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Identification and Analysis of Dry Periods in New Jersey Using the New Brunswick Precipitation Record

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Abstract: *Dry periods are studied using the long precipitation record of New Brunswick, NJ (1900–1999). This entails first determining which three-month periods were in the driest 20 percent using all similar calendar months then determining the beginning and ending month of an extended dry period using a scheme designed for that purpose. The resulting identification of dry periods and related statistics is both objective and simple, two desired attributes for this study. The results are of use to those needing a historical listing of dry periods in New Jersey and to those needing a perspective of dry period characteristics such as average length, longest length, and average time between prolonged dry periods. There are 66 dry periods identified, with the average length of about 9 months. There are 18 dry periods of 12 months or longer and 4 dry periods of 24 months or longer. There is a slight tendency for the fall months to be a turning point, either into or out of a dry period. The 1930s and 1960s are the driest decades while the 1900s and 1990s are the least dry from the perspective of this study. In general the last three decades have had fewer than average number of months classified as dry. The average period between dry periods is also about 9 months, but lengthens to 19 months if only moderate or greater dry periods (i.e., 6 months or greater length) are considered.*

Key Words: New Jersey, New Jersey drought, New Jersey precipitation, New Jersey climate

INTRODUCTION

Periods of abnormally low precipitation have significant socioeconomic consequences ranging from crop failure to failed businesses resulting from severe water restriction. The term "drought" is commonly used to describe this situation but no universally agreed upon definition of drought suffices in all circumstances of location and time of year. Literally dozens of definitions have been employed historically. Wilhite and Glantz (1985) categorize drought definitions into four approaches: meteorological, hydrological, agricultural and socioeconomic. They describe meteorological drought as an expression of precipitation's departure from normal over some period of time. These definitions are usually region-specific, and presumably based on a thorough understanding of regional climatology. Agricultural drought occurs when soil moisture is insufficient to meet the needs of crops at a particular time. During the growing season, agricultural drought happens after meteorological drought but before hydrological drought. Hydrological drought refers to deficiencies in surface and subsurface water supplies. When precipitation is reduced or deficient over an extended period of time, this shortage will be reflected in declining surface and subsurface water levels. Lastly, they list socioeconomic drought, which is what happens when physical water shortage starts to affect society.

Some specific approaches for the calculation of meteorological drought as described by Hayes (from 'Drought Indices' by Michael J. Hayes, Climate Impacts Specialist, National Drought Mitigation Center at http://enso.unl.edu/ndmc/enigma/indices.htm) include: percent of normal, deciles, standard precipitation index (SPI), and the Palmer Drought Severity Index (PDSI). A brief summary of his description and commentary follows.

Percent of normal is calculated by dividing actual precipitation by normal precipitation, often a 30-year mean, and multiplying by 100%. This can be calculated for a variety of time scales. Usually these time scales range from a single month to a group of months. Normal precipitation for a specific location is considered to be 100%. One of the disadvantages of using the percent of normal precipitation is that the mean, or average, precipitation is often not the same as the median precipitation, which is the value exceeded by 50% of the precipitation occurrences in a long-term climate record. The reason for this is that precipitation on monthly or seasonal scales often do not have a normal distribution. Use of the percent of normal comparison implies a normal distribution where the mean and median are considered to be the same.

Arranging monthly precipitation data into deciles is another drought-monitoring technique. It was developed by Gibbs and Maher (1967) to avoid some of the weaknesses within the "percent of normal" approach. The technique they developed divided the distribution of occurrences over a long-term precipitation record into tenths of the distribution. They called each of these categories a "decile." The first decile is the rainfall amount not exceeded by the lowest 10% of the precipitation occurrences. The second decile is the precipitation amount not exceeded by the lowest 20% of occurrences. These deciles continue until the rainfall amount identified by the tenth decile is the largest precipitation amount within the long-term record. By definition, the fifth decile is the median, and it is the precipitation amount not exceeded by 50% of the occurrences over the period of record. The deciles are grouped into five classifications. It is relatively simple to calculate, and requires less data and fewer assumptions than the Palmer Drought Severity Index (Smith et al. 1993). The uniformity achieved in drought classifications, unlike a system based on the percent of normal precipitation is an advantage. One disadvantage of the decile system is that a long climatological record is needed to calculate the deciles accurately.

