*__Charlie A. Liles__ is the Chief Meteorologist/Manager of the National Weather Service (NWS) Forecast Office in Albuquerque, New Mexico. He received his B.S. in meteorology from the University of Oklahoma in 1974, and M.S. in meteorology at Texas A&M University in 1976. While teaching in graduate school, Charlie researched severe thunderstorm cases. After working briefly with a private corporation as a forecaster and consultant, he joined the National Weather Service in 1977. He became a senior forecaster at the Jackson, Mississippi NWS office in 1981. He worked at the Environmental Research Laboratory in Boulder, Colorado in 1983 and 1984, publishing a book on the forecasting of thunderstorms. As a senior forecaster at the Jackson, Mississippi NWS office, he also taught meteorology at Jackson State University in 1986 and 1987. In 1988, Charlie became Deputy Meteorologist-in-Charge of the Albuquerque NWS office, and in 1990, Area Manager. He has written a number of research papers, published and unpublished, over his career, with his most recent work focusing on climate issues in New Mexico. Charlie has worked with the New Mexico Drought Task Force on drought-related climate issues since 1996.*

# DROUGHT, AND RELATIONSHIPS BETWEEN THE PACIFIC DECADAL OSCILLATION, THE EL NIÑO - SOUTHERN OSCILLATION, AND NEW MEXICO ANNUAL AND SEASONAL PRECIPITATION

Charlie A. Liles
National Weather Service
2341 Clark Carr Loop SE
Albuquerque, NM 87106

## Introduction

In the summer of 1996, when New Mexico was in the midst of a drought, Governor Johnson's office began an initiative to develop a drought task force for the state. A number of federal agencies, the National Drought Mitigation Center and State of New Mexico worked together to develop a drought contingency plan for the state. This document is and always will be a work in progress.

The New Mexico Drought Contingency Plan states drought is a complex physical and social process of widespread significance. The plan further states that despite all the problems droughts have caused, drought has proven to be difficult to define and there is no universally accepted definition. There are a number of reasons for this. Drought, unlike floods, a winter storm, or a tornado, is not a distinct event with a well-defined beginning and ending. Indeed, it is often some time after a drought when we look back in history and can have a good idea of when a drought began and when it ended. Some droughts can end fairly quickly while others fade away. However, droughts never have abrupt beginnings. They tend to develop slowly, spread, and gradually infiltrate all facets of life.

By convention and tradition, the most commonly used definitions of drought have been based on **meteorological, agricultural, hydrological**, and **socioeconomic** effects. Droughts are usually first defined by recognizing a period of substantially diminished precipitation through one or more of various drought indices. It is usually after this first step when an agricultural drought becomes obvious when there is no longer adequate soil moisture to meet the needs of a particular crop at a particular time. An individual growing one particular crop may perceive or recognize a drought at a particular time while someone growing another crop does not experience a drought issue because their crop does not need more moisture at that time. Once a drought has been meteorologically recognized and has begun to affect the agricultural community, hydrological drought typically becomes more apparent. This refers to deficiencies in surface and subsurface water supplies. Here in New Mexico, we typically note reductions in stream flow, drops in reservoir levels, a lack of snow pack, and wells going dry.

As drought worsens or deepens, water shortages begin to affect the health, well-being, and quality of life of people. "Water wars" increase and people begin to behave differently.

Typically, in an effort to gauge the intensity of a drought, people want to compare a current drought with a drought in history to determine the recurrence interval for a specific condition. For example, many people want to know if a drought is a "25-year, or 100-year" drought. Unfortunately, droughts cannot be accurately assessed in this manner. The planet is anything but a static system. Populations change, demands change, laws change, and systems change. The following table illustrates an attempt to compare the drought of 2002 in New Mexico with the drought of the 1950s.

By the end of September, 2002, the Palmer Drought Severity Index (PDSI) had detected severe or extreme drought conditions (index of lower than -3.0) for six months in the present drought. During the period from 1949 through 1956, the PDSI was below -3.0 for 67 months. Temporally, the drought of the 1950s was far more significant than the drought of 2002. However, the PDSI in 2002 dropped to -6.9 in climate division 2 (the northern mountains), which equaled the lowest value of 1950s. This might suggest the *intensity* of the 2002 drought was similar to that of the 1950s, if one can use the PDSI as a gauge of drought intensity.

