economic development of a region, man creates a demand for more water than is normall available (Hoyt, 1938).

(17) Drought is a phenomenon taking many forms, but its most specific and most essential feature is a disparity between the plant's requirements of moisture and the latter's supply from the soil (Kulik, 1965).

Clearly, the preceding examples show the concept of drought is variable. To foresters, drought is the susceptibility of surface conditions to the threat of fire. The concern of the agriculturist, centers about his crop's water-needs and soil conditions. To the hydrologist, drought is evidenced by dropping stream and groundwater levels. However, basic to each of the previously mentioned physical definitions is the fact that drought represents a negative departure from the expected moisture availability of an area.

## Drought Measurement: Past

The measurement of drought intensity and the determination of the threshold value which initiates the onset of the "dry spell" have been no less varied than the many definitions previously presented.

Between 1900 and 1910 the U.S. Weather Bureau tested for drought utilizing rainfall records. "Any period of twenty-one days or more with rainfall 30 percent or more below normal (Tannehill, 1947)," was considered a drought. In an application of this measure to the District of Columbia, it was found that 62 cases of drought had occurred in 33 years. Further examination of rainfall data indicated that in most cases cited, "there had been ample or heavy rainfall preceding the dry period, and there was enough soil moisture to support vegetation" (Tannehill, 1947).

Though the status of available moisture for vegetation is not the sole factor to consider with respect to dry periods, the foregoing findings do reveal the inadequacy of several drought indices. There is the failure to take into consideration the water reservoir within the soil. As Jen-Yu Wang states, "during drought (moisture deficient) soil moisture acts as a limiting factor" (1963). Whether a drought is preceded by a wet or dry period can add to the intensity of a given drought or aid in relieving it. The level of available soil moisture at any time provides an indicator to the moisture-status of the preceding period.

Kulik (1965) described moisture deficiency with the use of two terms: 1) a drought period occurs when the available moisture reserves in the first twenty centimeters of soil are less than 20 millimeters for a period of 10 days; and 2) a dry period occurs when the available moisture reserves in the first twenty centimeters of soil are less than 10 millimeters for a period of 10 days.

A major drawback to Kulik's work is the soil moisture requirement of 20 millimeters or more in the upper 20 centimeters for drought not to exist. Under this assumption, the more porous soils would always experience drought as would soils in arid climatic zones. Though the more porous soils may be droughty in nature, the climatic environment need not be experiencing dry conditions. Soils nearby may be well above field capacity due to recent precipitation. His methodology does not identify drought but, in particular cases, identifies droughtiness of soils.

Kulik also classified soils with normal moisture retention of less than 20 millimeters as continually experiencing drought, thus, including the soils of arid climatic regimes. Similarly, Thornthwaite (1963) has coined the term perennial drought for those areas where potential evapotranspiration needs are not sufficiently met by precipitation. However, can an arid climatic regime actually experience drought? The answer should be apparent. If Phoenix, Arizona expects to receive an average of eight inches of precipitation a year and only receives three or four inches in a given year, it is experiencing drought. Utilizing Thornthwaite's terminology, however, Phoenix would be experiencing perennial drought plus additional drought of 4 to 5 inches.

Referring to the list of drought definitions mentioned previously, the one point of agreement is that drought represents a period of time wherein moisture status is below that normally expected. Phoenix does not experience perennial drought, but does undergo period of drought.

Barger and Thom (1949) attempted a drought prediction study in Iowa by correlating rainfall data with corn yields. Even though this study produced positive results for Iowa, the study was extremely limited in areal application. The great weakness of this endeavor was that it measured drought solely in terms of one crop--corn, and was useful only during the growing season.

## Drought Measurement: Recent

Keetch and Byrum (1968) developed an index for use by fire control managers in estimating degree of drought. Their index was based on soil moisture status and its relationship to the flammability of organic fuels. This index portrayed, as intended, a measure of flammability of fuels, but it is not useful for portraying total environmental stress.

Carreker and van Bavel (1957), although not really developing a drought index in the purist sense, have devised a methodology for calculating drought probability. They are primarily concerned with "agricultural drought" which they define as "a condition in which sufficient soil moisture is not available in the root zone for plant growth and development." They use four major governing factors within their system: rainfall, evapotranspiration, available soil moisture, and the moisture requirements of the plant.

The most widely applied drought measure was devised by Palmer (1965), who characterized drought solely in terms of meteorological phenomena. His definition of drought is:

> An interval of time, generally on the order of months or years in duration, during which the actual moisture supply at a given place rather consistently falls short

> of the climatically expected or climatically appropriate moisture supply. Further, the severity of drought may be considered as being a function of both the duration and the magnitude of the moisture deficiency.

Evapotranspiration is a variable in the Palmer Index, which classifies a station into degrees of wetness (surplus moisture) as well as into degrees of dryness (drought). The Palmer Index breaks down moisture availability into eleven different categories, perhaps unnecessarily detailed.

Palmer's methodology has gained a high degree of popularity among U.S. Weather Service personnel involved with climatological work and, though tedious and involving numerous variables has been applied to several states. To the author's knowledge, the following states have had the index applied: Alabama, California, Georgia, Idaho, Kansas, Nevada, North Carolina, South Carolina, Tennessee, Washington, and West Virginia.

The accomplishment of Palmer was without question a monumental task which has stimulated further research into the drought phenomenon. He expanded the scope of the drought concept and provided a standardized definition that is applicable to several aspects of the physical environment.

## Drought and the Concept of Potential Evapotranspiration

In order to recognize drought as occurring at a given time and place, there must first exist a water-need; since if no water-need existed, negative departures would be of questionable significance.

Solar heating induces a loss of moisture from the surface by means of evaporation and transpiration. Transpiration maintains temperature balance on leaf surfaces and is vital to plant respiration. It prevents the surface of the leaf from overheating and represents a transfer of water to the atmosphere through living plant cells. Evaporation is that amount of water returned to the atmosphere from open areas and represents a conversion in the state of water from its liquid to gaseous form.

In understanding the water status of an area, knowledge of the balance between incoming moisture and that lost through evaporation and transpiration must be considered. Lowery and Johnson 91942) recognized the above fact and coined the term "consumptive use." They defined "consumptive use" as being "the quantity of water, in acre-feet per cropped acre per year, absorbed by the crop and transpired or used directly in the building of plant tissue, together with that evaporated from the crop producing land."

Based on the foregoing and similar studies, attempts to determine "consumptive use" followed. Thornthwaite (1948) redefined the term, labelled it "potential evapotranspiration", and stated:

> Potential evapotranspiration is an index of thermal efficiency. It possesses the virture of being an expression of day length as well as of temperature. It is not merely a growth index but expresses growth in terms of the water that is needed for growth. Given the same units as precipitation it relates thermal efficiency to preciptation effectiveness.

Temperature is the principal factor in determining the amount of "consumptive use" and has been used in various formulas to obtain potential evapotranspiration or water-need values for a particular site. Holdridge (1964) notes that when temperature is used alone as an indicator of potential evapotranspiration, it is difficult to account for differences produced by local soils, vegetation, and atmospheric conditions. However, if the "specifications of a zonal soil and a zonal climate are included in the definition of potential evapotranspiration, the utilization of a nomogram or formula based on temperature alone for obtaining a precise value becomes possible."

In summarizing the views on evaporation and transpiration measurement, potential evapotranspiration may be defined as the total amount of water which could be evaporated and/or transpired under optimum conditions of soil moisture and vegetation on a zonal soil and in a zonal climate.

Once the potential evapotranspiration requirements of an area are established and subsequently balanced with incoming precipitation over a long time period, it is possible to determine the normal water status of the location. Negative departures from the normal, or expected, water status provide a measure of drought.

# CHAPTER II

## The Study Area

The area for this research includes the selected states located east of the Mississippi River (Figure 1). To cover the area adequately without using data from all climatic division (155), approximately twenty-five percent of the divisions were chosen for analysis through use of a random numbers table. All states are represented except Delaware, Michigan, Massachusetts, Ohio, Maine, and New Jersey. The climatic divisions chosen are listed by an identification number in Table 1 with their approximate locations are illustrated in Figure 1. Climatic divisions are multicounty areas having basically the same temperature and precipitation characteristics as defined by the National Climatic Data Center.

## Methodology

To determine the impact of moisture demand and availability of moisture in this drought study, the Shear-Steila Drought Index is used in conjunction with the Thornthwaite Water Budget Model. Forty-seven years of monthly climatological data (1931-1977) were analyzed via the Thornthwaite Model to establish moisture demand and supply. These parameters developed within the Thornthwaite Water Budget were then utilized to calculate the Shear-Steila Index to determine the intensity of actual moisture-status departure from normal.

## TABLE 1

## Climatic Divisions by Numbers

Alabama
  1. Upper Plains
  2. Piedmont Plateau
  3. Coastal Plain

Connecticut
  4. Coastal

Florida
  5. Northwest
  6. Lower East Coast

Georgia
  7. West Central
  8. Central

Illinois
  9. Northeast
  10. Central
  11. Southwest

Indiana
  12. West Central
  13. Southwest

Kentucky
  14. Western

Maryland
  15. Northeastern Shore
  16. Allegheny Plateau

Mississippi
  17. Upper Delta
  18. Southwest

New Hampshire
  19. Northern
  20. Southern

New York
  21. Hudson Valley
  22. St. Lawrence Valley

North Carolina
  23. Central Piedmont
  24. Southern Coastal Pl.
  25. Northern Coastal Pl.

Pennsylvania
  26. Central Mountains

South Carolina
  27. Mountain
  28. Southern

Tennessee
  29. Middle

Vermont
  30. Southeastern

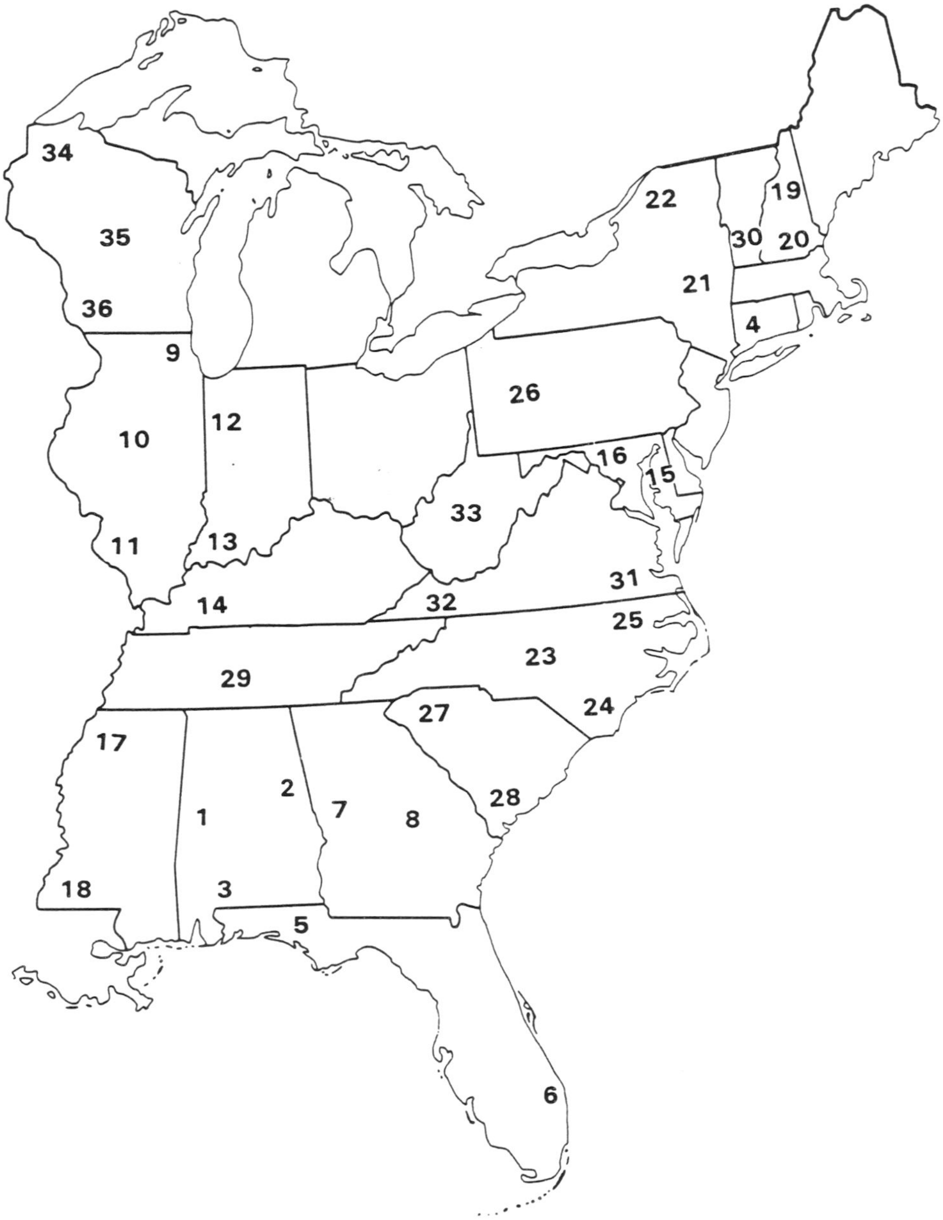
Virginia
  31. Tidewater
  32. Southwestern Mountain

West Virginia
  33. Central

Wisconsin
  34. Northwest
  35. Central
  36. Southwest

Source: U.S. Department of Commerce, Weather
<u>Climatological Data</u>

# THE STUDY AREA



(Numbers correspond to Climatic Divisions listed in Table 1.)

Figure 1

The data base was obtained from the Environmental Sciences Service Administration and NOAA. The Thornthwaite Water Budgets and Shear-Steila Indices were generated with a computer program developed by Dr. Donald Steila ( 1971). An additional computer program was developed, to determine the percent of departure from normal moisture status attributable to each of the primary components of drought: precipitation and evapotranspiration via temperature.

A sample water budget of the South Carolina Mountain Division-1965 (Table 2) illustrates how the Thornthwaite and Steila methodologies interact. The first thirteen rows of the Water Budget represent the Thornthwaite Model while the last row depicts Steila Drought indices.

## Explanation of the Sample Water Budget

The first row (T) contains a record of the average monthly temperature. These averages were applied to the Thornthwaite tables (Thornthwaite 1957) to obtain heat indices (I) represented in row two.

Summing the monthly heat indices yields the annual heat index. Using this total, unadjusted potential evapotranspiration ratings (UNAD PE) were determined with Thornthwaite Tables and recorded in row three.

