Climatological Aspects of Drought in Ohio[1]

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ABSTRACT. **Precipitation and Palmer hydrological drought index (PHDI) data have been used to identify past occurrences of Ohio drought, to illustrate the temporal variability occurring statewide within dry periods, and to compare some of the key dry spells to those of 1987-88 and 1991-92. Periods of hydrologic drought and low precipitation generally persist for 2 to 5 years and tend to cluster in time, such as occurred from 1930-1966. It is not uncommon for precipitation to return to normal or near normal conditions while short-term drought persists in terms of streamflow, ground water supply, and runoff, as measured by the PHDI. The period April 1930 to March 1931 is the driest on record in Ohio although longer periods of low precipitation have occurred from 1893-1896, 1952-1955, and 1963-1965. The temporal clusters of droughts are separated by prolonged wet periods, including those extending roughly from 1875-1893, 1905-1924, and 1966-1987. Correlations between Ohio monthly precipitation and mean air temperature suggest that drought is linked to unusually high summer temperatures through mechanisms such as increased evapotranspiration, leading to increased fluxes of sensible heat from dry soil surfaces. In winter, warm conditions tend to favor higher precipitation, soil recharge, and runoff. Variations in mean temperature and atmospheric circulation may also be linked to other observed climatic features such as long-term trends in soil-water recharge season (October-March) precipitation.**

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INTRODUCTION

Palmer (1965) defined *drought* as ". . . an interval of time, generally of 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." The magnitudes and durations implied in this definition are not easy to define and might vary depending upon whether one's interest is meteorological, agricultural, hydrological, environmental, or economic. The definition may also vary between humid and semi-arid climates, but the term "drought" is typically used when a moisture shortage begins to affect the economy of a region (Palmer 1965).

In the United States, the currently used drought indices are those devised by Palmer (1965) and involve the development of three measures of moisture supply including a short-term moisture anomaly index, a hydrological drought index, and a meteorological drought index. Papers by Alley (1984), Karl (1983, 1986), and Karl et al. (1987) discuss these indices and provide succinct reviews of Palmer's mathematical model.

The Palmer hydrological drought index (PHDI) is obtained by calculating the current monthly precipitation that is "climatologically appropriate for existing conditions" (Palmer 1965, Karl 1983) and then comparing it to the observed precipitation in order to obtain the moisture anomaly index. The analysis requires that the current monthly and long-term mean values of evapotranspiration, runoff, soil water loss, and soil water recharge be determined, as well as the "potential" measures of these quantities (potential evapotranspiration, potential runoff, etc.). The moisture anomaly index in turn is used to obtain the PHDI (and the meteorological drought index) value, categories for which are given (Table 1). Computation of the PHDI is currently based on climatic means for a period beginning in 1931.

The PHDI changes gradually toward zero (normal moisture conditions; Table I) when precipitation returns to a region as a drought ends. It changes sign only after the moisture conditions associated with soil water recharge, evaporative demand, and runoff have been brought back to normal or above normal; essentially occurring in the final month in a sequence of months having sufficient moisture to end the drought (Karl et al. 1987). In contrast, the meteorological drought index, also known as the Palmer drought severity index, rapidly approaches a value of zero during the first month that weather begins to change from dry spell to a moist spell (or vice versa), regardless of whether soil moisture, ground water, or reservoir levels are still below normal. Numerical differences in the values of the meteorological drought severity index and the PHDI are small during the middle of a drought or

TABLE 1

Categories of the Palmer Hydrological Drought Index (PHDI).

PHDI Value		Moisture Characteristics
Above +4.00	=	Extreme moist spell
3.00 to 3.99	=	Very moist spell
2.00 to 2.99	=	Unusually moist spell
1.00 to 1.99	=	Moist spell
0.50 to 0.99	=	Incipient moist spell
-0.49 to +0.49	=	Near normal
-0.50 to -0.99	=	Incipient drought
-1.00 to -1.99	=	Mild drought
-2.00 to -2.99	=	Moderate drought
-3.00 to -3.99	=	Severe drought
Below -4.00	=	Extreme drought

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a moist spell, but they are sizeable at the onset or endings of dry or wet periods, with the severity index moving toward normal conditions earlier than the PHDI. The drought severity index cannot be used operationally because it is difficult to predict in advance that the current monthly conditions are indeed those starting a new weather regime ending either an ongoing drought or an ongoing wet period. The National Weather Service issues an index twice a month for all the climatic divisions around the state and country that is called the Palmer drought severity index, but which is in fact a modified version of the PHDI.

In general, about 28 cm of Ohio's annual 97 cm of precipitation (see Table 2) immediately becomes runoff, 5 cm is retained in the surface layer and eventually evaporates or transpires, and the remainder enters the unsaturated zone of the ground with most eventually lost to evapotranspiration, although a small remainder becomes ground water recharge (Shindel and Eberle 1988). Spatial variation in the 97 cm annual mean precipitation is such that southern Ohio receives between 100-106 cm of precipitation annually with the quantity decreasing northward to about 80-85 cm in the extreme northwest (Wendland et al. 1992). A secondary maximum of 100-106 cm occurs over northeastern Ohio as a result of additional lake-effect precipitation in the colder portion of the year.