During the present drought, New Mexico's statewide precipitation deficit has averaged (as of September, 2002) about six inches over a three-year period. This has ranged from 10-12 inches in portions of the northern mountains to only a couple of inches in some other areas of the state. However, during the 1950s, the statewide deficit averaged 24 inches over a seven-year period. The fact that the stream flows in 2002 set many daily record lows coupled with these precipitation deficits may suggest that increased demand and other changes play a huge role in the drought impact in New Mexico. In other words, it takes a much smaller precipitation deficit now than those experienced during the 1950s to "get us into significant trouble."

It's very difficult to compare reservoir levels of the 1950s with present levels, because the reservoir system is not the same. Mankind has intervened throughout the years to change the system. What can we say about the subsurface water supply now compared to the 1950s? Does anyone really know how much "water is in the tank?"

In spite of 150 drought definitions, which could suggest to us we still don't know how to define

**Table 1**

| INDICATOR | DROUGHT OF 2002 | DROUGHT OF 1950s |
|---|---|---|
| Palmer Index in Severe/Extreme categories | 6 | 67 |
| PDSI lowest value | -6.9 | -6.9 |
| Statewide Precipitation deficit | 6 inches | 24 inches |
| Streamflow | Record low | |
| Reservoirs | ?? | ?? |
| Subsurface Water | ?? | ?? |

drought, I've noticed increasing dialogue to attempt to create yet another definition. On the national drought monitor forum in which I participate, there has been recent dialogue that it may be time to look at drought more in terms of supply and demand than just by using indices. However, this approach also raises some big questions. If we gauge drought using a supply and demand approach, if water resources are not properly managed, or even if they are and demand exceeds supply, is it okay to say we are in a drought during times when precipitation has been "normal?" Indeed, the day is coming when there will be water-supply issues even when the atmosphere has produced "normal" precipitation. Also, the day is coming (or is already here) when "normal" doesn't mean acceptable. Consider Elephant Butte Reservoir, for example. For the period 1953-1979, the average storage at Elephant Butte was approximately 324,000 acre-feet. During the abundant rainfall periods of the 1980s and 1990s, storage topped 2 million acre-feet in the late 1990s. By late 2002, storage was back down to roughly 350,000 acre-feet. For an index that uses historical records (instead of 30 year normals), the present level of Elephant Butte is not too far from normal, but is 350,000 acre-feet acceptable? Considering the demands of the present day along with the wording of the Rio Grande Compact Commission documents, many would argue that 350,000 acre-feet is not an acceptable level for Elephant Butte Reservoir.

One could also argue that it is "normal" for New Mexico to be in a drought. For the period 1896 through 2002, severe to extreme drought (defined by -3.0 or less on the PDSI) has affected at least a portion of New Mexico during 59 of those 107 years, or 55 percent of those years. Each of the eight climate divisions in New Mexico has been in severe to extreme drought approximately 8 to 15 percent of the time (see Figure 1). Colorado's climate division 5, which should be considered near and dear to the hearts of New Mexicans, has been in severe to extreme drought at least 20 percent of the time during the period from 1895 through 1995. Colorado climate division 5 is responsible for a very significant contribution to the stream flow on the Rio Grande.

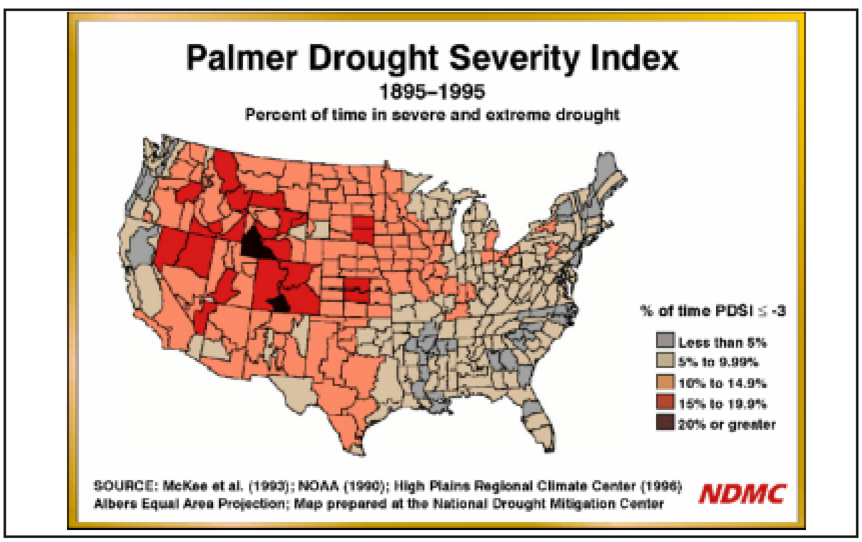


**Figure 1**

As you can see in Figure 1, drought affects virtually every part of the United States. However, the greatest frequency for drought is over the western U.S., especially along the Rocky Mountain chain where year to year and season to season variability can be great. It should be apparent that drought, no matter how we define it, has been a normal part of life in New Mexico's history. Tree rings show great variability and very significant droughts over the past couple of thousand years. Faced with significant drought, civilizations of the past likely had no choice but to get up and move during those times.