Row four contains the duration of sunlight or latitudinal correction factors related to variations in length of daylight

Table 2

## THORNTHWAITE WATER BALANCE*
## SOUTH CAROLINA: MOUNTAIN DIVISION (1965)

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature (T) | 38.30 | 38.10 | 43.60 | 57.60 | 65.90 | 67.60 | 74.40 | 71.70 | 67.60 | 54.20 | 47.70 | 40.00 |
| Heat Index (I) | 0.58 | 0.55 | 1.47 | 4.87 | 7.45 | 8.02 | 9.71 | 9.46 | 8.02 | 3.92 | 2.32 | 0.84 |
| Duration Sunlight (DUR SUN) | 0.87 | 0.85 | 1.03 | 1.10 | 1.21 | 1.22 | 1.24 | 1.16 | 1.03 | 0.97 | 0.86 | 0.84 |
| Unadjusted PE (UNAD PE) | 0.32 | 0.30 | 0.74 | 2.24 | 3.31 | 3.54 | 4.22 | 4.12 | 3.54 | 1.83 | 1.13 | 0.44 |
| Potential Evapotranspiration (PE) | 0.28 | 0.26 | 0.77 | 2.46 | 4.00 | 4.32 | 5.23 | 4.78 | 3.65 | 1.78 | 0.97 | 0.37 |
| Precipitation (P) | 3.01 | 4.84 | 7.16 | 4.15 | 4.19 | 4.02 | 4.66 | 4.33 | 4.01 | 3.96 | 2.14 | 0.36 |
| Precipitation-PE (P-PE) | 2.73 | 4.58 | 6.39 | 1.69 | 0.19 | -0.30 | -0.57 | -0.45 | 0.36 | 2.18 | 1.17 | -0.01 |
| Accumulated Water Loss (AWL) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.30 | -0.87 | -1.32 | -0.88 | 0.00 | 0.00 | -0.01 |
| Soil Storage (ST) | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 | 5.71 | 5.18 | 4.80 | 5.16 | 6.00 | 6.00 | 5.99 |
| Surplus (SUR) | 2.73 | 4.58 | 6.39 | 1.69 | 0.19 | 0.00 | 0.00 | 0.00 | 0.00 | 1.34 | 1.17 | 0.00 |
| Storage Change (ST CHG) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.29 | -0.53 | -0.38 | 0.36 | 0.84 | 0.00 | -0.01 |
| Actual Evapotranspiration (AE) | 0.28 | 0.26 | 0.77 | 2.46 | 4.00 | 4.31 | 5.19 | 4.71 | 3.65 | 1.78 | 0.97 | 0.37 |
| Deficiency (DEF) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | -0.04 | -0.07 | 0.00 | 0.00 | 0.00 | 0.00 |
| Drought Index (I) | -1.75 | 0.27 | 1.88 | -0.64 | -0.26 | 0.03 | -1.16 | -1.87 | -1.15 | -0.18 | -1.55 | -4.39 |

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*Temperatures are in degrees Farenheit, all others are in inches.

(DUR SUN). Unadjusted potential evapotranspiration values were multiplied by correction factors to calculate potential evapotranspiration (PE).

Row six is a record of average monthly precipitation (P) as intercepted by standard rain gauges. Available moisture (P-PE) is represented in the following row, a result of subtracting potential evapotranspiration figures from precipitation. Negative values in this row indicate that precipitation was insufficient to meet the evapotranspiration demands for those months.

Accumulated water loss (AWL) is the amount of unfulfilled water demand. It is calculated by summing the increase of potential evapotranspiration demands in excess of precipitation.

Stored soil moisture (ST) has the ability to offset some moisture deficiency from inadequate precipitation and must be considered as part of the available moisture.

In months where there is more moisture than demanded by potential evapotranspiration, and the soil moisture is at capacity, there is a surplus (SUR).

Changes in the soil storage (ST CHG) occur when soil moisture is depleted by evapotranspiration or when there is a soil moisture recharge taking place from excess precipitation.

Actual evapotranspiration (AE) is the amount of moisture that is actually evaporated and transpired at a location. Actual evapotranspiration equals potential evapotranspiration when precipitation and/or soil moisture can meet potential evapotranspiration needs. However, if precipitation and/or soil moisture are insufficient to meet potential evapotranspiration requirements, then actual evapotranspiration equals precipitation received plus released soil moisture.

Differences between actual and potential evapotranspiration are deficiencies (DEF). A negative value indicates that precipitation and released soil moisture were unable to meet potential evapotranspiration needs.

## The Steila Drought Index Methodology

The last row on the sample water budget indicates the Steila Drought Indices (DI). These values indicate departure from the mean moisture status, either positive (excess moisture) or negative (moisture shortage). The mean moisture status is the average monthly moisture status for each climatic division for every month from 1931 through 1977.

The Steila Drought Index ranks the derived values of environmental moisture status into six categories (Table 3). These categories demonstrate the severity of a drought condition based on the amount of negative departure from mean moisture status.

Positive measurements of the Index occur when actual moisture status exceeds mean moisture status. During these times moisture status equals soil storage and existing surpluses.

## Table 3

## Steila Drought Indices

| | |
|---|---|
| Above Normal Moisture | > -1.00 |
| Near Normal Moisture | 0.99 to -0.99 |
| Mild Drought | -1.00 to -1.99 |
| Moderate Drought | -2.00 to -2.99 |
| Severe Drought | -3.00 to -3.99 |
| Extreme Drought | < -4.00 |

Negative indices computed in the sample identified in Table 2 resulted from moisture deficiencies. For the dry months, actual moisture status equaled the deficiencies subtracted from soil storage moisture. Drought intensity is determined in terms of the magnitude of the negative departure from mean moisture status (zero). A drought index value of -4.86 is more intense than a reading of -0.97.

Temperatures which deviate from those normally expected play an important role in the intensity of drought. A situation can exist in which normal amounts of precipitation are insufficient to keep the moisture status of an area at expected levels due to an accompanying situation of higher than normal potential evapotranspiration. Another situation can exist in which below normal precipitation may not constitute a negative departure in moisture status because of below normal potential evapotranspiration demands. Furthermore, if both precipitation and potential evapotranspiration are below normal, the intensity of negative moisture departure may be reduced significantly by the below normal potential evapotranspiration factor. Finally, it is also possible to have both above normal precipitation and potential evapotranspiration, resulting in a condition of below normal moisture status.

Figure 2 facilitates an understanding of these relationships between precipitation and potential evapotranspiration deviations from normal Environmental Moisture Status (EMS). In example "A", above normal moisture status is associated with above normal precipitation and below normal potential evapotranspiration. Example "B" identifies an above normal moisture status existing due to above normal precipitation; yet, environmental wetness is reduced by the above normal potential evapotranspiration.

Examples "C", "D" and "E" illustrate the impact of potential evapotranspiration during periods of below normal moisture status. "C" depicts the ameliorating effect of below normal potential evapotranspiration on drought intensity. In "D" the effect of above normal potential evapotranspiration demonstrates the increased intensity of drought. Example "E" portrays below normal moisture status existing solely due to deficient precipitation, with potential evapotranspiration having absolutely no effect on either ameliorating or intensifying the situation; i.e. below normal precipitation and normal potential evapotranspiration.

RELATIONSHIP OF P.E. UPON EMS

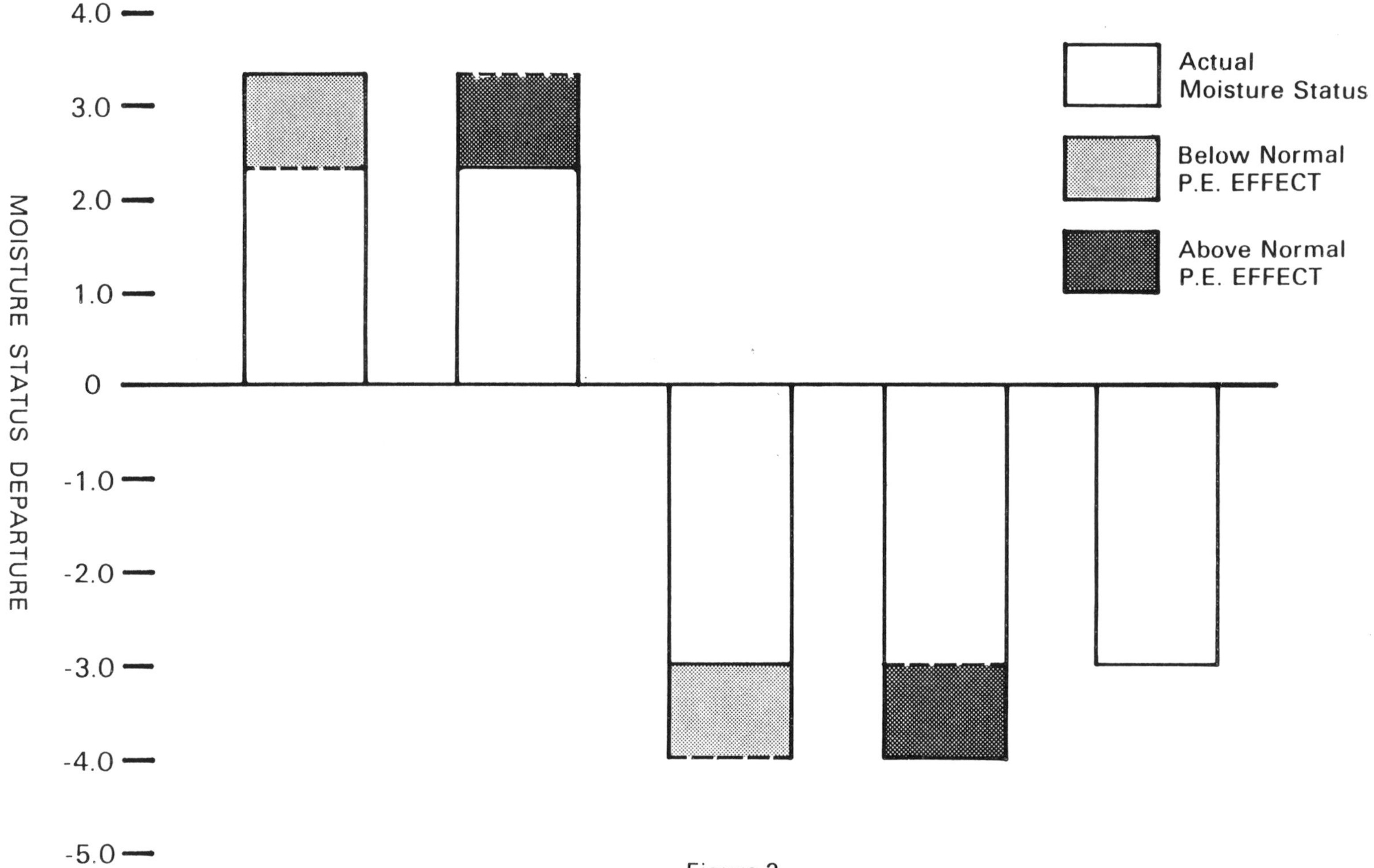

Figure 2

# CHAPTER III

# DISCUSSION OF SELECTED EXAMPLES

After reviewing the data generated for the study area, several drought periods have been selected for discussion. Criteria used for selection included a drought period of at least two months duration and a Steila Drought Index intensity level of -3.00 or greater.

## The Mountain Climatic Division of South Carolina

In the summer and autumn of 1954 many areas of the southeastern United States experienced severe to extreme drought for several months. One area severely affected was the Mountain Climatic Division of South Carolina. From July through November the Drought Index exceeded -3.00 and for September as -6.00. Figure 3 depicts the actual moisture departure effect on the intensities. From July through October higher than normal temperatures increased the negative moisture departure. Below normal temperatures for November reduced the intensity of negative departure slightly. In September above normal potential evapotranspiration accounted for 6.7 percent of drought intensity. During July above normal potential evapotranspiration was significant, in as much as, the high temperature effect caused a change in the Drought Index category for the month. Without the high temperature effect, the month would have been

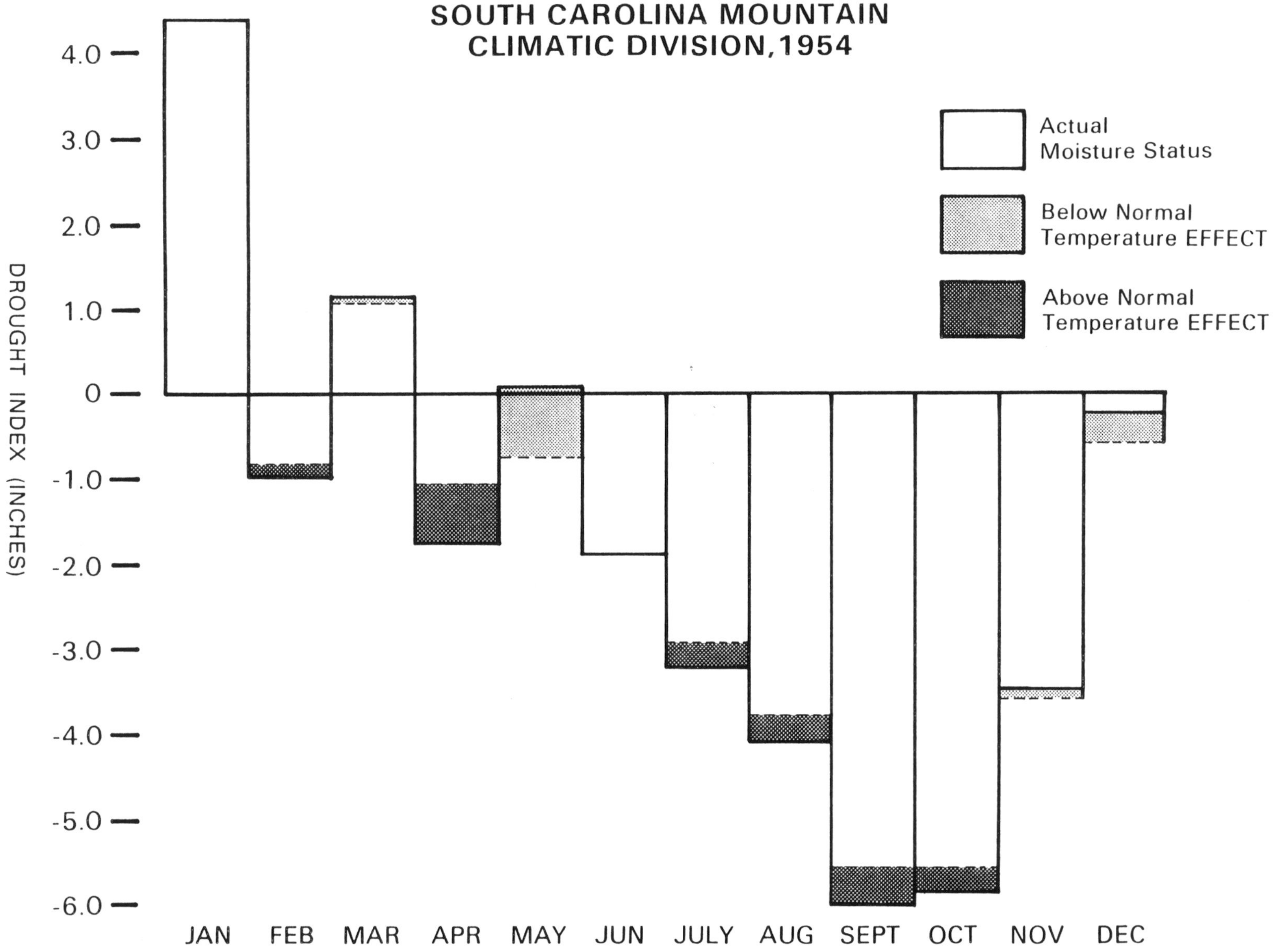
SOUTH CAROLINA MOUNTAIN
CLIMATIC DIVISION, 1954
Actual Moisture Status
Below Normal Temperature EFFECT
Above Normal Temperature EFFECT
DROUGHT INDEX (INCHES)
4.0
3.0
2.0
1.0
0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
JAN
FEB
MAR
APR
MAY
JUN
JULY
AUG
SEPT
OCT
NOV
DEC

Figure 3

classified as having Moderate Drought; but the above normal potential evapotranspiration caused the intensity of drought to be significantly higher, classifying the month in the Severe Drought category.