The Standardized Precipitation Index (SPI) was designed by McKee et al. (1993) to quantify the precipitation deficit for multiple time scales. The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee 1997). Positive SPI values indicate greater than median precipitation, while negative values indicate less than median precipitation. A drought event occurs any time the SPI is continuously negative and reaches intensity where the SPI is –1.0 or less.

The Palmer Drought Severity Index (PDSI) (Palmer, 1965) is a meteorological drought index and responds to weather conditions that have been abnormally dry or abnormally wet. The PDSI is calculated based on precipitation and temperature data, as well as the local Available Water Content (AWC) of the soil. From the inputs, all the basic terms of the water balance equation can be determined, including evapotranspiration, soil recharge, runoff, and moisture loss from the surface layer. Palmer developed the PDSI to include the duration of a drought (or wet spell). His motivation was as follows: an abnormally wet month in the middle of a long-term drought should not have a major impact on the index, or a series of months with near-normal precipitation following a serious drought does not mean that the drought is over. McKee et al. (1995) suggested that the PDSI is designed for agriculture, but does not accurately represent the hydrological impacts resulting from longer droughts.

After examining the various alternatives for defining drought (hereafter referred to as a "dry period" to avoid a controversy over terminology) it was decided to use a modified SPI and apply it to the precipitation record of New Brunswick, NJ. This station has a relatively long data record, so it is suitable for statistical analysis. The rationale for the methodology is given in the next section.

The objectives of the study are twofold:

1. To identify important dry periods in New Jersey using a long data record. This may be helpful to other researchers that require this information.

2. To determine characteristics of dry periods such as frequency, length, and timing. This will aid in putting future dry periods into historical perspective.

MATERIALS AND METHODS

The PDSI is quite popular for use in drought monitoring and analysis, and is easily obtained for an extensive historical period for each climatic division in the US. However, the available PDSI was not used here for the following reasons, identified by Hayes (from 'Drought Indices' by Michael J. Hayes, Climate Impacts Specialist, National Drought Mitigation Center at http://enso.unl.edu/ndmc/enigma/indices.htm):

1. The PDSI may not identify well the beginning and ending of dry periods, because it does not tend to respond quickly to important precipitation changes.

2. The values used to quantify drought intensity are based on Palmer's work that focused on the central US Plains region.

3. The PDSI is sensitive to soil moisture type and conditions, so it has its best application for agricultural purposes.

The SPI was identified as superior for use in this study since it identifies important dry periods without lag, it can be computed on any desired time scale, it is better for non-agricultural use (i.e., it has wider application), and it is easily understood and computed. The SPI requires only precipitation as input. In the usual procedure the SPI is used to identify a 'drought' period for a given time scale, for example three months, if the precipitation in the period is more than one standard deviation below the median value for the transformed time series of values. In the present study a slightly different approach is followed to identify 'dry' three-month periods, then a unique procedure is employed to specify the specific beginning and end month of the dry period. It is noted that historical SPI data is not widely available for distant past periods so it could not be taken "off the shelf" for use in even the first stage of identifying the beginning and end month of dry periods in New Jersey. The specific procedure used here follows.

Dry periods are initially identified by using three-month precipitation totals. Shorter period precipitation totals such as daily, weekly, or monthly have a large degree of variability so numerous short, dry periods would be identified. In addition, serious consequences of below average precipitation are not normally felt until the dryness persists for several months.