Just as tree rings show cycles of the past couple of thousand years, meteorological records show similar patterns over the past 100 years or so. The table below shows the significant droughts in New Mexico (as defined by PDSI values less than -3.0) since 1895.

The one thing we can say with great confidence is that, just as there have been droughts in our past, there will be droughts in the future. Drought in our future is a given. Our preparation and response is to be determined.

**Table 2**

**Severe and Extreme Droughts in New Mexico**

| YEAR | #Months (SVR (SVR/Extreme) | Worst Area Affected | Lowest PDSI |
|---|---|---|---|
| 1896 | 2 | South | -3.2 |
| 1899-1905 | 64 | Most of state | -6.6 |
| 1909-1911 | 20 | Most of state | -5.2 |
| 1913 | 1 | Southeast | -3.1 |
| 1917-1918 | 16 | Eastern Plains | -4.2 |
| 1925 | 4 | Nrn/Cntrl Mtns | -4.6 |
| 1928 | 1 | Northwest | -3.2 |
| 1934-1935 | 18 | Most of state | -5.5 |
| 1943 | 4 | Northeast | -3.9 |
| 1946 | 5 | Northeast | -3.5 |
| 1947-1948 | 12 | Central Mountains | -5.2 |
| 1950-1957 | 67 | Became statewide | -6.9 |
| 1959-1965 | 22 | Mainly Northwest | -5.1 |
| 1967 | 5 | Northern Mountains | -4.8 |
| 1971 | 5 | Southwest | -4.3 |
| 1972 | 5 | Northwest | -4.7 |
| 1974 | 4 | Most of state | -4.2 |
| 1976-1977 | 12 | Northwest | -4.3 |
| 1981 | 9 | Northern Mountains | -4.3 |
| 1989-1990 | 10 | Northwest | -4.0 |
| 1994-1996 | 15 | Became statewide | -5.9 |
| 2000 | 5 | Became statewide | -5.1 |
| 2001-2002 | 6* | Northern mountains | -6.9 |

* Current as of October, 2002.

## WHAT DOES OUR FUTURE HOLD?
## WHAT IS THE FORECAST FOR THE NEXT 20 YEARS?

Meteorology, weather forecasting, and climate forecasting are all frontiers. There have been many discoveries in these fields over the past 100 years, and the future should bring more discoveries of cycles and trends where we presently have no clues. Recently, it has become apparent that at least two distinctive signals in the Pacific Ocean have a profound influence on New Mexico's precipitation. One of these signals has become familiar to many people since the early 1980s, and is referred to as the El Niño-Southern Oscillation (ENSO). This includes the extremes of a cycle, that is El Niño and La Niña. Many researchers have studied and identified weather patterns associated with ENSO.

Another signal that was first explored by Nate Mantua and co-authors in 1997 is the Pacific Decadal Oscillation (PDO). Presently, scientists do not understand the relationships between these two signals, and some scientists may even still doubt the existence of the PDO.

ENSO cycles range from about 2 to 7 years, with an average of around 4 years. The range shows considerable variability. PDO cycles are typically 50-60 years, but there aren't very many to study. Figure 2 shows typical sea surface temperature anomalies in the Pacific for the PDO and ENSO cycles.

Figure 2 can be used to demonstrate the Pacific temperature differences between the positive and negative phases. Someone familiar with ENSO will also note quite a bit of similarity between the positive PDO and El Niño, as well as the negative PDO and La Niña. However, calculations of the ENSO are performed using data along the equator, while calculations for the PDO are much farther north. For this discussion, when I am mentioning ENSO, I am referring to the patterns of sea surface temperatures and pressure patterns along the equator. For the PDO, I am referring to the area over the central and northern Pacific Ocean.

A typical El Niño during a neutral PDO phase will look similar to the positive PDO shown on the left side of Figure 2, but without the colder than normal temperatures over the northern portion of the Pacific. A typical La Niña will look like the equatorial region shown for a negative PDO, but without the anomalies over the northern Pacific.