## The Central Climatic Division of Georgia

Another area suffering drought in 1954 was the Central Georgia Climatic Division (Figure 4). Only August and September exceeded -3.00 on the Drought Index but September was as severe as in the South Carolina Mountain Division, recording a -6.12. In both months higher than normal temperatures increased the intensity of the moisture deficiency considerably. The higher than normal potential evapotranspiration was sufficiently significant to cause August to be classified as having Severe Drought instead of Moderate Drought, and September's deficiency to be intensified by 13.2 percent or 0.81 inches. The above normal temperatures accounted for 11 percent of the moisture deficiency for the month of August.

## The Southern Coastal Plain Climatic Division of North Carolina

The Southern Coastal Plain Climatic Division of North Carolina experienced drought conditions from July through September in 1954 (Figure 5). The departure from Mean Moisture Status ranged from -4.18 in July to -6.07 inches in September. Although above normal temperatures contributed to the increased

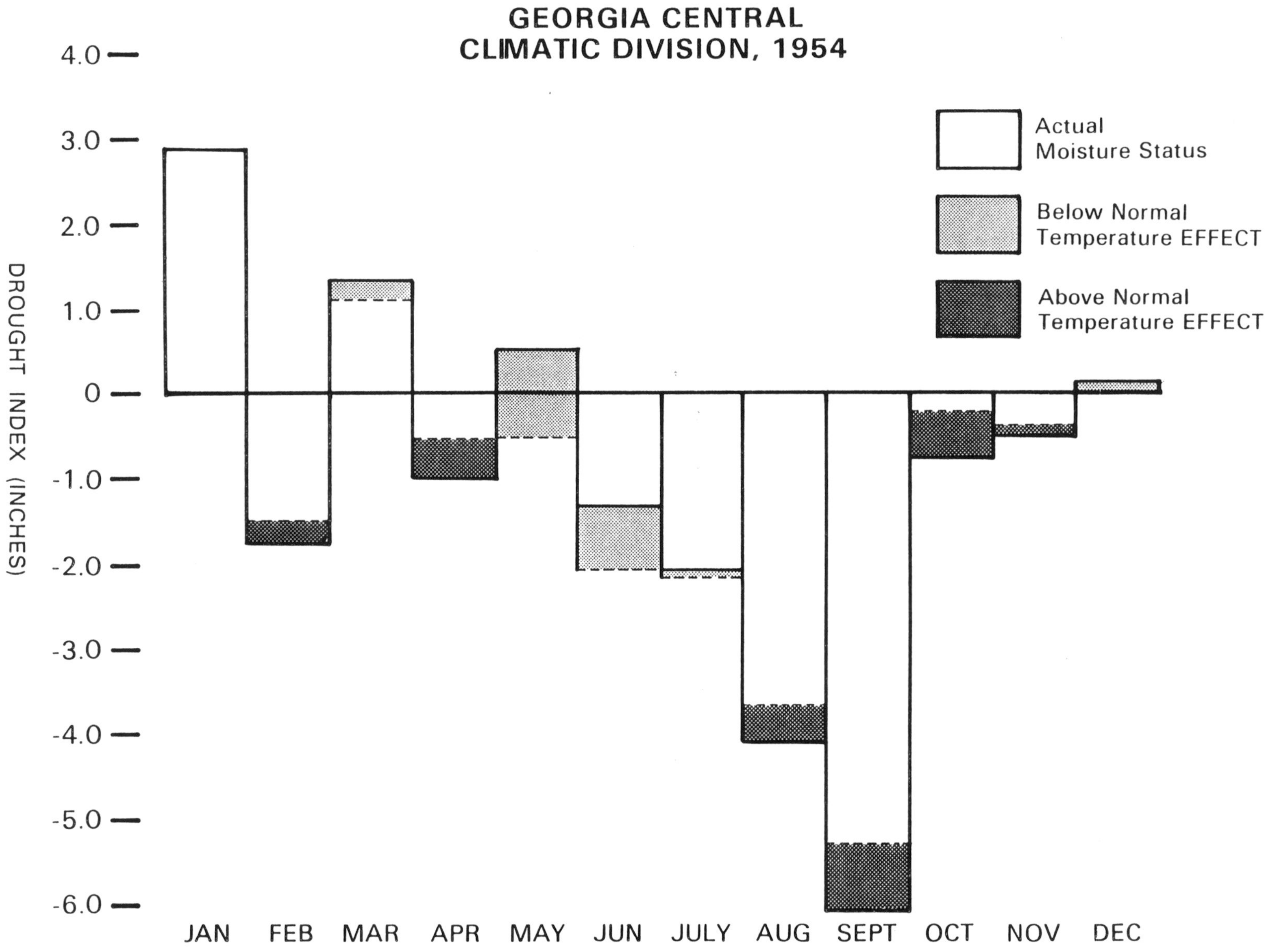
GEORGIA CENTRAL
CLIMATIC DIVISION, 1954
Actual Moisture Status
Below Normal Temperature EFFECT
Above Normal Temperature EFFECT
DROUGHT INDEX (INCHES)
4.0
3.0
2.0
1.0
0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
JAN
FEB
MAR
APR
MAY
JUN
JULY
AUG
SEPT
OCT
NOV
DEC

Figure 4

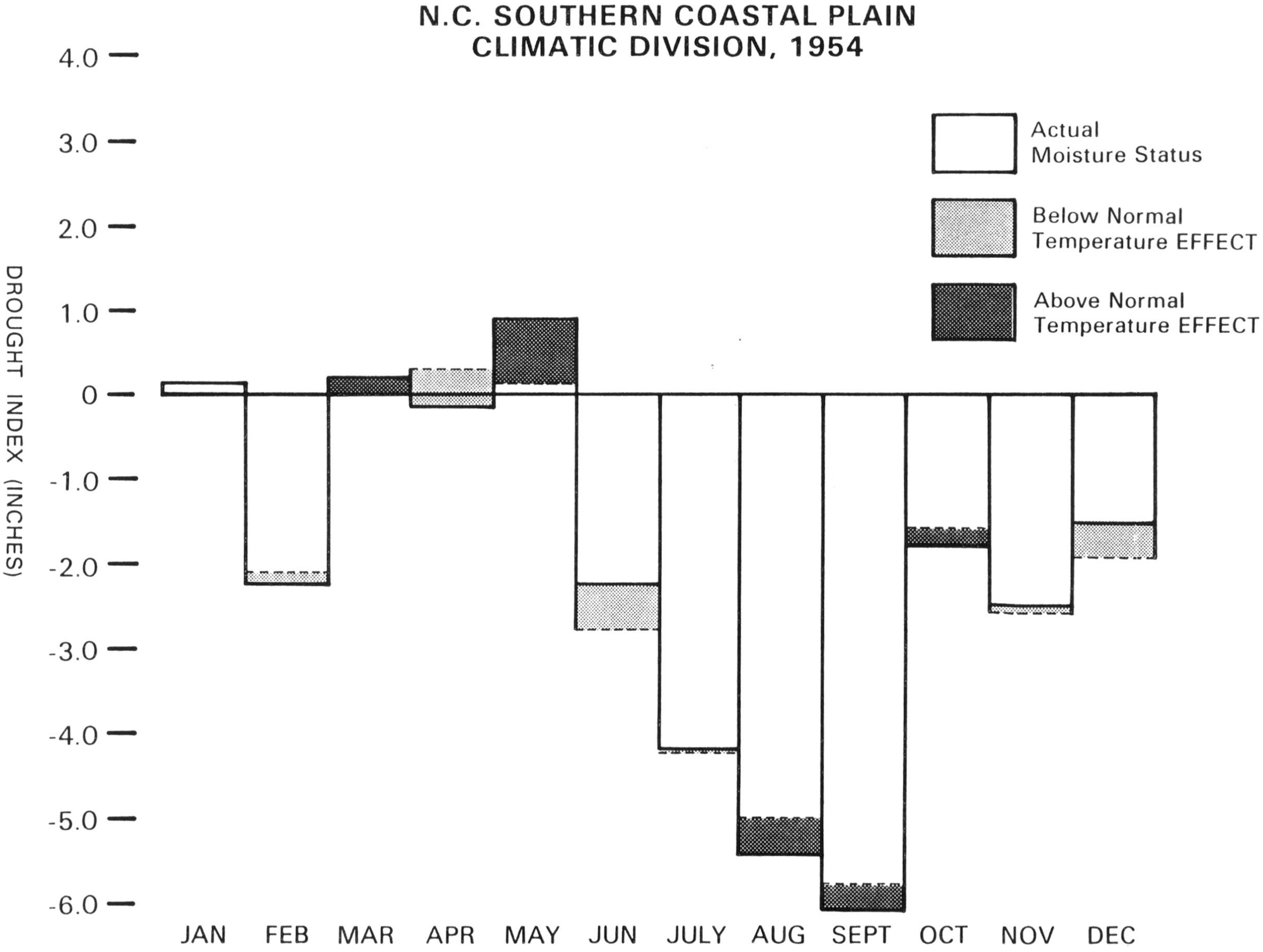
N.C. SOUTHERN COASTAL PLAIN
CLIMATIC DIVISION, 1954
Actual
Moisture Status
Below Normal
Temperature EFFECT
Above Normal
Temperature EFFECT
DROUGHT INDEX (INCHES)
4.0
3.0
2.0
1.0
0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
JAN
FEB
MAR
APR
MAY
JUN
JULY
AUG
SEPT
OCT
NOV
DEC

Figure 5

moisture deficiencies for August and September (7.4 percent for August and 5.4 percent for September), it was not as significant a factor as in the previous two examples. Note that temperatures for July were virtually normal and all moisture deficiency is attributable to below normal precipitation.

## The Western Climatic Division of Kentucky

For the last seven months of 1954 the Western Climatic Division of Kentucky suffered moderate to extreme drought (Figure 6). In each of these months drought intensity was increased by above normal potential evapotranspiration, significantly so for June. Of the -3.62 moisture deficiency, -1.24 inches (34%) was attributable to the above normal potential evapotranspiration component. With the exception of April and May, temperatures were above normal for the entire year. These above normal temperatures accounted for increased drought intensities ranging from 8 percent to 34 percent for the months of June through September. The drought intensity in this climatic division attained its most extreme condition in November and December, but above normal temperatures were not significant as 98 percent of the negative moisture status was a result of below normal precipitation.

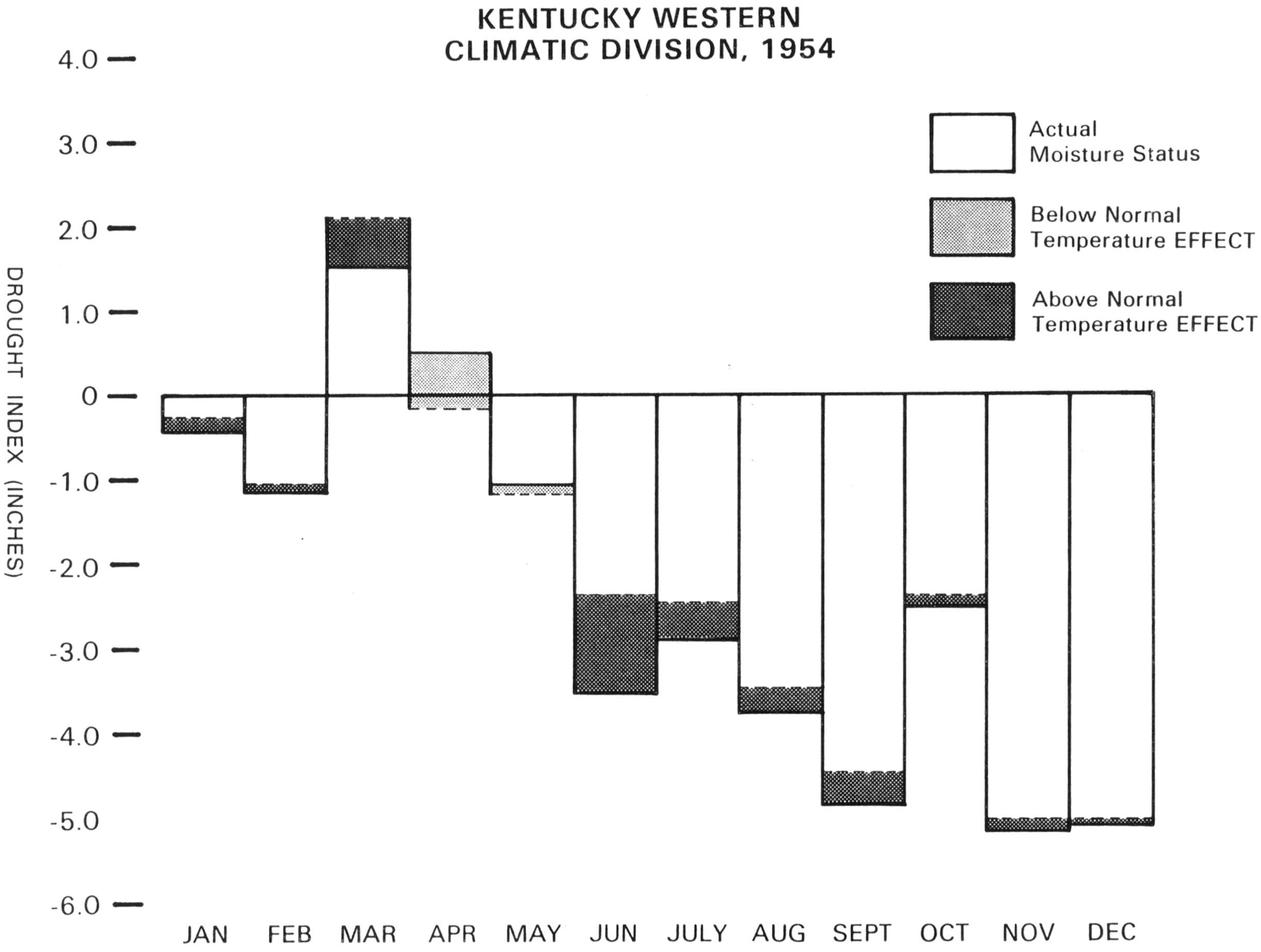
KENTUCKY WESTERN
CLIMATIC DIVISION, 1954
4.0
3.0
2.0
1.0
0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
DROUGHT INDEX (INCHES)
Actual Moisture Status
Below Normal Temperature EFFECT
Above Normal Temperature EFFECT
JAN
FEB
MAR
APR
MAY
JUN
JULY
AUG
SEPT
OCT
NOV
DEC

Figure 6

## The Northeastern States

During 1964 and 1968 the New England States experienced some drought conditions, but not to the extent of the Southern States in 1954. The dry conditions seemed to be more spotty in this area while in the Southern States it was widespread. As an example, the Southern Climatic Division of New Hampshire experienced moderate drought in 1964, but the Northern Climatic Division did not have a drought.