The next decision to make involved the selection of a *critical value* to objectively identify a "dry" three-month period. In order to identify only important dry periods the chosen value needed to be small enough to result in the phenomena being somewhat rare in occurrence, yet to capture events having likely socioeconomic consequences. The precipitation value (termed the critical value herein) corresponding to the driest 20 percent of the record for each three-month combination was computed. The precise procedure used to do this is as follows:

1. For the purposes of objectivity, not for significance testing, it was assumed that the three-month precipitation data varied according to the normal distribution. Precipitation data appears to be "more normal" as the time period increases from daily to seasonal. While histograms show a slight degree of skewness in the three-month data, this is unimportant for the purpose described here.

2. Using the normal distribution, the number of standard deviations corresponding to the driest 20 percent of all cases was determined. This value is .83 .

3. The critical three-month precipitation value used to identify dry periods for each three-month combination was calculated using: $CV = M - (.83)S$ where CV is the critical three-month precipitation value, M is the 100 year mean three-month precipitation total, and S is the 100 year three-month precipitation standard deviation.

Next, every individual three-month period was compared to the appropriate critical value to identify dry three-month periods. Once a three-month dry period was identified, following a non-dry period, a new extended dry period was assumed to have commenced. In order to identify the specific starting and ending month for an extended dry period, the following procedure was devised:

1. The starting month must have precipitation below the recent 30-year mean value for that calendar month.
2. The starting month must be part of a three-month period that has a precipitation total that is less than the critical value.
3. The ending month must have precipitation below the recent 30-year mean value for that calendar month.
4. The ending month plus one must have precipitation above the recent 30-year mean value for that calendar month.
5. The ending month plus one must be part of a three-month period that is above the recent 30-year mean value for that three-month period.
6. The ending month plus two must be at the start of a three-month period that is above the recent 30-year mean value for that three-month period.

This procedure prevents a designated dry period from being declared at an end from just an isolated single month of above average precipitation. Once a defined dry period has begun a persistent period of above average precipitation (i.e., two or more months) must occur to declare the dry period ended. Of course this may only be temporary, and a new dry period may begin within a few months if three-month total precipitation falls significantly. Therefore, sometimes a dry period is only two or three months in length.

The aforementioned mean (or average) used to help in determining beginning and end of a dry period was based on the most recent 30-year period. The 30 year means are updated every ten years for application to each decade of data. For example, 1931 is the first year for which mean values are computed using the 1901–1930 base period. The year 1940 is the last, while 1941 is the first year to use the 1911–1940 base period, and so on. A sliding mean value is used instead of a long term (about 100 years) mean value for computation of the beginning and end month of identified dry periods for the following reason: Society adjusts gradually to gradual changes in climate, in this case precipitation changes. Therefore the consequences of a dry period tend to be a function of precipitation deviation from a mean computed from the recent past, rather than from the distant past. In any case, the statistics of dry periods are little changed regardless of which alternative mean value is used.

The precipitation record of New Brunswick, NJ is chosen for analysis due to its relatively long, continuous record, which dates back to 1900. This station is centrally located within the state. While it is accepted that the specifics of individual dry periods varies from station to station even within the small geographical area covered by New Jersey, it is likely that dry period *statistics* obtained from this single station is representative of most of the state. Monthly precipitation data (1900–1999) was obtained from records maintained at Rutgers University (currently at the Department of Environmental Sciences and in the Office of the State Climatologist for New Jersey).

In the next section each identified dry period is listed including the beginning and end month plus the computed duration in months. Based on this, additional statistics were generated such as the average dry and dry-free period length, frequency distribution of dry period length, frequency distribution of dry-free period length, frequency by month of the initiation and ending of dry periods, and the frequency by decade of dry periods.