The purpose of this paper is: l) to present a brief history of the occurrence of drought in Ohio, 2) to illustrate some of the temporal and spatial characteristics of rainfall and moisture availability during dry periods, and 3) to place the recent severe droughts of 1987-1988 and 1991-1992 in the context of past events. There is little written about historical occurrences of drought in Ohio. Anecdotal accounts of local dry periods, occurring since 1841, are found in Mindling (1944) and to a lesser extent in Alexander (1924). Strazheim and Falconer (1931) reviewed climatological and agricultural aspects of the drought of 1930, and a general overview of streamflow aspects of twentieth century Ohio droughts is recorded in Sherwood et al. (1991). Summaries pertaining to the individual components of the hydrologic cycle and drought, such as precipitation, evaporation, streamflow, and runoff, are more readily available (Sanderson 1950, Miller and Weaver 1969, Farnsworth and Thompson 1982, Hartstine 1991, Wendland et al. 1992).

MATERIALS AND METHODS

Monthly data for this study consisted of precipitation totals, mean air temperatures, and hydrological drought index values, averaged for each of the climatic divisions in Ohio (the divisions are outlined in Fig. 5, which is discussed later) for the period 1895-1991. The divisional means are based on data collected daily at a network of Ohio cooperative weather stations, organized by the federal government in 1891. The daily data are summed into monthly totals (precipitation), or expressed as monthly means (temperature), and then divisional averages are obtained and published in *Climatological Data for Ohio* by the National Climatic Data Center (NCDC). A single monthly statewide average and standard deviation is obtained for each of these parameters, based on the unweighted divisional means.

TABLE 2

The monthly, seasonal, and annually averaged statewide precipitation, and precipitation extremes, for the period 1854–1990.

MONTH/ SEASON	MEAN (cm)	STANDARD DEVIATION	MAXIMUM (YEAR) (cm)		PERCENT OF NORMAL	MINIMUM (YEAR) (cm)		PERCENT OF NORMAL
January	7.21	3.76	24.31	(1937)	337%	1.60	(1981)	22%
February	6.25	3.10	16.48	(1883)	260%	1.12	(1978)	18%
March	8.48	3.58	20.70	(1913)	244%	0.66	(1910)	8%
April	8.33	2.97	16.18	(1893)	194%	2.34	(1971)	28%
May	9.60	3.45	19.53	(1858)	203%	1.98	(1934)	21%
June	10.06	3.30	21.77	(1855)	216%	2.18	(1988)	22%
July	10.06	3.20	22.56	(1992)*	224%	3.86	(1930)	38%
August	8.61	3.02	17.22	(1980)	200%	2.95	(1881)	34%
September	7.67	3.58	24.56	(1866)	320%	1.50	(1908)	20%
October	6.50	3.15	16.00	(1919)	246%	0.58	(1924)	9%
November	7.34	3.33	23.29	(1985)	317%	1.02	(1904)	14%
December	7.14	2.74	19.41	(1990)	272%	1.30	(1955)	18%
ANNUAL	97.35	12.06	130.51	(1990)	134%	67.31	(1963)	69%
Winter	20.70	5.77	39.24	(1950)	190%	8.97	(1977)	43%
Spring	26.42	6.12	41.17	(1964)	156%	13.36	(1941)	51%
Summer	28.73	5.99	46.89	(1958)	163%	14.94	(1894)	52%
Autumn	21.51	6.05	40.92	(1866)	190%	7.11	(1908)	33%

*Not used in calculating the July or Annual mean, replaces 20.47 cm in 1896.

State averages of monthly precipitation for the period from 1854-1911, and of mean air temperature from 1883-1911, are also available (Patton 1934). Patton's statewide precipitation and air temperature averages are based on the available weather station data collected by volunteers prior to 1895. The number of stations contributing to the statewide average steadily increased from 17 in 1854 to 40 by 1886 and 104 by 1892 near the onset of the formal cooperative observer network. The overlapping statewide mean precipitation totals for 1895-1911 in Patton (1934) agree with those published by the NCDC. However, the mean air temperature data are consistently elevated by 0.3° to 0.7° C in every month during the 1895-1911 period. As a result, the 1883-1894 monthly values are reduced by the average amount that Patton's temperatures exceed those of *Climatological Data for Ohio* during 1895-1911.

Linear regression and correlation analysis are used in evaluating precipitation and PHDI data for the existence of, and statistical significance of, time series trend. Correlation is also used to evaluate the relation between Ohio monthly precipitation and mean air temperature. The two-tailed *t*-test is used to compare the mean values of precipitation and the PHDI, obtained for subsets of the full time series, to determine if they are significantly different from each other.

The year is divided in half for part of this analysis. The first half is the growing season (April-September) in which: 1) vegetation is actively using soil water, 2) water is rapidly evaporating from the soil, and 3) transpiration from vegetation is high. The other half of the year, October through March, is termed the soil-water recharge season, when evaporation and transpiration are minimal, the soil recharges with water, and excess water becomes runoff to rivers and streams after the soil is saturated. Mean precipitation and runoff at Berlin Lake in eastern Ohio (Fig. 1) is reasonably representative of the state's moisture seasons. The growing season has high precipitation but very little water runoff or recharge of soil and ground water supplies (Fig. 1). From October through March, soil water recharge occurs and runoff steadily increases through the period, despite the fact that precipitation is somewhat lower than in the warm season.