### The Southeastern Climatic Division of Vermont and The Southern Climatic Division of New Hampshire

In 1964 the Southeastern Climatic Division of Vermont (Figure 7) and the Southern Climatic Division of New Hampshire (Figure 8) had similar patterns of drought. The most significant months were the autumn months of September, October, and November as opposed to the summer and autumn months in the Southeastern States. Another major difference between the two regions was the effect of potential evapotranspiration on the drought intensity. While above normal temperatures were significant in increasing drought intensities in the South; below normal temperatures played the role of reducing drought intensities in the Northeast. Drought intensity was ameliorated on an average of about 7 percent for these climatic division in Vermont and New Hampshire.

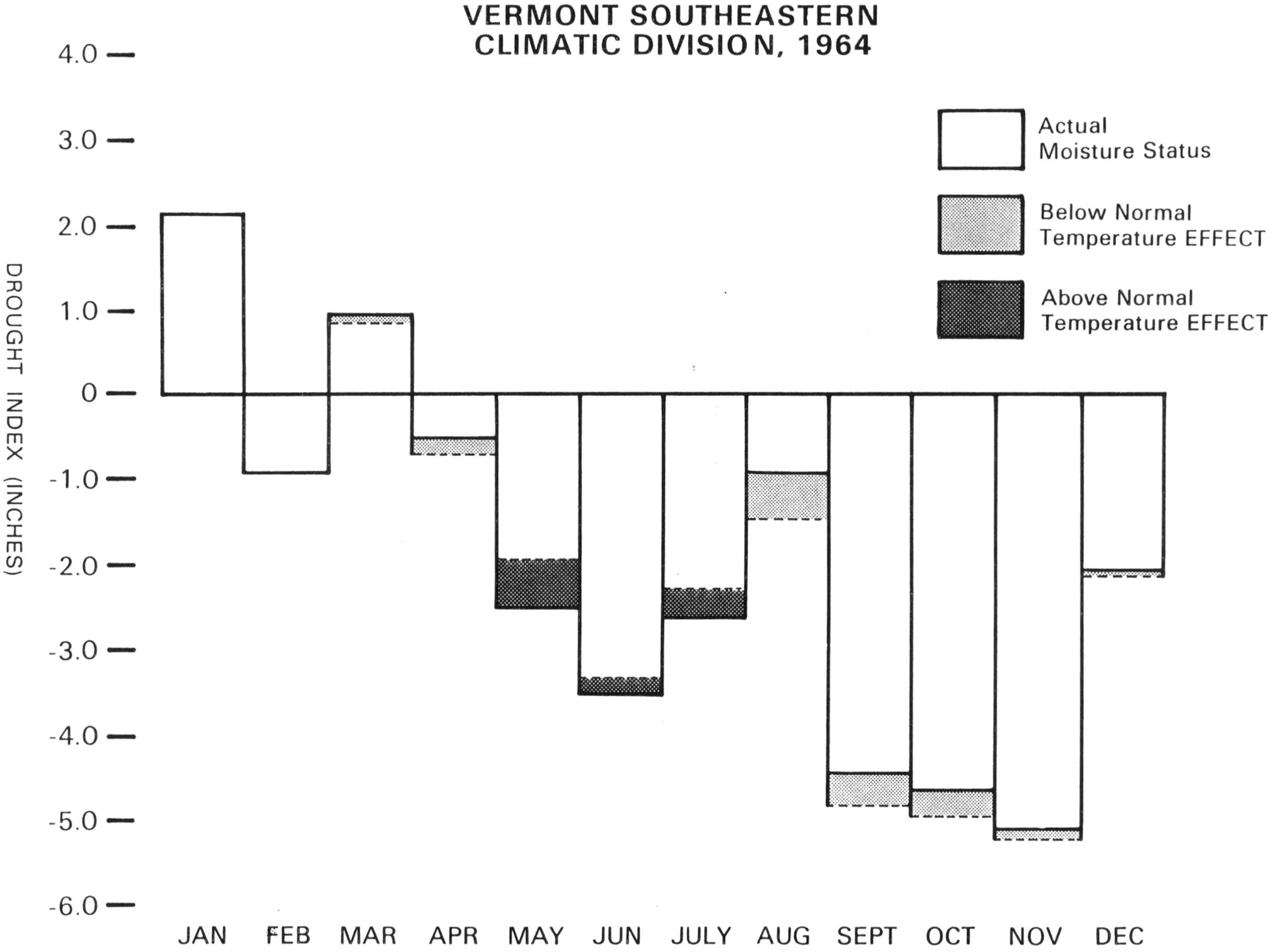
VERMONT SOUTHEASTERN
CLIMATIC DIVISION, 1964
4.0
3.0
2.0
1.0
0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
DROUGHT INDEX (INCHES)
Actual Moisture Status
Below Normal Temperature EFFECT
Above Normal Temperature EFFECT
JAN
FEB
MAR
APR
MAY
JUN
JULY
AUG
SEPT
OCT
NOV
DEC

Figure 7

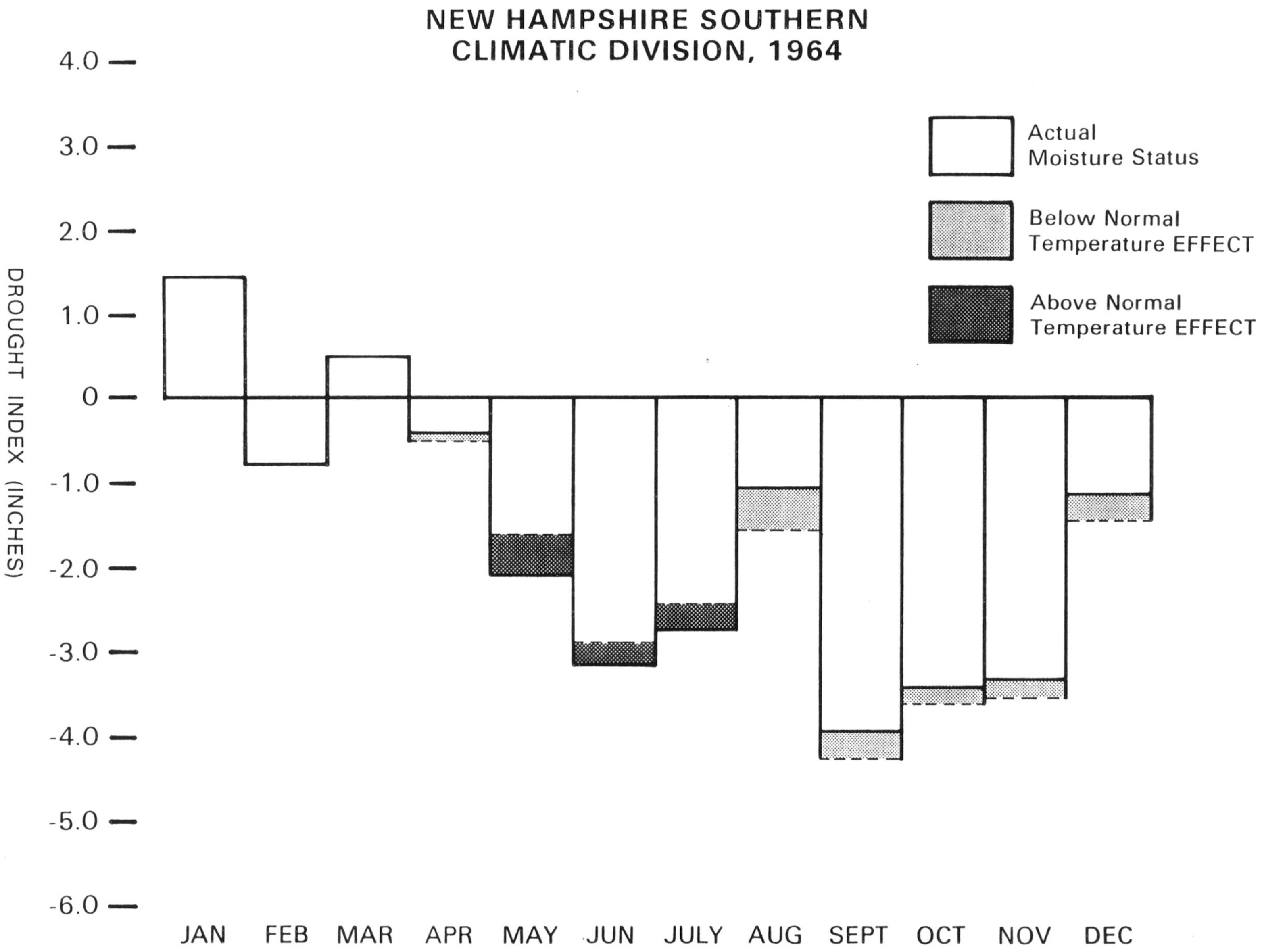
NEW HAMPSHIRE SOUTHERN
CLIMATIC DIVISION, 1964
DROUGHT INDEX (INCHES)
4.0
3.0
2.0
1.0
0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
Actual Moisture Status
Below Normal Temperature EFFECT
Above Normal Temperature EFFECT
JAN
FEB
MAR
APR
MAY
JUN
JULY
AUG
SEPT
OCT
NOV
DEC

Figure 8

## The Northern Climatic Division of New Hampshire

In 1968 the Northern Climatic Division of New Hampshire experienced dry conditions for September and October (Figure 9). Although the drought intensity was not as great as in southern Vermont and New Hampshire in 1964, there is an important difference in the two drought periods. The 1968 northern New Hampshire dry period was increased in intensity as a result of above normal potential evapotranspiration, indicating that higher than normal temperatures can contribute to drought intensity in the more northern latitudes. Although the increase in the intensity was only four to five percent, it is worth noting.

More often than not, however, the temperature effect in this area was one of reducing drought intensities rather than increasing them.

## The Saint Lawrence Valley Climatic Division of New York

The Saint Lawrence Valley Climatic Division of New York experienced its driest month for the 47 years of data in October 1963 (Figure 10). The Drought Index for that month was -4.02, an extreme drought. However, since only September and November experienced mild drought, the severity of drought was limited to a short time. During September the negative moisture status was significantly ameliorated (0.95 inches, -41.3 percent) by temperatures well below the normal expected. Had it not been for

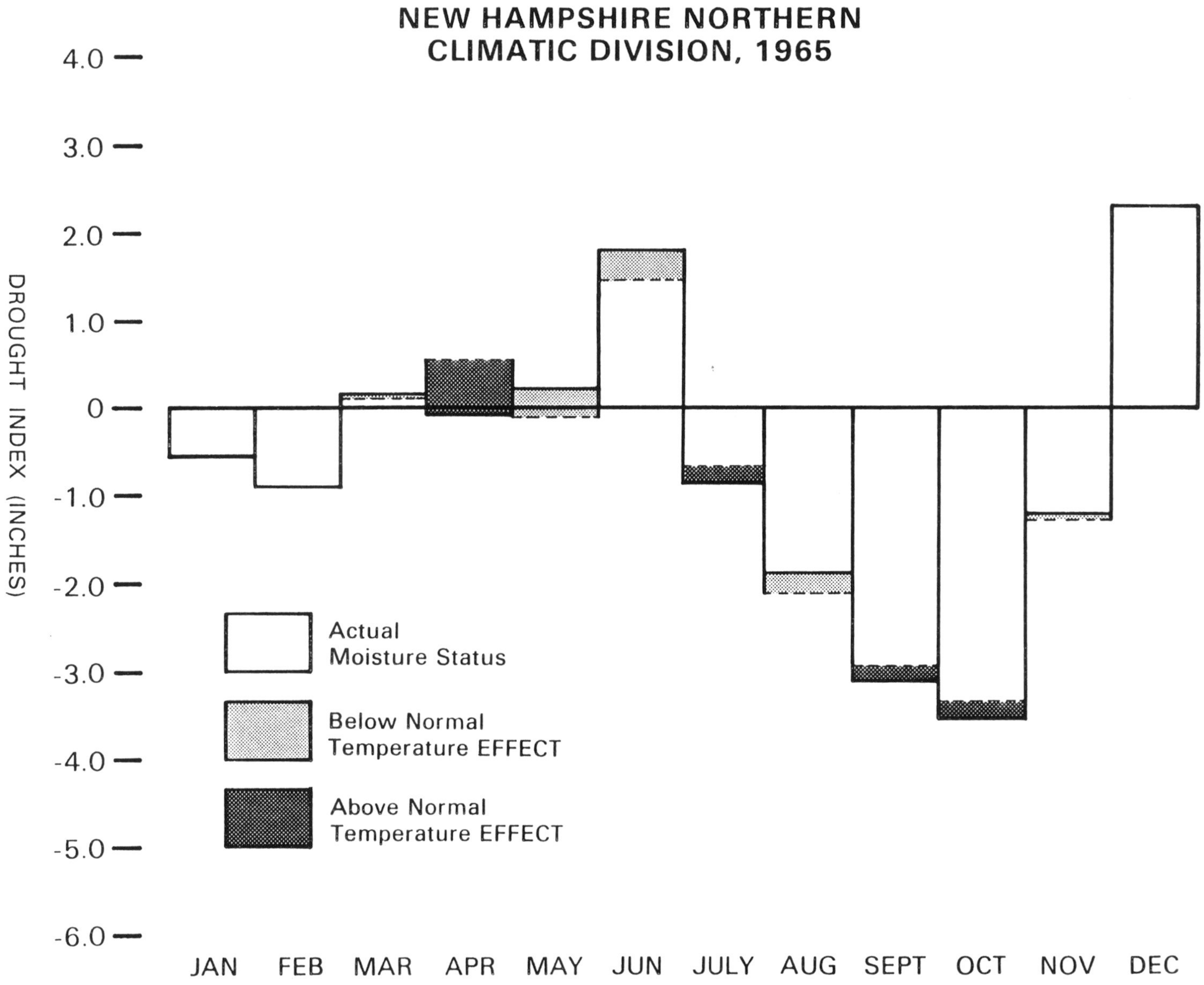
NEW HAMPSHIRE NORTHERN
CLIMATIC DIVISION, 1965
4.0
3.0
2.0
1.0
0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
DROUGHT INDEX (INCHES)
Actual
Moisture Status
Below Normal
Temperature EFFECT
Above Normal
Temperature EFFECT
JAN
FEB
MAR
APR
MAY
JUN
JULY
AUG
SEPT
OCT
NOV
DEC