It is certainly possible to have El Niño occurring during either the negative or positive PDO phase, or La Niña occurring during either the negative or positive PDO phase. That is, ENSO and PDO can be in conflict, or in harmony. When they are in conflict, our confidence in relationships between the signals and our expected weather is diminished, but when they are in harmony, our confidence in seasonal forecasts is enhanced.

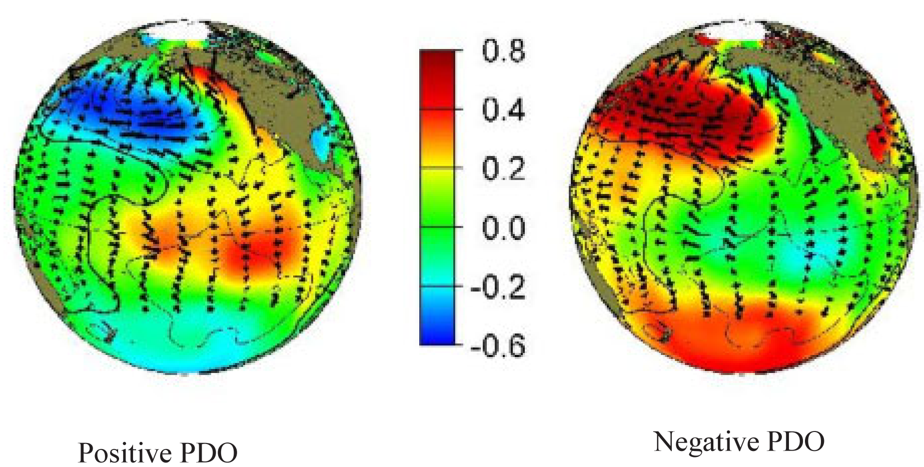


**Figure 2**

When an El Niño occurs during times when the PDO is significantly positive (positive by at least one standard deviation from the mean), the El Niño is likely to be enhanced. Such cases lead to super wet years such as 1941, when White Tail (near Cloudcroft) received 62.45 inches of precipitation. This remains the record for maximum annual precipitation for New Mexico.

On the other hand, when La Niña occurs during years in which the PDO is significantly negative, the La Niña tends to be enhanced. These two signals work in harmony to produce substantially diminished precipitation in New Mexico. They lead to super droughts such as the one experienced in the 1950s.

Meanwhile, a negative PDO coupled with El Niño or positive PDO coupled with La Niña produces conflicting signals. Confidence in seasonal forecasting is not especially high during these episodes. However, it appears to be quite difficult to get a strong El Niño/La Niña during significantly negative/positive PDO years. When the ENSO and PDO are in conflict and either an El Niño or La Niña occurs, the PDO is frequently only slightly negative/positive at that time, and usually responds to the ENSO signal by temporarily reversing signal for a time scale of months. Also, preliminary work suggests that the ENSO signal will typically be the more influential signal during the cooler times of the year for the areas of the state where the ENSO is typically strongest, that is, mainly southern New Mexico.

ENSO considered by itself exhibits a fairly confident relationship with precipitation in New Mexico from autumn through spring. Both the Climate Prediction Center graphics shown in figures 3-5 for 11 El Niño events and local research for 20 El Niño events (Figure 6) show New Mexico benefits during El Niño cool seasons. However, other factors must be introduced. Figures 3-5 (especially Figure 4, which shows winter) show that as one heads north, the benefits from El Niño diminish, and the pattern reverses. Wyoming, Montana, and Idaho typically have dry winters when El Niño is occurring. The northern edge of El Niño's benefit tends to be somewhere near the Colorado-New Mexico border, and during the last event in 1997-98, the northern benefit was even farther south, near the latitude of Santa Fe. Consequently, chances for a wet cool season are best in southern New Mexico, and diminish northward. The Rio Grande depends on the melting of snow over northern New Mexico and southern Colorado, so when the Rio Grande Basin is in drought, El Niño can't be counted on to alleviate drought in all cases.