RESULTS

Precipitation Climatology

Some basic features of the Ohio long-term (1854-1990) monthly, annual, and seasonally averaged precipitation data are presented (Table 2). Ohio precipitation reaches a maximum during June and July, making summer (June-August) the wettest season of the year. A precipitation minimum occurs in February and October, and winter (December-February) is the driest season. The annual mean precipitation is 97.35 cm with a standard deviation of 12.06 cm. Thus statewide mean precipitation under 73.23 cm is two standard deviations below normal. Record monthly precipitation minima are generally under 2 cm only in the cooler portion of the year. The all-time minimum precipitation values for May, June, July, November, December, and the annual value occur in well-defined drought years, as is shown below.

The time series of precipitation during the soil-water recharge season (Fig. 2a) exhibits a general downward trend from the 1880s through the 1960s. The comparatively wet period from 1905-1930 is followed by distinctly drier years, culminating with 1956-1971. The downward trend has a slope of 0.11 cm per year over the 1906-1969 period,

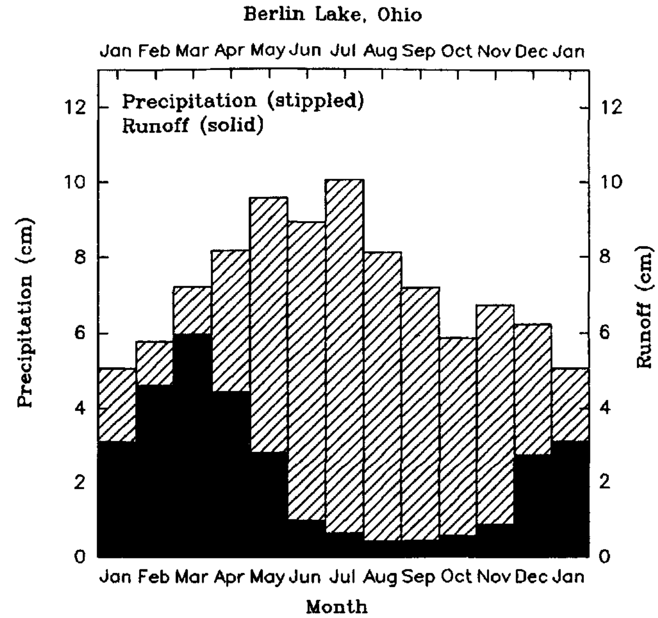

FIGURE 1. The monthly mean precipitation (stippled) and runoff (solid) at Berlin Lake in eastern Ohio as measured at the U.S. Army Corps of Engineers dam site. Data provided by the U.S. Army Corps of Engineers.

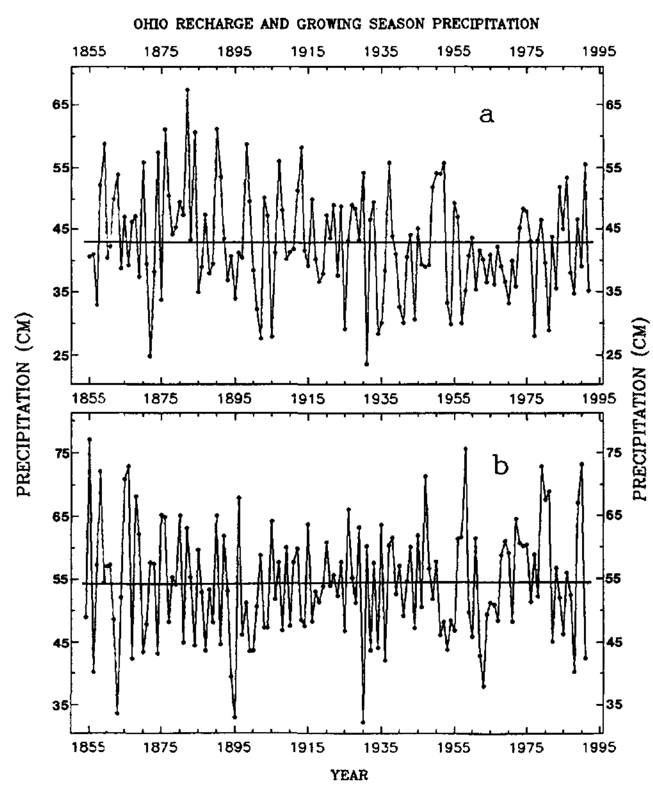

FIGURE 2. Time series of precipitation (cm) averaged over (a) the soil-water recharge season (October-March) for 1854-55 through 1991-92, and (b) the growing season (April-September) for 1854-1991. The horizontal lines represent the long-term mean seasonal precipitation total.

but the trend only accounts for about 7% of the data variance and is barely significant at the 95% statistical confidence level. In winter (December-February), the precipitation downtrend is also present (not shown) but the reversal of the trend toward higher values in recent decades is weak. The recent upward trend is more apparent in October and November data (not shown).

Little tendency toward long-term trends in mean growing season precipitation is obvious (Fig. 2b). The time series fluctuates about the long-term mean with occasional periods since the 1950s, usually of 2-5 year duration, when the mean total stays near one extreme or the other.