Figure 9

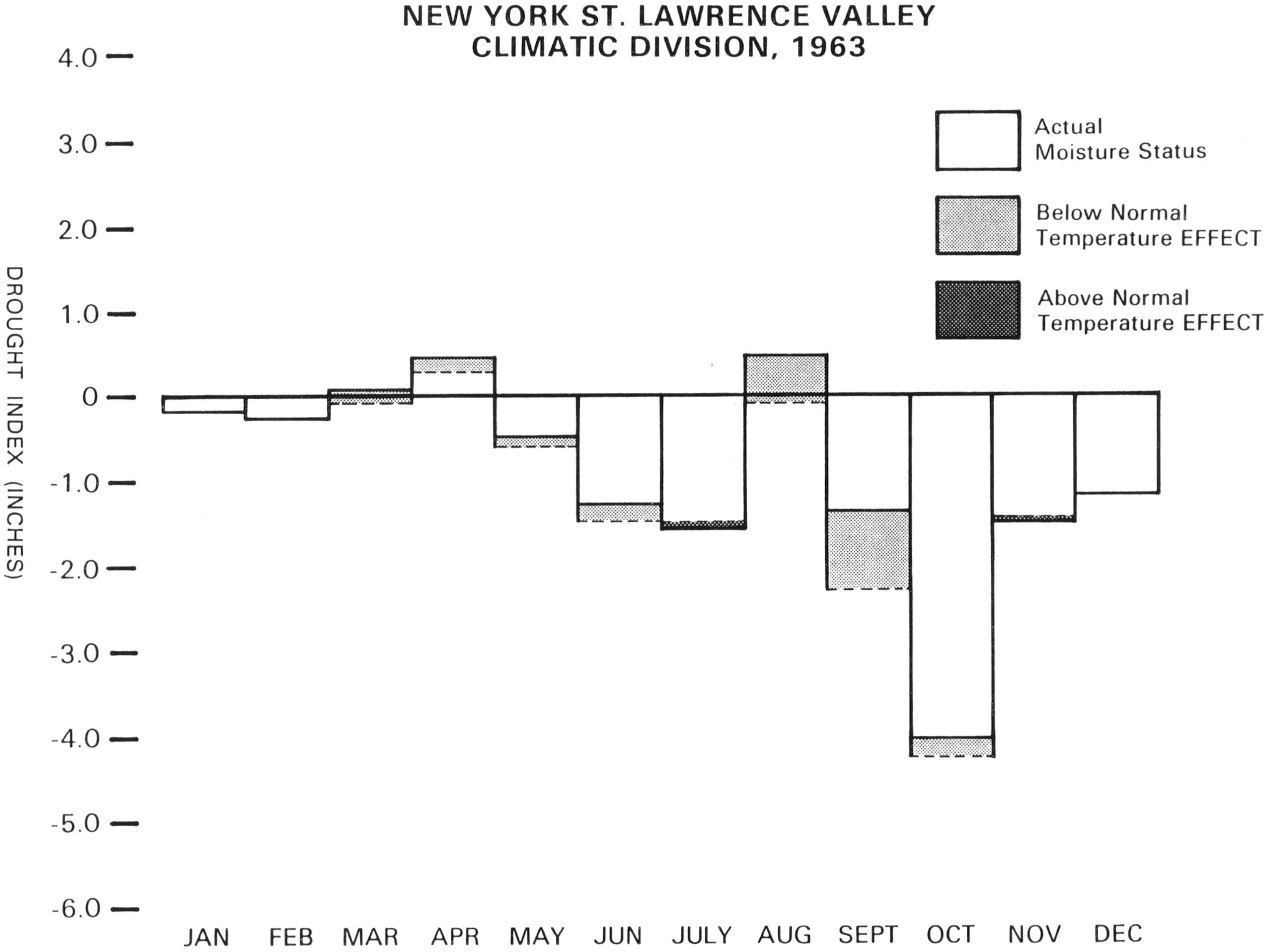
NEW YORK ST. LAWRENCE VALLEY
CLIMATIC DIVISION, 1963
DROUGHT INDEX (INCHES)
4.0
3.0
2.0
1.0
0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
Actual Moisture Status
Below Normal Temperature EFFECT
Above Normal Temperature EFFECT
JAN
FEB
MAR
APR
MAY
JUN
JULY
AUG
SEPT
OCT
NOV
DEC

Figure 10

the below normal potential evapotranspiration, September would have been classified as having moderate drought.

## The Southwest Climatic Division of Illinois

A much different situation can be noted for the Southwest Climatic Division of Illinois for 1953 and 1954 (Figures 11 and 12). A severe to extreme drought condition endured for ten consecutive months, from June 1953 through March 1954. In every one of these months above normal potential evapotranspiration contributed significantly to the drought intensity. The degree of impact on the drought intensity ranged from a low contribution of approximately 6 percent in December 1953 and January 1954 to a maximum effect of 30 percent in June 1953. This particular drought would have been severe to extreme with normal temperatures, but the higher than normal temperatures made the drought more intense. Over the twenty-four month period of 1953 and 1954 this climatic division experienced below normal potential evapotranspiration for only four months; a significant factor with regard to moisture demand. Since both precipitation and potential evaporation was above normal for only four months during this period, the area was not able to recharge the accumulated moisture losses. This was a contributing factor for drought continuing into the second year.

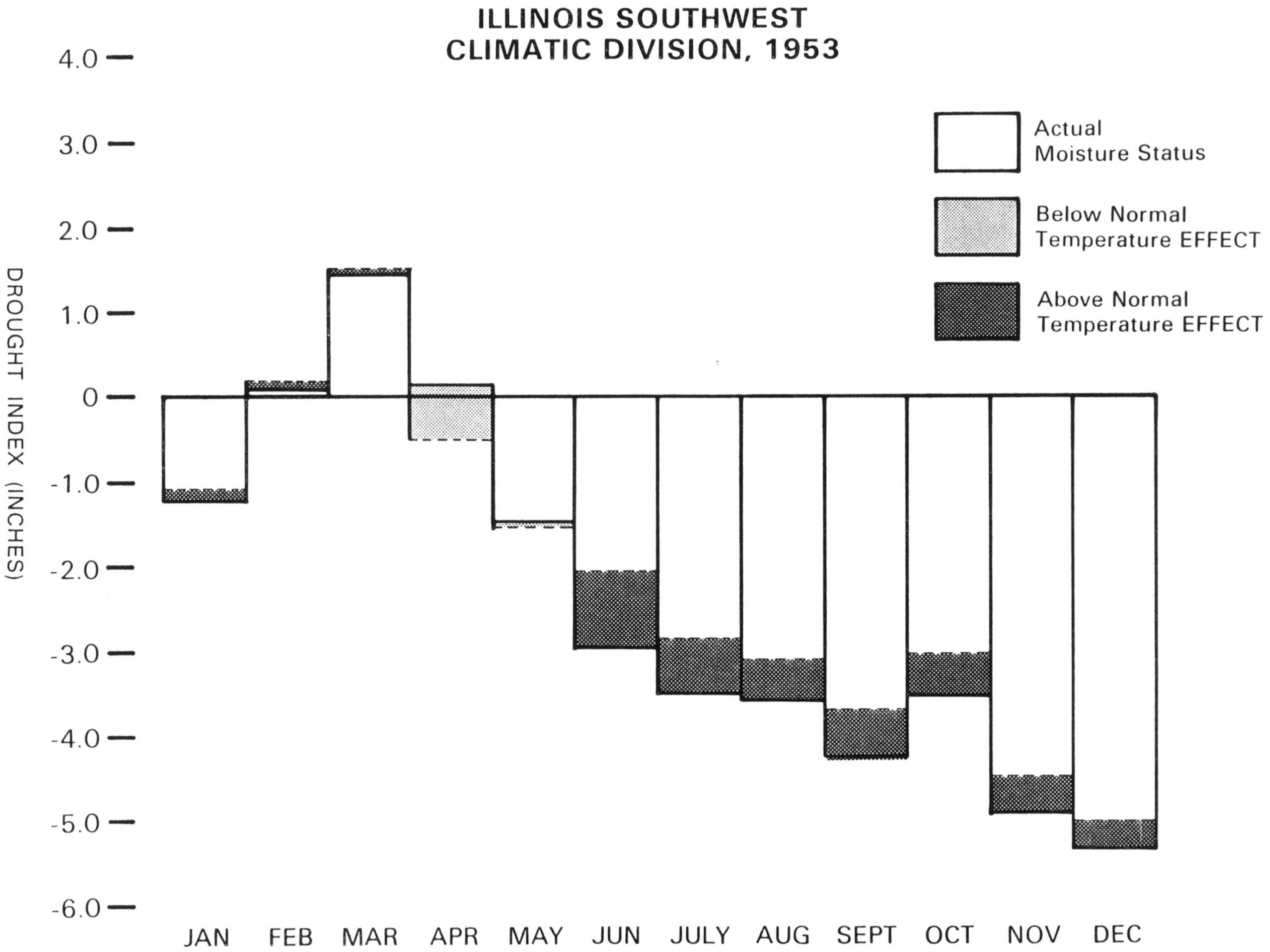
ILLINOIS SOUTHWEST
CLIMATIC DIVISION, 1953
Actual Moisture Status
Below Normal Temperature EFFECT
Above Normal Temperature EFFECT
DROUGHT INDEX (INCHES)
4.0
3.0
2.0
1.0
0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
JAN
FEB
MAR
APR
MAY
JUN
JULY
AUG
SEPT
OCT
NOV
DEC

Figure 11

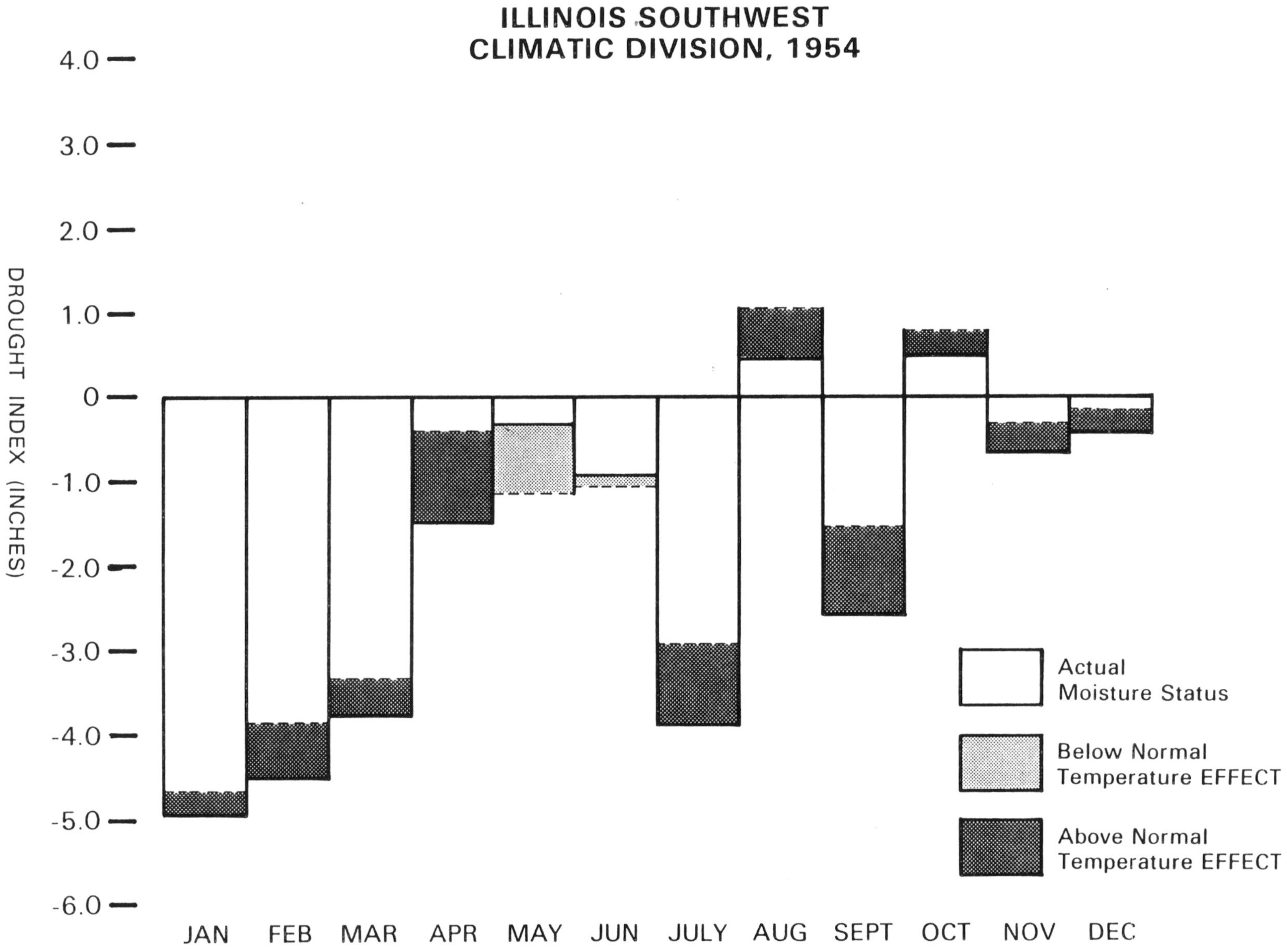
ILLINOIS SOUTHWEST
CLIMATIC DIVISION, 1954
DROUGHT INDEX (INCHES)
4.0
3.0
2.0
1.0
0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
JAN
FEB
MAR
APR
MAY
JUN
JULY
AUG
SEPT
OCT
NOV
DEC
Actual Moisture Status
Below Normal Temperature EFFECT
Above Normal Temperature EFFECT

Figure 12

# CHAPTER IV

# ANALYSIS OF DROUGHT COMPONENTS

The three basic components of drought are: (1) precipitation, (2) potential evapotranspiration, and (3) available soil moisture; with the latter being dependant to a significant degree on the first two.