RESULTS AND DISCUSSION

Table I (see next page) shows a listing of each identified dry period in the record (1/1900 to 12/1999). In addition to showing the beginning and ending month, the driest three-month interval, in terms of percent below normal, is indicated. From this listing the frequency of dry period length was calculated and displayed. This is shown in Fig. 1. There are 66 dry periods identified, with the average dry period length of about 9 months. The latter value falls to about 6.5 months if the five longest dry periods (length 22 months or longer) are not considered. There are 30 dry periods (45% of the total) with length less than 6 months. These are referred to as "mini-dry" periods. On the other end of the scale are the long dry periods, referred to as "major-dry" (length between 12 and 17 months) or "mega-dry" (length greater than 17 months). There are 12 identified major dry periods and an additional 6 mega-dry periods. The three longest dry periods are: 1/1930 to 8/1932 (32 months), 6/1980 to 12/1982 (31 months), and 3/1964 to 8/1966 (30 months).

Ludlum (1983), based on a subjective combination of published Palmer Drought Severity Index values and historical sources (e.g., newspaper accounts), describes four twentieth-century droughts in New Jersey: July 1929 to September 1932, June 1953 to July 1955, August 1961 to September 1966, and summer of 1980. Each of these is identified in the current results, however the specific months and period length vary. For example, Ludlum's long period drought of 1961 to 1966 is shown as 6 periods here, ranging from 30 to 3 months in length. In the 1950's the current work shows two dry periods between June 1953 and July 1955, with a break between them of 5 months (August 1954 through December 1954). Note that this identified break had three tropical storms (Carol, Edna, and Hazel), giving significant rain to the state.