Historic Drought Occurrences and Temporal Variability

The PHDI is a measure of hydrological conditions and the intensity of drought. The recharge season PHDI has many positive (moist) values through the first 3 decades of this century (Fig. 3a). However, index values are lower and occasionally become quite negative, from the 1930s through the 1960s. The mean PHDI from 1895-96 to 1929-30 is +0.42 and it is +0.92 from 1969-70 to 1991-92. The mean PHDI from 1930-31 to 1968-69 (mean = -0.85) is significantly lower (99% confidence) than that for either of the other two subperiods based on a two-tailed *t*-test. In the growing season PHDI time series (Fig. 3b), periods of negative index values (drought) occur along with large swings back to moist conditions in many years from 1931-1969. PHDI values during the 1931-1969 growing season period are not as low as in the recharge season.

The lowest soil-water recharge and growing season PHDI values are listed (Table 3). Some of the drought events are of short duration (a few months only), such as the recharge-season drought of 1908-09. Some important drought events, such as those of 1930 and 1991, are not listed (Table 3) because the spring months of those years had moderately high moisture availability and the slow-to-respond PHDI index remained high until the summer months, creating an unusually high (moist) 6-month mean index value compared to actual conditions.

TABLE 3

List of the occurrences of the lowest state averaged Palmer Hydrological Drought Index (PHDI) values during the soil water recharge and growing seasons in Ohio, 1895-1992.

Soil Water Recharge Season (October–March)		Growing Season (April–September)	
1930/31: -5.75	(+0.3° C)	1931: -4.51	(+0.8° C)
1934/35: -5.17	(+1.2° C)	1934: -4.17	(+1.6° C)
1953/54: -5.05	(+1.6° C)	1954: -3.95	(+0.6° C)
1963-64: -4.63	(+0.1° C)	1988: -3.06	(+0.6° C)
1991-92: -3.52	(+1.2° C)	1895: -2.99	(+0.7° C)
1901-02: -3.51	(-1.3° C)	1953: -2.63	(+0.6° C)
1895-96: -3.29	(-0.9° C)	1900: -2.58	(+1.1° C)
1900-01: -3.26	(-0.2° C)	1901: -2.57	(+0.1° C)
1964-65: -3.17	(-0.3° C)	1964: -2.42	(+0.4° C)
1944-45: -3.08	(0.0° C)	1941: -2.41	(+1.2° C)
1908-09: -2.73	(+0.8° C)	1935: -2.40	(-0.5° C)
1960-61: -2.57	(+0.1° C)	1965: -2.35	(+0.2° C)
1952-53: -2.55	(+1.4° C)	1902: -2.09	(-0.7° C)
1939-40: -2.39	(-1.1° C)	1925: -2.06	(+0.5° C)
1933-34: -2.39	(-0.9° C)	1932: -2.00	(+0.3° C)
1899-00: -2.31	(-0.3° C)	1936: -1.99	(+1.1° C)
1904-05: -2.07	(-1.7° C)	1963: -1.88	(-0.8° C)

Numbers in parentheses are the seasonal mean temperature departure (° C) from the long-term (1883-1991) normal.

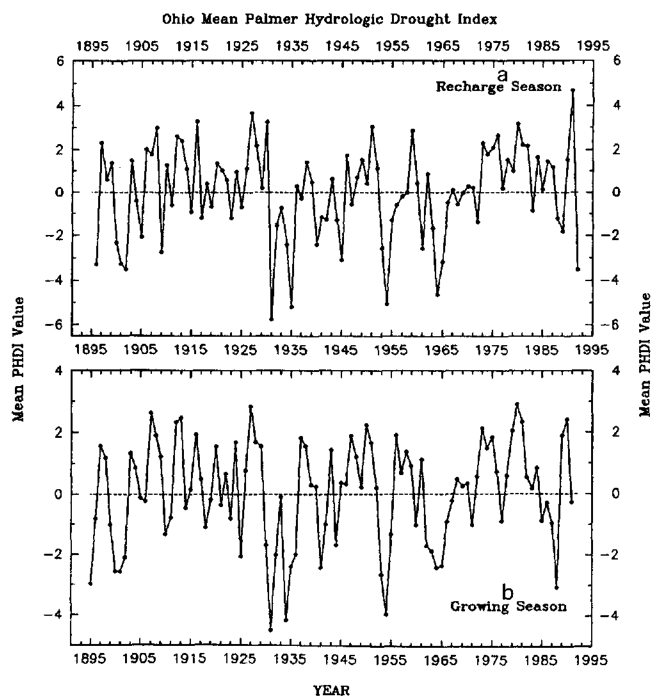

FIGURE 3. Time series of Palmer drought severity indices averaged over (a) the soil-water recharge season (October-March) for 1854-55 through 1991-92, and (b) the growing season (April-September) for 1854-1991. The horizontal line extends through the zero PHDI value.

Another method of determining drought occurrences is to calculate 12-month running sums of the monthly averaged statewide precipitation, effectively creating running annual precipitation totals. This method is not restricted to defining a "year" as January through December and is useful in identifying pre-1895 droughts and for comparisons to the PHDI. The periods of protracted low precipitation have been identified (Table 4), when the 12-month running totals reach their lowest values below 75 cm (approximately two standard deviations below normal during the traditional "year" [Table 2]).