## PRECIPITATION

As noted earlier, many drought definitions are based solely on deficient precipitation. Precipitation is the single most important determining component of environmental moisture status. Whenever precipitation amounts fall below the normal expected, environmental moisture status usually diminishes.

If there is little or no rainfall during the summer months, the environment becomes noticeably "dry", however, during the cooler winter months the "dryness" may not be noticed as much if precipitation is below normal. For most humid areas the cooler winter months are times for soil moisture recharging, and if precipitation is below normal at this time, the long range effect can be devastating. If there as been sufficient precipitation to recharge the soil moisture to capacity during the cooler winter months, then shortages of rainfall during the summer months will not be as detrimental to environmental moisture status unless the dry period is for an extended period of time.

Can drought occur during periods of surplus environmental moisture status? Many qualitative definitions of drought refer to the phenomenon as a "state of dryness" (McBryde, 1982). Quantitative research clearly identifies periods wherein an environment has surplus moisture availability; yet, at the same time, total water supplies are appreciably below those normally associated with the same region. Under such conditions the area is _not_ "dry", but it is below its expected norm with respect to water supply (Palmer, 1965; Steila, 1971, 1974; Sanders, 1972). In short there is drought with regard to expected environmental moisture status.

Petterson (1980) substantiated the consequences of these statements in her analysis of the 1977 drought in the Southeastern United States. In several parts of the study area, water budget analysis and hydrological data indicated surplus water to be available during the winter of 1977. Precipitation amounts, however, were well below the normal expected. This is also the case for the 1954 drought of the same area. Although these environments were _not_ "dry", they received too little precipitation to adequately recharge groundwater and soil moisture reserves to normal levels.

In all cases evaluated in this study where drought was deemed to be extreme or severe, the chief component was below normal precipitation. As the drought periods intensified and became more severe, the percentage of departure from normal moisture status attributable to deficient precipitation increased. This substantiates that below normal precipitation is the primary drought component.

## POTENTIAL EVAPOTRANSPIRATION (TEMPERATURE)

The monthly contributions of above normal potential evapotranspiration have been evaluated as a percentage of the total drought status. Findings for the 1954 drought in the southeastern United States indicate that the above normal potential evapotranspiration demand accounted for as little as 2 percent to as much as 35 percent of total drought status during given months. The 35 percent figure is quite high considering that the only months closely examined had a Drought Index value of -3.00 or greater.

Steila (1971, 1983) found that above normal potential evapotranspiration accounted for as much as 75 percent of drought status for a given month during the 1936 drought in the southeastern United States. However, the largest percentages in his study were for months with minor negative environmental moisture status departures.

As the examples discussed have shown, above normal potential evapotranspiration can occur for any month and will have a negative effect on environmental moisture status for that month. During the normally cool winter months above normal potential evapotranspiration can negate surplus precipitation and therefore impede the recharging processes for groundwater and soil moisture storage.

Potential evapotranspiration demands are not always above normal and in many instances may be below normal. When temperatures are significantly below the normal expected a noticeable reduction in drought intensities occurs. This ameliorating effect is documented in the examples of the more northern latitudes. This was particularly significant in the Saint Lawrence Valley examples where negative moisture status was ameliorated by 41.3 percent.

Even in the southern latitudes below normal potential evapotranspiration can have a significant ameliorating effect. However, below normal potential evapotranspiration tends to have a greater impact on environmental moisture status when the negative departures are less than -3.00 inches on the Drought Index.

## AVAILABLE SOIL MOISTURE

When a drought occurs the most noticeable effect is that which is observed on vegetation. When available moisture in the rhyzosphere has been used by the plants and rainfall is absent, the area's vegetation suffers and may die. Some agricultural crops may survive but produce significantly lower yields or none at all.

A significant factor is the ability of the soil to store moisture effectively. The characteristics of the soil determine its moisture holding capabilities. For example, soil texture is extremely important regarding soil moisture retention. Sandy porous soils will lose their moisture rather quickly while those soils with a higher concentration of clays will retain moisture over a longer period of time. The fine texture of the clay soils enable them to release their stored moisture to vegetation over a longer period of time than the sandy soils. However, these clay soils are also more difficult to recharge with moisture since moisture absorption is also at a slower rate.

During the cooler winter months when soil moisture is recharged, adequate precipitation must fall to bring soil moisture to capacity. If this fails to occur and precipitation continues to be below normal throughout the spring and summer months, then the onset of drought will be earlier and more severe. Should temperatures be above normal at this time, the evaporation demand from the soil will be higher, depriving the vegetation of some of the available soil moisture.

In short, the characteristics of the soil, particularly texture, have an effect on how significant deviations from normal precipitation and potential evapotranspiration will be for a particular area for a given length of time.

# CHAPTER V

## POTENTIAL EVAPOTRANSPIRATION DROUGHT INTENSIFICATION: AN AREAL ANALYSIS

The concept of temperature variation as a significant parameter of drought and its intensity is relatively new. In particular, studies conducted by Palmer (1958), and Steila (1971) incorporated temperature-induced evapotranspiration demands as an element significant to either intensifying or ameliorating an area's environmental moisture status.

This study shows that above normal potential evapotranspiration is not only a significant component of drought and its intensification; but that there is an areal differentiation of the potential evapotranspiration factor through time, in as much as, the areal patterns of significance shift through the seasons of the year.

A 20 year period of monthly data were randomly selected for each climatic division within the study area to evaluate potential evapotranspiration as a factor altering moisture status a twenty year period of monthly data were randomly selected for each climatic division within the study area. Sabin and Shulman (1985) concluded that ten years of data were probably as suitable as thirty-five or forty years of data for evaluating climatological phenomena. Data from all months for the twenty-year period from all the climatic divisions randomly selected for this study were examined, and only those months with a Drought

Index value of -1.00 or greater were selected for further evaluation. This data was then grouped by seasons for analysis.

The months which exhibited an increased drought intensity attributable to above normal potential evapotranspiration were tabulated and an occurrence-percentage calculated against all months for the period. The calculated drought-intensification, monthly occurrence-percentages for each season are listed in Table 4 by climatic division number.

These percentages were then used to construct a series of seasonal isoline maps to illustrate the areal patterns associated with above normal temperatures and their potential evapotranspiration equivalents (PE). It is important to note that these maps offer predictive indices of drought recurrence in association with potential evapotranspiration deviation from normal. For example areas showing an occurrence-percentage of 18 to 20 percentage means that above normal potential evapotranspiration contributed to drought intensity 18 to 20 percent of the time.

## WINTER (January-March)

The most significant influence of potential evapotranspiration during winter is along the south Atlantic coastal region and at the confluence of the Ohio and Mississippi Rivers (Figure 13). There is no effect across the northern tier of states and only slight influence along the western slopes of

## TABLE 4

## OCCURRENCE-PERCENTAGES OF DROUGHT INTENSIFICATION ATTRIBUTABLE TO ABOVE NORMAL PE BY CLIMATIC DIVISIONS

| DIV# | WINTER | SPRING | SUMMER | AUTUMN | AUTUMN WINTER | SPRING SUMMER |
|---|---|---|---|---|---|---|
| 1. | 13.3 | 23.3 | 23.3 | 15.0 | 14.2 | 23.3 |
| 2. | 11.7 | 21.7 | 25.0 | 16.7 | 14.2 | 23.3 |
| 3. | 16.7 | 20.0 | 26.7 | 15.0 | 15.8 | 23.3 |
| 4. | 3.3 | 18.3 | 23.3 | 20.0 | 11.7 | 20.8 |
| 5. | 16.7 | 23.3 | 26.7 | 16.7 | 16.7 | 21.7 |
| 6. | 16.7 | 16.7 | 21.7 | 20.0 | 18.3 | 19.2 |
| 7. | 13.3 | 21.7 | 23.3 | 16.7 | 15.0 | 22.5 |
| 8. | 11.7 | 21.7 | 23.3 | 16.7 | 14.2 | 22.5 |
| 9. | 10.0 | 18.3 | 25.0 | 15.0 | 15.0 | 20.8 |
| 10. | 15.0 | 20.0 | 25.0 | 18.3 | 20.0 | 22.5 |
| 11. | 21.7 | 28.3 | 25.0 | 23.3 | 20.8 | 26.5 |
| 12. | 18.3 | 18.3 | 21.7 | 16.7 | 17.5 | 20.0 |
| 13. | 18.3 | 21.7 | 23.3 | 20.0 | 19.2 | 22.5 |
| 14. | 20.0 | 26.7 | 23.3 | 28.3 | 24.2 | 25.0 |
| 15. | 11.7 | 20.0 | 21.7 | 18.3 | 15.0 | 20.8 |
| 16. | 6.7 | 20.0 | 21.7 | 15.0 | 11.7 | 20.8 |
| 17. | 13.3 | 25.0 | 25.0 | 20.0 | 16.7 | 25.7 |
| 18. | 15.0 | 18.3 | 25.0 | 13.3 | 14.2 | 21.7 |
| 19. | 0.0 | 16.7 | 23.3 | 10.0 | 5.0 | 20.0 |
| 20. | 1.7 | 16.7 | 23.3 | 15.0 | 8.3 | 14.2 |
| 21. | 0.0 | 18.3 | 23.3 | 15.0 | 7.5 | 20.8 |
| 22. | 0.0 | 11.7 | 25.0 | 10.0 | 5.0 | 18.3 |
| 23. | 11.7 | 18.3 | 21.7 | 13.3 | 9.2 | 20.0 |
| 24. | 15.0 | 16.7 | 23.3 | 18.3 | 16.7 | 22.5 |
| 25. | 15.0 | 21.7 | 23.3 | 18.3 | 16.7 | 22.5 |
| 26. | 5.0 | 20.0 | 18.3 | 13.3 | 9.2 | 19.2 |
| 27. | 15.0 | 18.3 | 23.3 | 13.3 | 14.2 | 22.5 |
| 28. | 18.3 | 23.3 | 23.3 | 18.3 | 18.3 | 23.3 |
| 29. | 10.0 | 18.3 | 25.0 | 11.7 | 10.8 | 21.6 |
| 30. | 1.7 | 18.3 | 25.0 | 15.0 | 7.5 | 20.8 |
| 31. | 13.3 | 20.0 | 21.7 | 16.7 | 15.0 | 20.8 |
| 32. | 6.7 | 20.0 | 20.0 | 13.3 | 10.0 | 20.0 |
| 33. | 5.0 | 20.0 | 18.3 | 11.7 | 8.3 | 19.2 |
| 34. | 5.0 | 15.0 | 20.0 | 13.3 | 9.2 | 17.5 |
| 35. | 6.7 | 15.0 | 20.0 | 15.0 | 10.8 | 17.5 |
| 36. | 10.0 | 18.3 | 23.3 | 15.0 | 12.5 | 20.8 |

## MONTHLY DROUGHT OCCURRENCE—PERCENTAGES DUE TO > $\overline{PE}$

### WINTER (JAN/MAR)

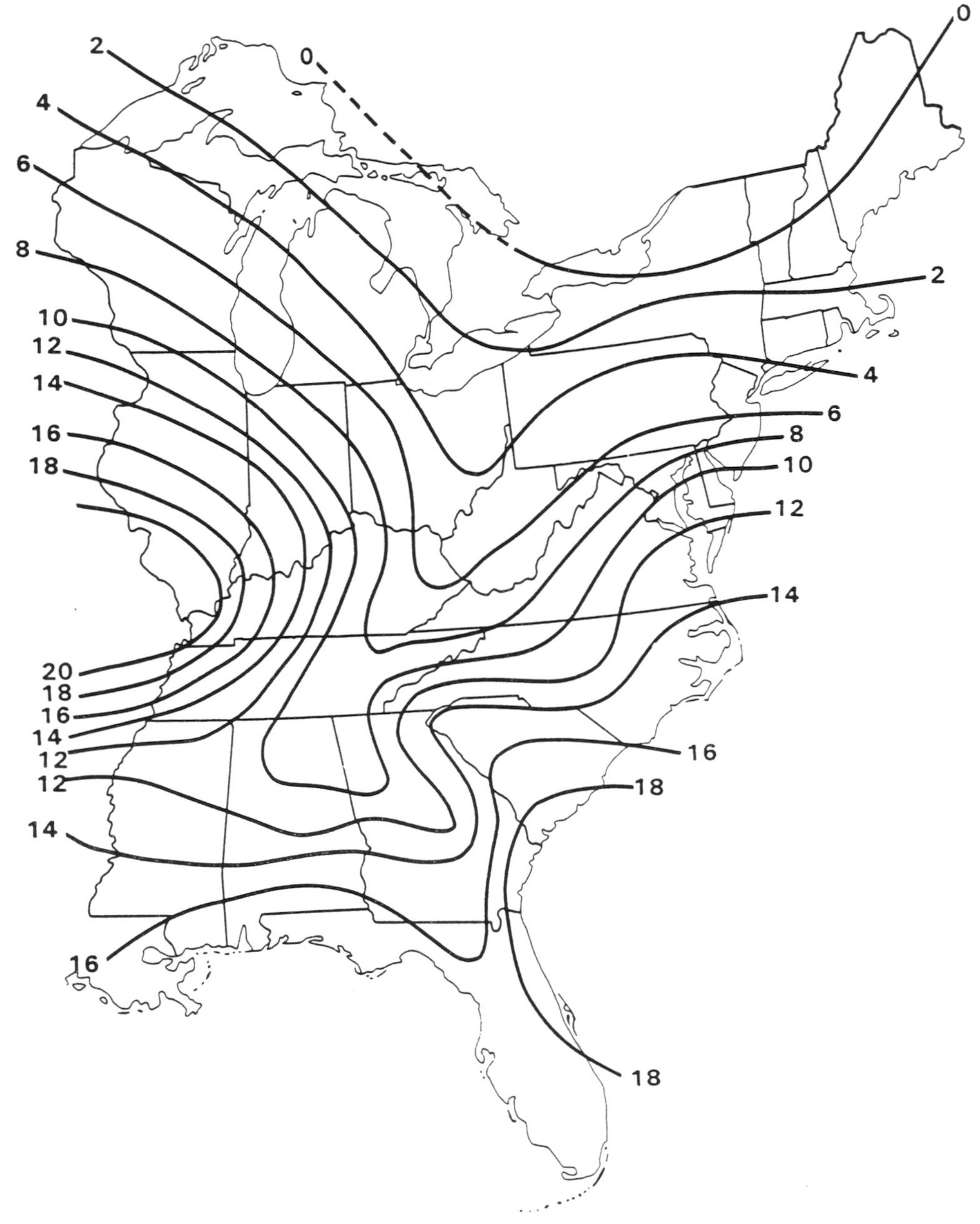

Figure 13

the Appalachian Mountains. Note the general pattern of a Northeast to Southwest trend in intensification, and a trough of lower values paralleling the Appalachian Plateau.