FIG. 1. FREQUENCY BY LENGTH OF DRY PERIOD

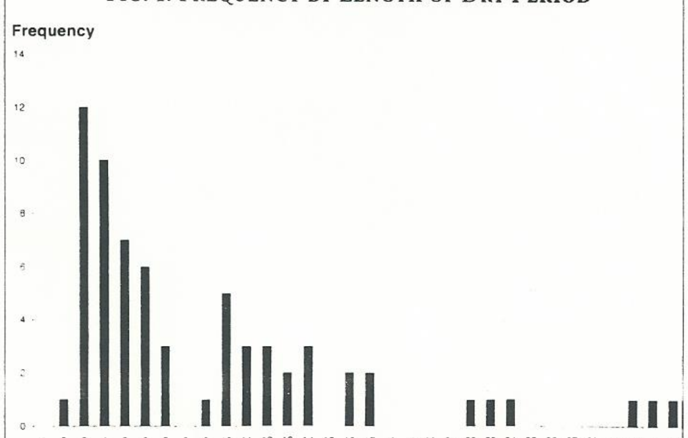

TABLE I: DRY PERIODS FOR NEW BRUNSWICK, NJ

INITIATION MONTH/YEAR	ENDING MONTH/YEAR	# OF MONTHS	DRIEST 3 MONTH INTERVAL IN DRY PERIOD	% BELOW NORMAL	INITIATION MONTH/YEAR	ENDING MONTH/YEAR	# OF MONTHS	DRIEST 3 MONTH INTERVAL IN DRY PERIOD	% BELOW NORMAL
12/1900	2/1901	3	12/1900–2/1901	49.4	8/1947	10/1947	3	8/1947–10/1947	41.7
9/1901	12/1901	3	9/1901–11/1901	38.3	9/1948	10/1948	2	9/1948–11/1948	37.3
3/1905	2/1906	12	4/1905–6/1905	41.6	6/1949	10/1950	17	6/1949–8/1949	48.9
9/1906	6/1907	10	9/1906–11/1906	33.2	7/1951	9/1951	3	7/1951–9/1951	40.4
9/1908	1/1909	5	9/1908–11/1908	30.0	6/1953	7/1954	14	7/1953–9/1953	49.2
5/1909	11/1909	7	5/1909–7/1909	39.1	1/1955	7/1955	7	5/1955–7/1955	52.6
5/1910	7/1910	3	5/1910–7/1910	36.0	11/1955	9/1956	11	11/1955–1/1956	51.0
6/1912	10/1912	5	6/1912–8/1912	44.7	1/1957	10/1957	10	5/1957–7/1957	64.2
5/1913	9/1913	5	6/1913–8/1913	50.9	11/1958	9/1959	11	12/1958–2/1959	35.3
6/1914	10/1914	5	8/1914–10/1914	69.4	4/1960	6/1960	3	4/1960–6/1960	24.3
3/1915	6/1915	4	3/1915–5/1915	32.5	5/1962	8/1963	16	4/1963–6/1963	73.9
9/1915	8/1917	24	8/1916–10/1916	48.9	3/1964	8/1966	30	6/1966–8/1966	67.0
11/1917	12/1918	14	8/1917–10/1917	43.8	11/1966	4/1967	6	12/1966–2/1967	28.0
9/1921	2/1922	6	10/1921–12/1921	36.6	9/1967	11/1967	3	9/1967–11/1967	35.0
8/1922	11/1922	4	9/1922–11/1922	57.1	2/1968	6/1969	17	4/1969–6/1969	28.7
4/1923	8/1923	5	6/1923–8/1923	56.9	1/1970	10/1970	10	1/1970–3/1970	23.5
10/1924	8/1926	22	10/1924–12/1924	58.3	4/1971	6/1971	3	4/1971–6/1971	38.7
1/1927	4/1927	4	1/1927–3/1927	48.2	7/1972	9/1972	3	7/1972–9/1972	52.6
1/1928	5/1928	5	3/1928–5/1928	27.2	7/1973	9/1973	3	7/1973–9/1973	25.2
10/1928	3/1929	6	10/1928–12/1928	48.0	6/1974	11/1974	6	5/1974–7/1974	35.4
1/1930	8/1932	32	9/1931–11/1931	54.2	2/1976	5/1977	16	11/1976–1/1977	54.1
12/1932	2/1933	3	12/1932–2/1933	29.5	2/1978	11/1978	10	9/1978–11/1978	37.7
10/1933	8/1935	23	10/1933–12/1933	48.9	11/1979	2/1980	4	12/1979–2/1980	46.2
7/1936	7/1937	13	7/1936–9/1936	34.1	6/1980	12/1982	31	11/1980–1/1981	52.3
12/1937	5/1938	6	12/1937–2/1938	36.8	6/1983	9/1983	4	6/1983–8/1983	43.4
5/1939	2/1940	10	11/1939–1/1940	52.9	8/1984	4/1985	9	11/1984–1/1985	34.4
2/1941	5/1941	4	3/1941–5/1941	27.0	5/1986	10/1986	6	5/1986–7/1986	51.0
8/1941	6/1942	11	8/1941–10/1941	61.9	12/1988	4/1989	5	12/1988–2/1989	38.3
1/1943	12/1943	12	7/1943–9/1943	38.6	9/1991	10/1992	14	9/1991–11/1991	39.6
5/1944	8/1944	4	6/1944–8/1944	53.1	5/1993	7/1993	3	5/1993–7/1993	41.9
1/1945	4/1945	4	1/1945–3/1945	24.3	9/1994	8/1995	12	3/1995–5/1995	50.6
1/1946	4/1946	4	2/1946–4/1946	42.9	8/1997	11/1997	4	8/1997–10/1997	32.2
9/1946	3/1947	7	10/1946–12/1946	44.1	7/1998	7/1999	13	10/1998–12/1998	55.8

A comparison was also made between some of the dry period statistics determined in this study to those calculated using droughts periods seen in the historic PDSI values for northern New Jersey. A critical value for the PDSI of –2 (referred to as a moderate drought) was used. This data was obtained at the National Climatic Data Center Web site (http://lwf.ncdc.noaa.gov/oa/climate/onlineprod/drought/main.html). Using the PDSI identified dry periods in comparison to those obtained here the following can be concluded:

1. There are a much smaller number of PDSI identified dry periods (38 vs. 66).
2. PDSI identified dry periods were shorter in length (average of 3.7 months vs. 9.0 months). It is clear that the dry periods identified here tend to start earlier and end later.
3. There was just one PDSI identified dry period lasting 12 months or longer (vs. 18).
4. The three longest PDSI identified dry periods (8/1964–8/1966, 12/1984–9/1985, and 9/1930–5/1931) were among the longest identified here, although in this study the dry period of 6/1980–12/1982 replaces the 1984–1985 PDSI identified dry period near the top of the dry ranking.