Several identical years can be used to help identify periods in which droughts have occurred (Tables 3, 4). These periods include 1894-1896, 1899-1902, 1904-05, 1924-25, 1930-31, 1934-1936, 1939-1941, 1944-45, 1952-1955, 1960-61, 1963-1965, 1987-88, and 1991-92. These short periods of drought cluster together in time, over periods of one to three decades, but each is generally separated, both in terms of precipitation and the PHDI, by comparatively moist spells. For example, precipitation reached a 12-month mean of 108.38 cm from June 1932 to May 1933, between the 1931 and 1934 drought years (Fig. 4a). Similarly, precipitation reached a value of 107.01 cm in March 1961-February 1962 between the

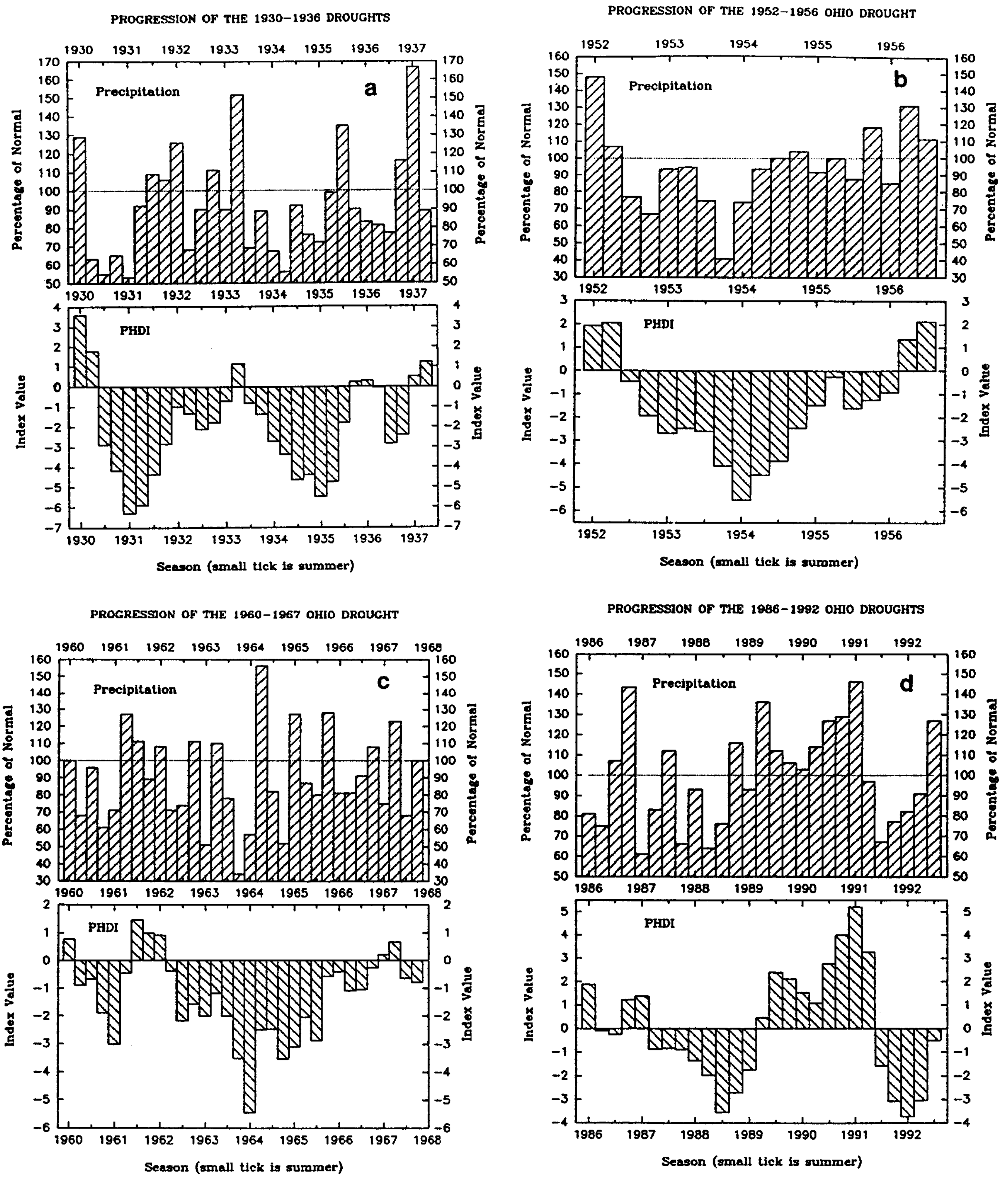

FIGURE 4. Time series of seasonal Ohio mean precipitation, represented as the seasonal percentage of normal (top), and seasonal PHDI values (bottom) during drought periods from (a) 1930-1936, (b) 1951-1956, (c) 1960-1966, and (d) 1986-1992. The large ticks on the horizontal axis mark the winter season (December-February), while small ticks are summer (June-August). Winters are dated so that 1930 represents 1929-30.

1960-61 and 1963 dry spells (Fig. 4c), and it reached an all-time calendar-year high of 130.51 cm (Table 2) in 1990 between the 1987-88 and 1991-92 droughts (Fig. 4d). Ohio precipitation reached 116.74 cm from March 1873 to February 1874 between the 1872 and 1875 droughts (Table 4). The longest time spans with 12-month precipitation totals above 75 cm occur from 1875-1894, between the weak droughts of 1905 and 1925, and between the severe droughts of the 1960s and 1987-88. Otherwise, the time interval between Ohio precipitation-

TABLE 4

List of the driest 12 month periods in Ohio, 1854–1992, as measured using monthly precipitation data.