The lack of potential evapotranspiration-departure influence along the northern tier of states is attributable to low mean monthly temperatures. Variations in temperature from means of $20^{\circ}$ to $30^{\circ}$ Farenheit have essentially zero significance in raising the potential evapotranspiration impact. Indeed, the Thornthwaite model--the basis for this analysis, does not account for evapotranspiration occurring at temperatures below freezing. The trough of low occurrence along the Appalachians is likewise related to high-altitude/low-temperature complexes.

As noted above, high frequency nodes occur in two locations. It is hypothesized that the Mississippi-Ohio River "high frequency" node is associated with a "backing effect" on low level high pressure systems that stagnate westward of the Appalachian Mountains. While intensifying to develop sufficient depth to cross the mountain chain, clear skies with surface warming conditions are experienced. The latter can provide for above normally expected temperatures and associated above normal potential evapotranspiration. Likewise, the South-Atlantic Coast "high frequency" node can be linked to oscillating strengthening-weakening patterns of the North Atlantic Subtropic·High Pressure Cell.

## SPRING (April-June)

The map for Spring (Figure 14) demonstrates complex changes taking place relative to potential evapotranspiration influences. The impact at the Ohio and Mississippi Rivers is significantly strengthened and the south Atlantic influence split and shifted northward and toward the southwest, dividing the region into three core-areas of high intensity with intervening depressions of lower intensity. Whereas the northern states had 0 percent effect during Winter, the occurrence-percentages of potential evapotranspiration contribution now totals as much as 14 percent.

Clearly, the surface warming and rising air temperatures are responsible for the increased occurrence of above-normal temperature-induced drought throughout the northern tier of states. The southwest-northeast trend of lowest occurrence appears well situated with respect to the dominant spring track of cyclonic storms. Greater cloudiness and precipitation suggest less temperature variability than to the west or east. The Gulf Coast "high frequency" node also reflects the northward storm-track shift and a period of decreased cloudiness/precipitation and consequently more frequent high-intensity solar-heating episodes; whereas the Mid-Atlantic States "high frequency" node is associated with the northward shift of the North Atlantic Subtropic High and the stabilizing effect of the Newfoundland

# MONTHLY DROUGHT OCCURRENCE—PERCENTAGES DUE TO > $\overline{PE}$

## SPRING (APR—JUN)

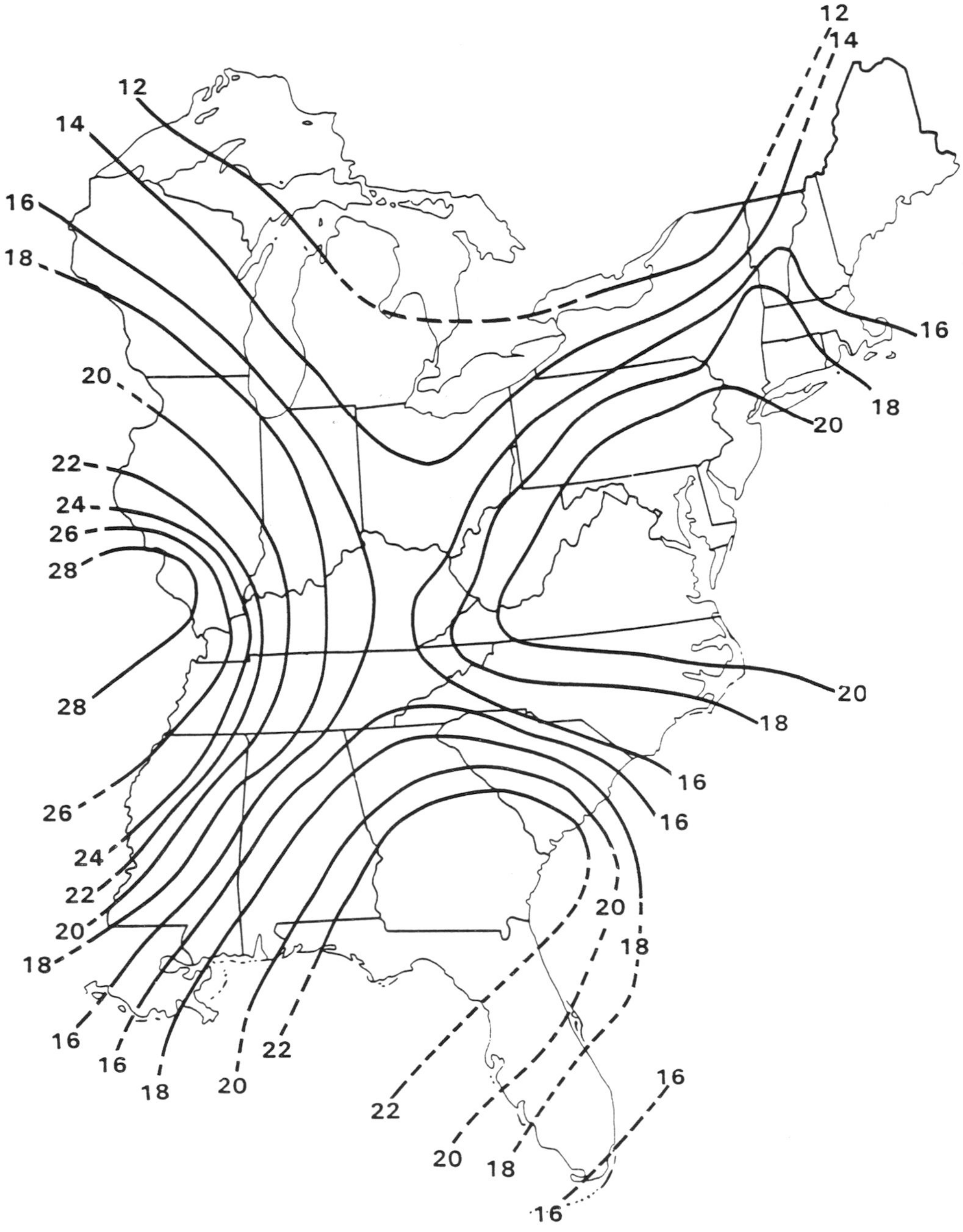

Figure 14

Current. The Mississippi-Ohio River node bears the continuing pattern of winter, but as will be shown, weakens rapidly with the onset of summer.

## SUMMER (July-September)

During the summer months the cells of potential evapotranspiration influence are less well-defined than during the other seasons (Figure 15). The patterns have largely merged and there is as much differentiation from East to West as there is from North to South. As is the case with Winter and Spring, the impact of potential evapotranspiration during Summer is not as high along the western slopes of the Appalachian Mountains, possibly as a result of a higher percentage of cloudy days associated with orographic precipitation.

The patterns for Summer parallel the circulation pattern that has weakened due to high-latitude solar heating. Although the percentages are relatively high, they basically follow a South to North diminishing trend. The single exception is the increased values of the New England States, reflective of high pressure system recurrence associated with the Arctic and lack of the Great Lakes moderating influence.

## AUTUMN (October-December)

With the onset of cooler temperatures and fewer hours of sunlight the patterns of potential evapotranspiration influence begin to shift southward during Autumn (Figure 16). Significant