Overall the objective classification system devised here appears to have correctly identified at least the major dry periods and to identify many more short dry periods. Perhaps the statistics would be more similar if PDSI values of –1 or less (instead of –2 or less) were used to identify dry periods.

Figure 2 shows the frequency of dry period beginning and ending by calendar month. September and January are the favored initiation months, while October edges out June and November as the favored ending months. Overall, September and June have the highest number of turning points. By season, fall (September–November) has the most.

FIG 2. FREQUENCY OF DRY PERIOD BEGINNING AND ENDING BY CALENDAR MONTH

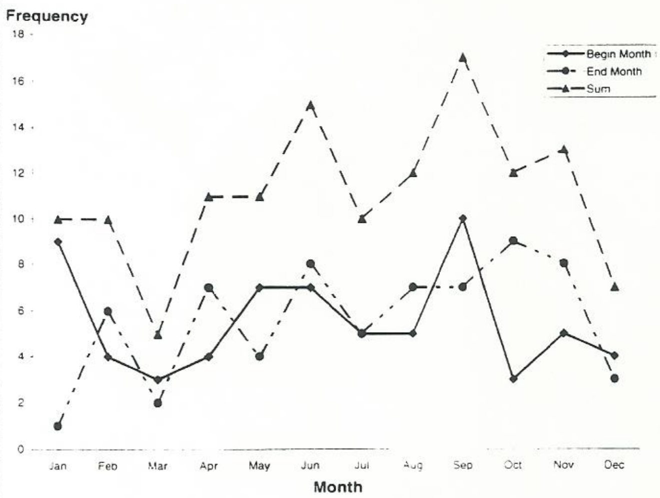

FIG 4. FREQUENCY BY LENGTH OF NON-DRY PERIODS

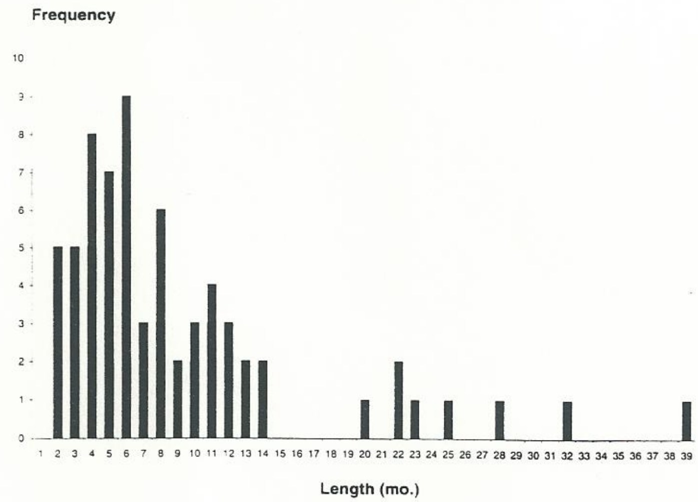

FIG 3. FREQUENCY OF DRY PERIOD OCCURRENCE BY DECADE

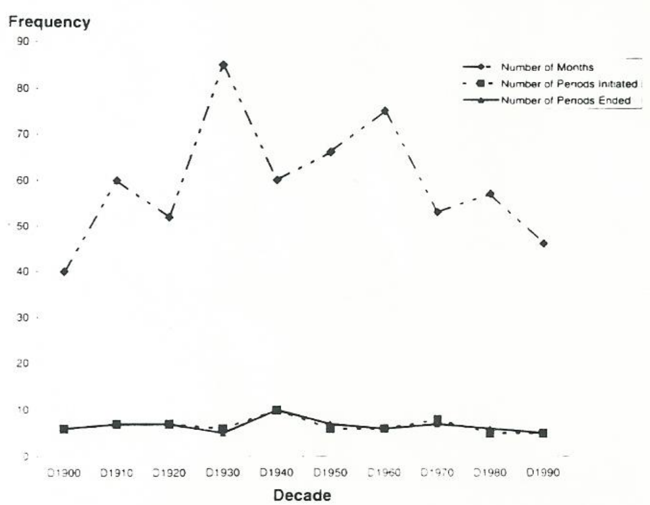

FIG 5. FREQUENCY BY LENGTH OF NON-DRY PERIODS OCCURRING BETWEEN DRY PERIODS GREATER THAN SIX MONTHS IN LENGTH

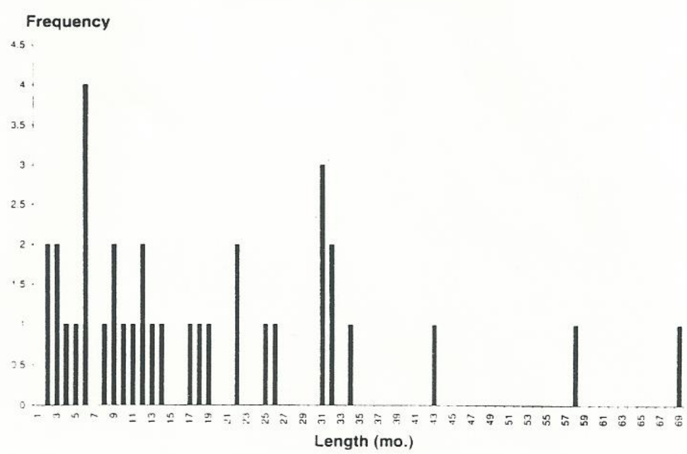

Figure 3 shows the frequency of dry period occurrence by decade. This shows that, as expected, the 1930's and 1960's are "dry" decades, while the 1900's and 1990's had many fewer dry period months. The most recent three decades have had lower than average number of months identified in dry periods. This suggests that any return to the relative dryness of the 1930's or 1960's will be a difficult adjustment for society.