Time Period	Precipitation Total
April 1930 – March 1931:	55.70 cm (21.93")
November 1894 – October 1895:	64.92 cm (25.56")
January – December 1963:	67.31 cm (26.50")
January – December 1934:	67.79 cm (26.69")
February 1953 – January 1954:	69.70 cm (27.44")
February 1856 – January 1857:	70.64 cm (27.81")
September 1987 – August 1988:	71.96 cm (28.33")
May 1874 – April 1875:	72.24 cm (28.44")
April 1863 – March 1864:	72.36 cm (28.49")
February 1960 – January 1961:	72.47 cm (28.53")
April 1871 – March 1872:	72.64 cm (28.60")
December 1900 – November 1901:	72.64 cm (28.60")
July 1924 – June 1925:	72.80 cm (28.66")
June 1940 – May 1941:	73.00 cm (28.74")
May 1904 – April 1905:	74.50 cm (29.33")
August 1943 – July 1944:	75.13 cm (29.58")
May 1991 – April 1992:	76.12 cm (29.97")

The precipitation amount (in cm and inches) is the 12-month sum of the monthly statewide precipitation average obtained using all available cooperative weather stations. The list presents the *lowest* 12-month averaged value occurring during a period when several adjacent 12-month periods may have also had less than 75 cm of precipitation (approximately two standard deviations below normal). The list continues with amounts above 75 cm until the 1991-92 drought, shown for comparative purposes.

defined short-term droughts is less than one decade, with the largest gap between 1944-45 and 1952-1955 during the 1930-1966 dry period.

The breaks in the droughts of the 1930s are also illustrated (Fig. 4a). The extremely dry period from April 1930 to March 1931 (Table 4) is followed by four seasons of near normal precipitation, starting in spring 1931, although the PHDI remained negative. The role that individual wet seasons (>120% of normal precipitation) play in either ameliorating severe or extreme drought or in ending a weaker drought (either temporarily or permanently) can be seen (Fig. 4a). The PHDI becomes slightly positive after extremely wet seasons in spring 1933 and summer 1935, and ultimately the drought ended with the very wet winter of 1936-37. Aside from the string of 12 consecutive months with subnormal precipitation at the start of the 1930-1931 drought, nearly 40% of the remaining months through December 1936 had above normal precipitation. The PHDI frequently lags the seasonal precipitation (Fig. 4).

Long periods of persistent subnormal precipitation, extending more than one year, occurred from June 1893 to May 1896, when 28 months had subnormal precipitation (of 36), May 1952 through July 1954 with 23 months (Fig. 4b), and April 1963 through November 1964 with 18 months (Fig. 4c).

The drought of 1952-1956 (Fig. 4b) is somewhat unique in that it consisted of only one protracted dry period and did not have any periods of precipitation and drought amelioration. Excessive precipitation (above 120% of normal) did not occur in any season until the end of the drought, although precipitation was near normal during and after the spring of 1954. The 1962-1966 drought (Fig. 4c) was very protracted, like 1952-1956, and was preceded by a milder drought in 1960-61. Three instances of high precipitation in spring 1964, and winter and autumn of 1965 ameliorated the drought but did not return the hydrologic index to positive values.

Droughts in Ohio since 1986 (Fig. 4d) are comparatively short and do not reach extreme conditions in the statewide PHDI averages. The severity of statewide drought conditions in the late summers of 1986 and 1987 was tempered by the fact that much of northern Ohio remained moist (Figs. 5a,b). The resulting standard deviations of the state mean PHDI values (Figs. 5a,b) exceed two index units and are among the highest in the monthly data since 1931. The year 1987 was the eighth driest of the twentieth century, with 80.57 cm of precipitation statewide. Severe and extreme drought spread over all of Ohio in 1988, with moisture conditions becoming worse over southern Ohio than in the two preceding summers (Fig. 5c). The standard deviation of the mean PHDI (Fig. 5c) is lower than in 1986 and 1987 and is more typical of mid-drought conditions, with consistently low moisture everywhere. Spring (March-May) 1988 was the fourth driest on record (behind 1930, 1934, and 1941), and the growing season was the third driest this century (behind 1930 and 1963) even though rain started to return to the state by late July.

Large spatial variability in Ohio drought intensity also occurred during 1991-92, creating misleadingly high values of monthly statewide mean precipitation and mean PHDI.

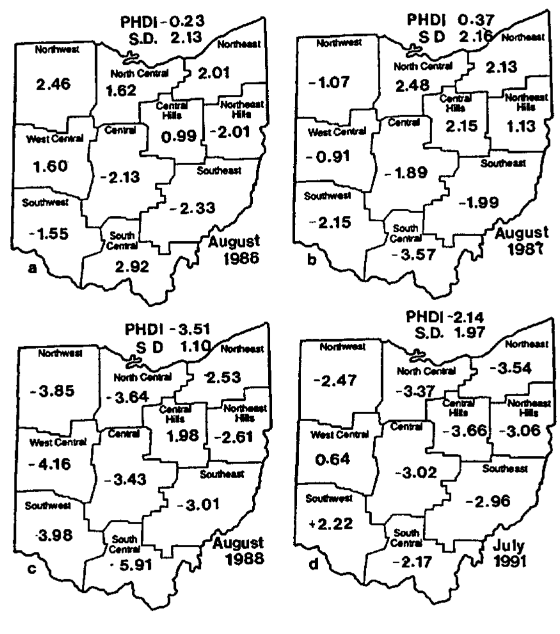

FIGURE 5. The divisional PHDI values during (a) August 1986, (b) August 1987, (c) August 1988, and (d) July 1991. The statewide PHDI average and standard deviation (s.d.) are also shown.