# MONTHLY DROUGHT OCCURRENCE—PERCENTAGES DUE TO > $\overline{PE}$

## SUMMER (JULY—SEP)

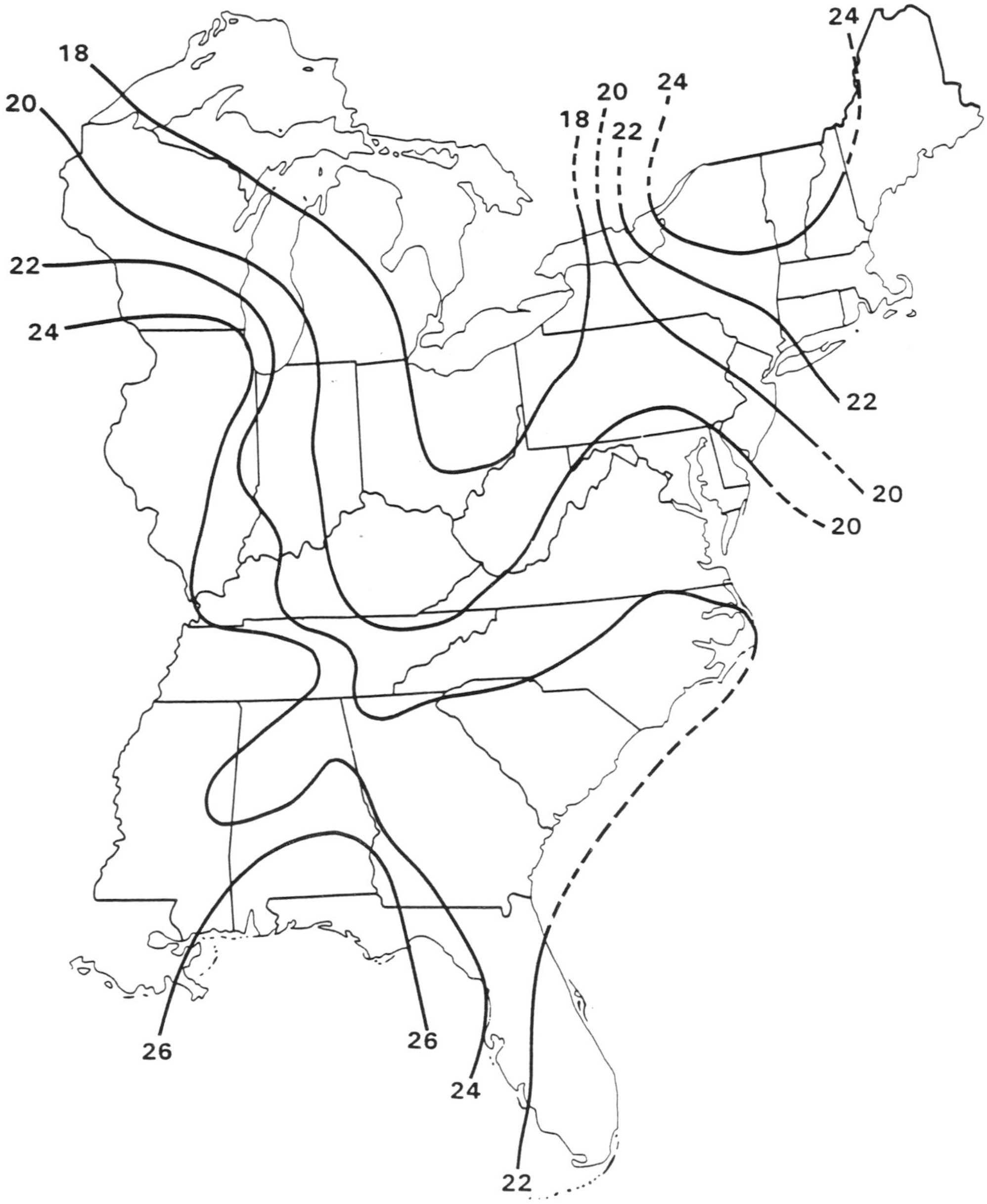

Figure 15

# MONTHLY DROUGHT OCCURRENCE—PERCENTAGES DUE TO > PE

## AUTUMN (OCT—DEC)

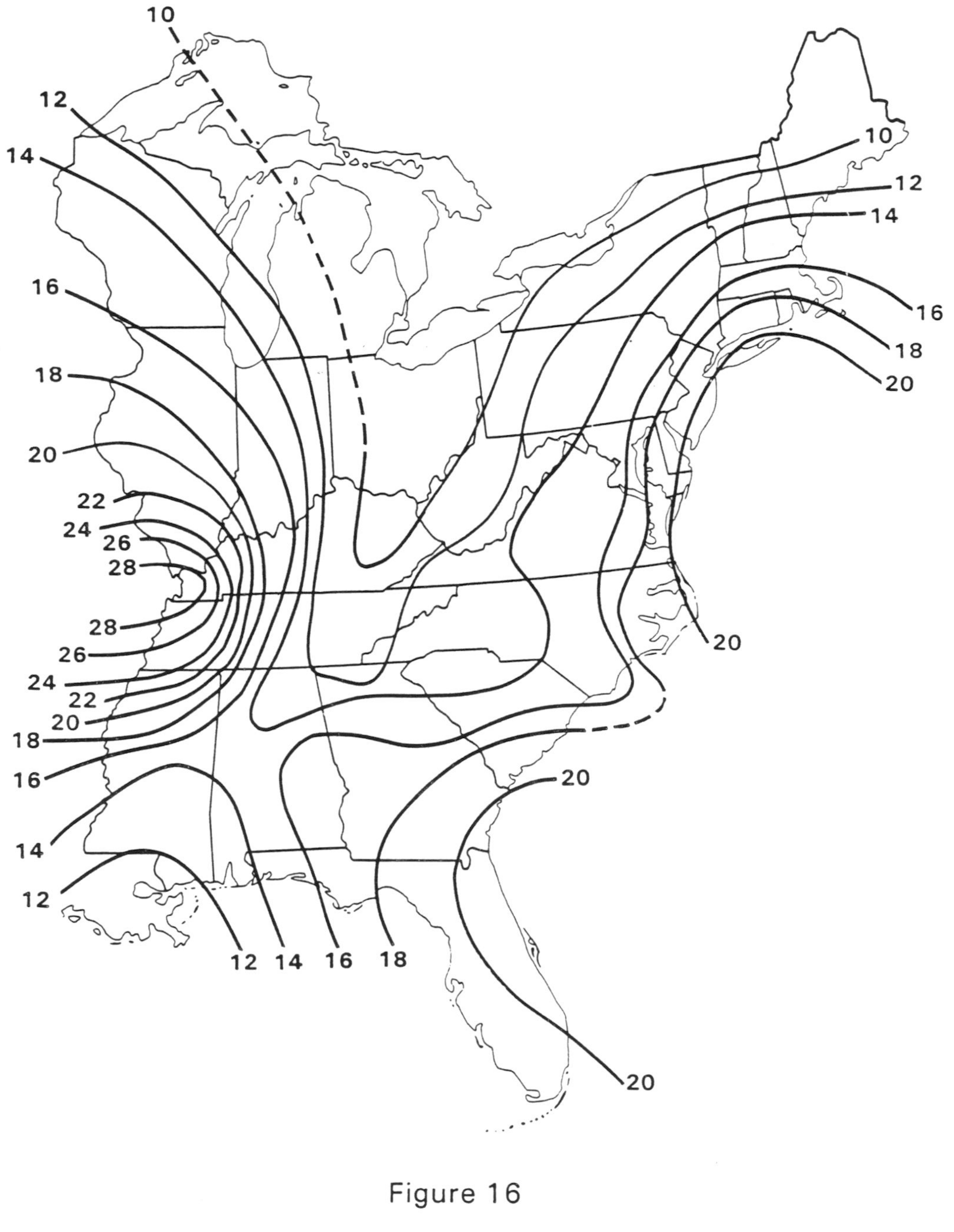

Figure 16

coastal influence is prevalent along the Atlantic seaboard associated with periods of minimal hurricane activity; and the strong, well-defined cell of influence at the Ohio and Mississippi Rivers confluence reappears. Again the lowest occurrence-percentages are across the northern states southward through the upper Ohio Valley and along the western Appalachian Plateau.

Autumn is almost a mirror image of Spring with minor exception. Occurrence of Gulf and Atlantic Coast hurricane activity can diminish coastal potential evapotranspiration effects; the lack thereof, results in the intensification shown, and the re-establishment of the cyclonic storm track provides a southwest-northeast corridor of lower potential evapotranspiration induced drought occurrence. Relatively, the low altitude high pressure cells once again are being blocked west of the Appalachians and the emerging winter "high frequency" node becomes entrenched at the Mississippi-Ohio River confluence.

## GENERAL PATTERNS

Two summary maps have been generated grouping Autumn and Winter (Figure 17) and Spring and Summer (Figure 18). These illustrate patterns similar to the seasonal maps, depicting the strong influence from the West as an area capable of generating high occurrence-percentages of temperature-induced drought intensification. Also the seasonal, shifting-influence of the

## MONTHLY DROUGHT OCCURRENCE—PERCENTAGES DUE TO > $\overline{\text{PE}}$

### AUTUMN/WINTER (OCT—MARCH)

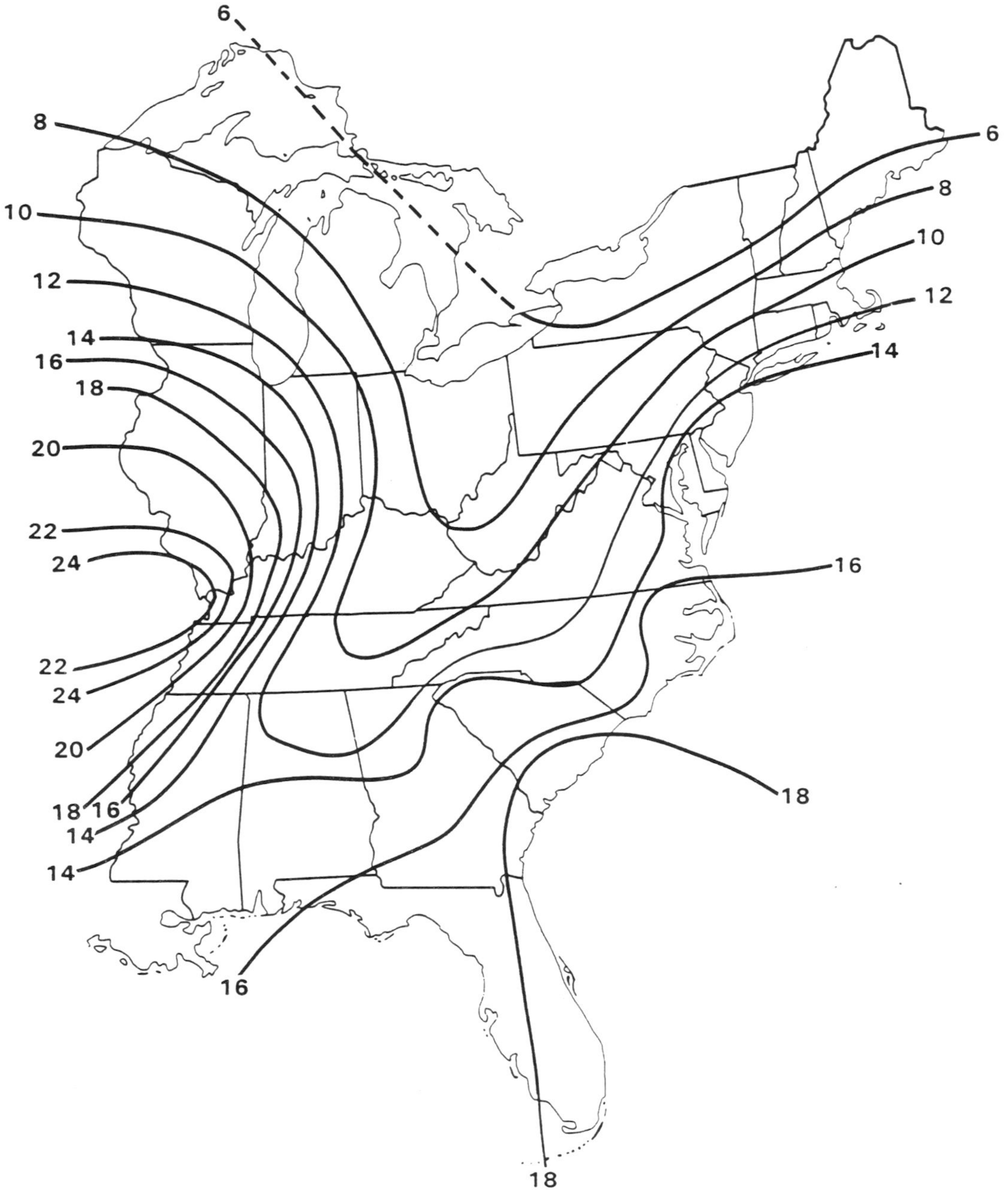

Figure 17

# MONTHLY DROUGHT OCCURRENCE—PERCENTAGES DUE TO > $\overline{PE}$

## SPRING/SUMMER (APR—SEP)

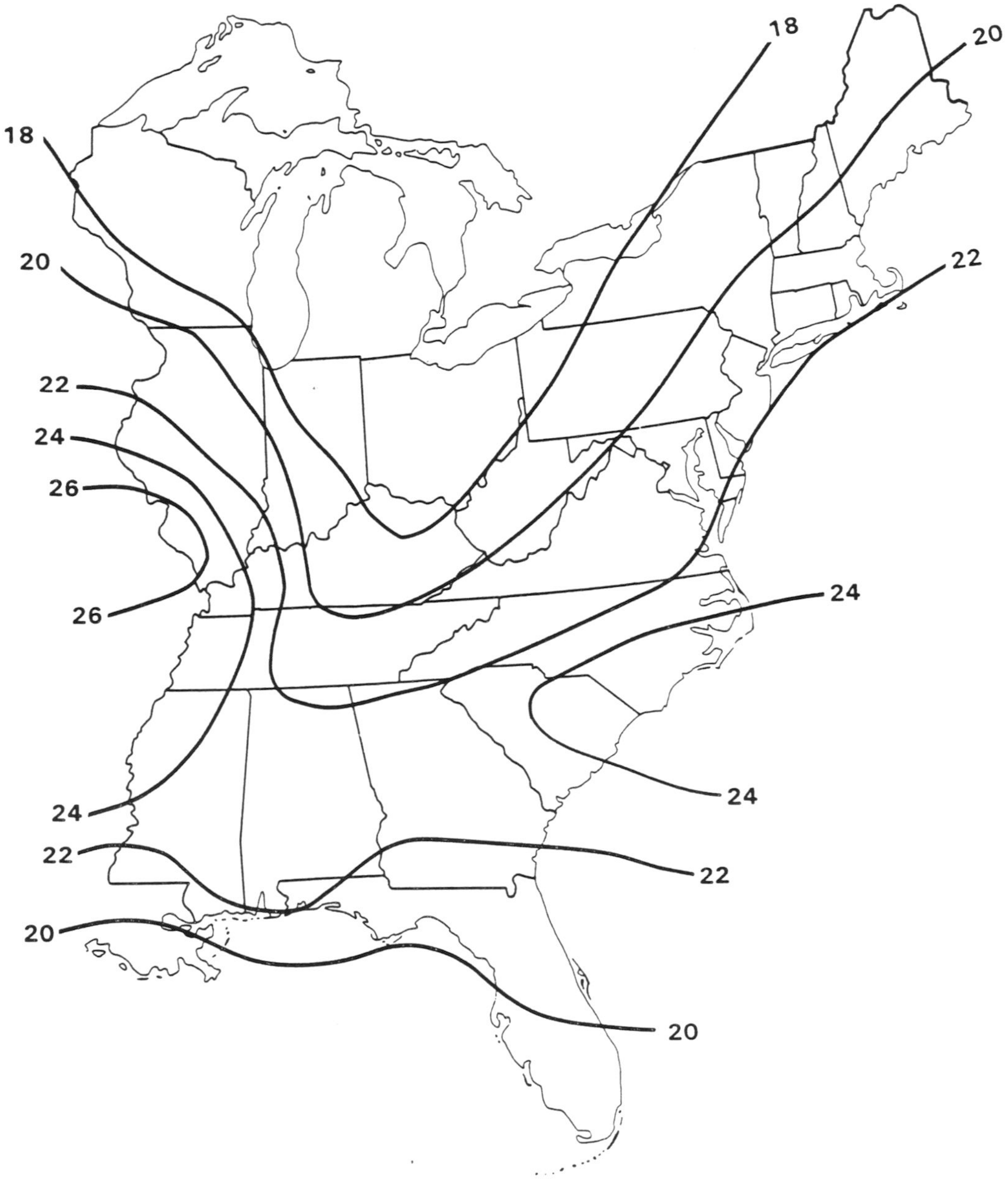

Figure 18

Bermuda High is well illustrated, as well as the tempering impact of the Appalachian Mountains.

It is apparent that potential evapotranspiration induced drought intensification changes with season, and exhibit distinctly different areal patterns of the drought phenomenon. Also noteworthy is the predictive value of these maps. The monthly drought recurrence associated with greater than normal potential evapotranspiration indices enable projection of drought-incidence associated with above normal potential evapotranspiration.

# CHAPTER VI

## SUMMARY AND CONCLUSIONS

Identification and evaluation procedures of drought have evolved slowly from very simplistic approaches that considered the phenomenon to be a rainfall deficiency, to problem-specific models of limited applicability, and finally, to sophisticated techniques that quantitatively appraise total environmental moisture status and its departure from normality. The latter have been available for research use for less than twenty years, but have already afforded valuable insights into the intensity, duration, and areal distribution of drought events. They have provided a means which enables a researcher to assess the relative severity of a given drought occurrence.

Of the three major components contributing to drought, below normal precipitation is certainly the chief factor. During periods of extreme and severe drought it accounts for 75 to 98 percent of the total negative moisture status. It is not unreasonable to understand why the early definitions of drought were based only on the parameter of precipitation.

Overlooked in those early definitions of drought was the impact of temperature variation from the normal expected as a component of drought. No doubt comments were made to the effect that a particular time seemed to be "hot and dry"; but beyond that, temperature was not considered to be an important factor.

This study has demonstrated that potential evapotranspiration is an important component in assessing a drought and its intensity. It has been proven quantitatively that departures from normal potential evapotranspiration is a significant contributing component to drought intensity. When an extreme or severe drought month has as much as one-third of its total negative departure from normal moisture status attributable to above normal temperatures, it is a significant factor.

Equally significant is the ameliorating effect on drought intensities of below normal potential evapotranspiration. With ameliorating percentages ranging from five to forty-one percent, it is clearly shown that temperatures less than normal have a significant impact on drought intensity.

In most cases the impact of potential evapotranspiration departure from normal was larger when total negative moisture status was less than -3.00 inches on the Drought Index. The temperature effect was more apparent during months of Mild or Moderate Drought than during months of Extreme or Severe Drought.

The role of available soil moisture as a component of drought is discussed briefly. The availability of soil moisture is directly related to precipitation and potential evapotranspiration along with the characteristics of the soil itself. In order for the soil to provide maximum available moisture there must be a complete recharging of soil moisture during the cooler winter months. Inadequate precipitation and/or above normal potential evapotranspiration demand can prevent recharging of the soil to its moisture holding capacity. How much available moisture the soil is able to provide will have an impact on the threshold of drought as well as the intensification of drought.

Throughout the study, the average annual contribution of above normal potential evapotranspiration to drought amounted to no more than fourteen to fifteen percent of total drought status. These findings suggest that negative precipitation amounts and soil-moisture-storage departures from normal may dominate the drought status of humid climates. These results, however, may not apply to other climatic regimes. Detailed research regarding the contribution of soil-moisture-storage has not yet been conducted and/or published, and this remains an area of much needed attention.

Regional causes for the development of the drought phenomenon are well known. Unknown, however, are the global dynamics that generate regional circulation patterns which can initiate drought conditions. This, therefore, places great limitations on when and where a drought is likely to occur.

Additional research regarding both components of drought and specific causes of drought will aid in the future development of ways to cope with the phenomenon and to better utilize our environmental resources.

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