In addition to dry period statistics this effort includes some statistics about the length of time between dry periods. The average length of period *between* dry periods (i.e., average length of dry-free period) is about 9 months, with the longest being 39 months (12/1901 to 3/1905). There are seven dry free periods of length greater than or equal to 20 months. Figure 4 shows the frequency distribution for dry-free period length. Figure 5 is similar except it shows the frequency distribution for dry-free periods between the end of one moderate or better dry period (i.e., dry period lasting 6 months or greater) and the next one. The average dry-free period for the latter circumstance is 18.6 months and the longest period is about 6 years. This figure indicates that a dry-free period greater than 3 years is rare, occurring just three times in the 100 year record.

For easy reference a summary of many of the characteristics of dry and non-dry periods follows:

Data period: 1/1900–12/1999 (1200 months)
Number of dry periods: 66
Average dry period length *(with all dry periods included):* 8.98 months. **Not including extremely long periods** *(i.e. 30 months or greater)*: 7.56 months **Not including long periods** *(i.e. 22 months or greater)*: 6.52 months
Longest dry period in data period: 32 months: 1/1930–8/1932
Other long dry periods: 31 months: 6/1980–12/1982 30 months: 3/1964–8/1966
Driest 3-month interval (1/1900–12/1999): 4/1963–6/1963 – 73.9% below normal
Shortest dry period in data period: 2 months: 9/1948–10/1948
Number of non-dry periods: 67
Average non-dry period length: 9.07 months
Longest non-dry period: 39 months: 12/1901–2/1905
Other long non-dry periods: 32 months: 1/1919–8/1921 28 months: 5/1989–8/1991 25 months: 11/1986–11/1988 22 months: 8/1910–5/1912, 7/1960–4/1962 20 months: 10/1951–5/1953

It is hoped that decision makers and the media in New Jersey will consider the statistics report herein when considering future dry episodes.

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