In previous (1931-1966) drought events, the state divisions were always uniformly dry while a drought was fully in progress. In 1991, the southwestern and west-central climatic divisions had positive PHDI values through July (Fig. 5d), and the drought never reached severe or extreme levels in southwestern or south-central Ohio. High spatial moisture variability kept the 12-month statewide precipitation total above 75 cm (Table 4). As is noted earlier, both the 1930 and 1991 droughts had abundant moisture early in the growing season that kept the average PHDI value too high for inclusion.

Precipitation and Air Temperature Correlations

The association between Ohio monthly precipitation and air temperature undergoes seasonal variability (Fig. 6). The two parameters are significantly, but weakly, correlated during the recharge months December through March, although the highest correlation (February) only corresponds to a coefficient of variation (r^2) of 14%. The precipitation/temperature correlation (Fig. 6) becomes zero in April, but gives way to weak, significant, negative correlations during May and June, suggesting that growing season months tend to be simultaneously drier and hotter than normal (or colder and wetter than normal). This is more strongly confirmed by noting that the majority of growing season droughts are associated with warmer than usual temperatures (Table 3). The warmest drought growing season was 1934, and 1991 was equally warm. The droughts of the 1960s are associated with some of the lowest mean air temperatures among Ohio droughts; recharge and growing season mean temperatures are at best near normal, and some extreme cold periods occur such as the 1962-63 winter and the 1963 growing season, which is the coldest on the list. By combining the monthly data in different ways, the temperature/precipitation correlation is r = -0.43 for the May-July averaged data (r^2 = 0.19) but only r = +0.29 for December through March averaged data.

Ohio mean air temperatures in summer, representative of those for the growing season, are persistently anomalously warm from 1930-1944, and from 1898-1901 and 1952-1955 (Fig. 7b). Mean air temperatures are generally below normal during the northeastern drought of the 1960s and during much of the prevailing wet periods from 1902-1929 and 1966-1988. The winters of the 1960s (Fig. 7a) were substantially colder than those of the preceding decade and are linked to the distinct recharge season precipitation minima (Fig. 2a). However, winter temperatures of the 1900-1960 period do not show a distinct downward tendency such as occurs in recharge season precipitation (Fig. 2a).

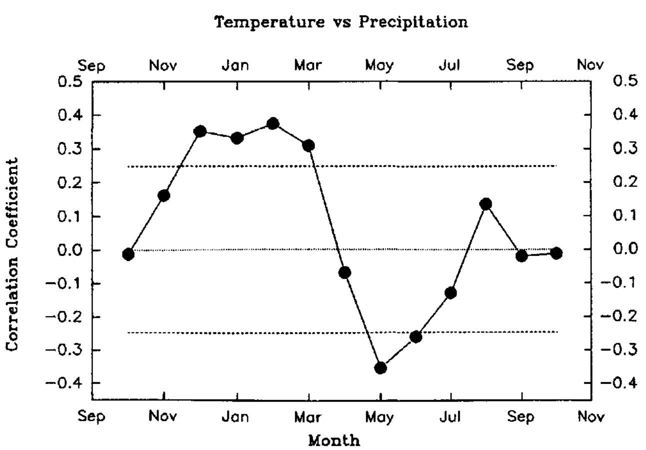

FIGURE 6. The correlations between monthly Ohio mean air temperatures and precipitation, 1883-1991 (109 cases each), plotted from October through October. The short dashed lines represent (r = ± 0.25) the statistical 99% confidence interval and those exceeding absolute r = 0.35 are significant with 99.9% confidence.

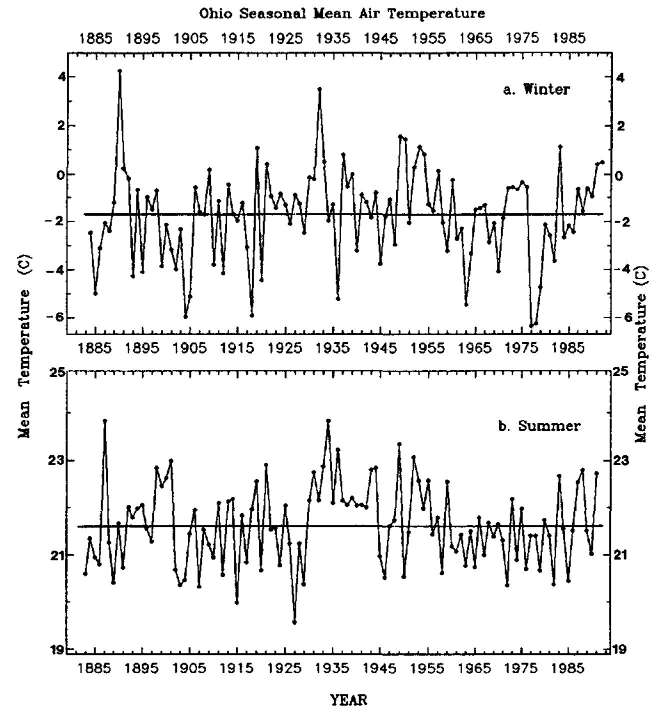

FIGURE 7. Time series of statewide mean air temperatures (° C) during (a) winter seasons 1883-84 to 1991-92, and (b) summers 1883-1991. The straight horizontal solid line represents the long-term mean temperature.

DISCUSSION

Ohio's moisture supply and moisture availability in the soil and ground water are characterized by both short-term and long-term variations (Figs. 2, 3). The latter are best represented by the 1930-1966 period of frequent drought and by an overall multiple-decade downward trend in recharge season precipitation (Fig. 2a). These characteristics are also found in time series of stream discharge for most Ohio rivers and large creeks (Sherwood et al. 1991). The 1960s in particular represented a period of protracted low stream discharge (Sherwood's Fig. 4) that followed three shorter low-discharge periods extending back to the 1930s. In some systems, such as the Mad River (Sherwood's Fig. 5) the long-term cumulative departures of streamflow and precipitation are still recovering from the low point around 1970.

The 1960s were comparatively cold and dry, both in winter and summer (Figs. 2, 7), and drought and recharge season precipitation minima in that decade are possibly linked to changes in the atmospheric circulation over

North America occurring in the late 1950s (Dickson and Namias 1976, Diaz and Quayle 1980, Leathers and Palecki 1992) . The cold winters of the 1960s and 1970s were characterized by a blocking of the prevailing westerlies, producing strong northwesterly flow and intrusion of bitterly cold, dry, air masses from Northern Canada, the Arctic, and even Siberia. Examples of atmospheric circulation variability during drought periods in the United States can be found in Namias (1966, 1983), Chang and Wallace (1987), and McNab and Karl (1992).

The causes of long-term atmospheric circulation changes are not well understood, but it is apparent from the temperature/precipitation correlations (Fig. 6) that other factors, only partly related to the atmospheric circulation, are linked to drought (Namias 1983). For example, the link between high summer air temperatures and low precipitation is enhanced by strong evapotranspiration and drying of the surface soil layer so that solar radiant energy can be used directly to heat the ground rather than in the evaporation of water. Lack of precipitation is exacerbated by limited cyclone and frontal activity in summer compared to that occurring in winter. Nationally, the strongest summer temperature/precipitation correlations (approximately r = 0.6 to 0.8) occur in the Great Plains and high plains (Namias 1983) . On the other hand, warm winters are associated with higher than normal precipitation. This probably occurs because: 1) warmer air has a higher saturation vapor pressure, 2) winter cyclones produce both strong heat advection and the strong vertical motions necessary to produce condensation and precipitation, and 3) cloud cover around the cyclones elevate nighttime temperatures. Nonetheless, while the cold winters of the 1960s were also dry (Fig. 6), no clear tendencies between the driest recharge seasons and temperature anomalies are obvious (Table 3).

Ohio was arguably the geographic center of the 1991-92 drought. This is nowhere better exemplified than in a national mid-winter drought summary (Weekly Weather and Crop Bulletin 1992) showing that the central and the three northeastern Ohio climatic divisions were the driest places in the country aside from three climatic divisions in Oregon and Washington. During the 1991 summer the PHDI drought indices were consistently lowest across Indiana, Ohio, West Virginia, Kentucky, and western Pennsylvania. National droughts of the past have been focused in virtually every other part of the country aside from the Ohio River valley region.

SUMMARY

Precipitation data and PHDI data have been used to evaluate the historical occurrences of drought in Ohio, and temporal and spatial variations in drought intensity. Precipitation was comparatively abundant during the first three decades of the twentieth century and periods of severe droughts became much more commonplace from 1930-1966 (Figs. 2, 3). Although growing season moisture has been comparatively abundant since 1966, precipitation in the soil-water recharge season has only recently recovered from long-term minima in the late 1960s and early 1970s (Fig. 2a). The recent droughts of 1987-88 and 1991-92 are a result of short-term decreases in precipitation against a background of high moisture supply rivaling the earliest decades of this century (Figs. 2a, 3a).

Moisture availability, as measured by the PHDI, is slow to change in streams and in the ground water layer during the course of a drought. It is not uncommon that moderate or worse drought may last two or more consecutive years. Meteorologically however, climatic data indicate that periods of persistent subnormal precipitation, lasting well over one year, have only occurred in three instances: 1893-1896, 1952-1954, and 1963-64. Overall however, the worst Ohio drought is that of 1930-31 when precipitation reached its lowest amount on record over a span of one year. Individual seasons with substantially above normal precipitation will tend to either cause amelioration of a severe or extreme drought and they can bring about the end of milder droughts. Record-breaking statewide precipitation in July 1992 (Table 2) are currently regarded as having ended the 1991-92 drought.

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The 1992 Paper of the Year Award

was presented at the Annual Meeting of the OAS
at
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on 1 May 1993
to:

Connie Schondel
and
Glenn Shields

Department of Social Work
Bowling Green State University
Bowling Green, Ohio

for their paper:

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