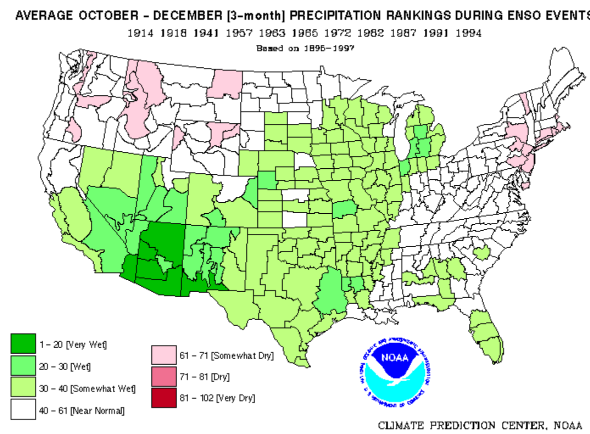


**Figure 3**

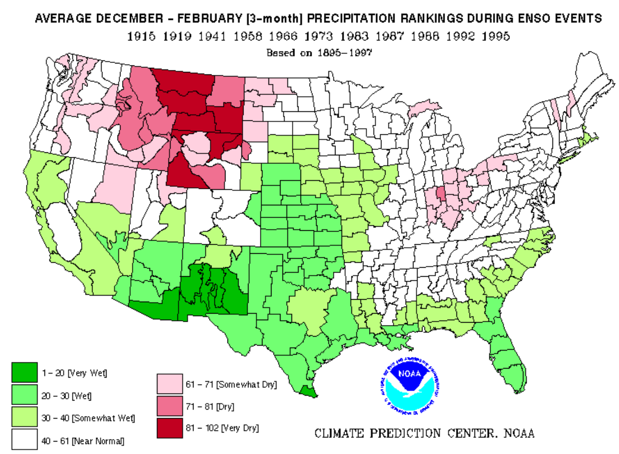


**Figure 4**

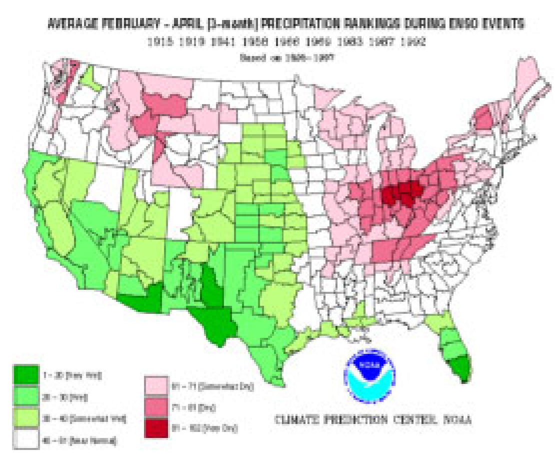


**Figure 5**

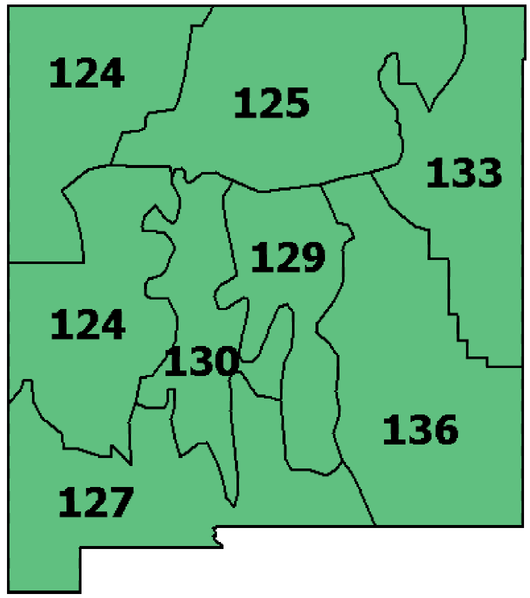


**Figure 6**

When looking ahead to the next 20 or 30 years, it seems the PDO is the main factor to consider because the PDO cycle is so much longer than the ENSO cycle. Figure 7 shows the PDO cycle since 1900.

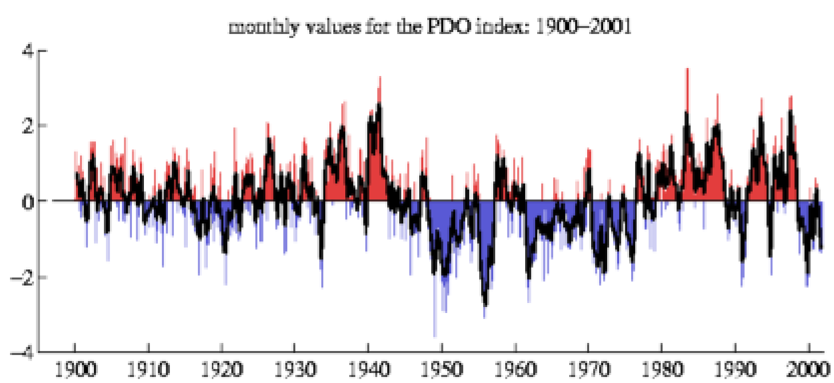


**Figure 7**

Although exactly when we've entered positive and negative PDO cycles is a matter for some debate, the generally-accepted time frames are given in the table below. The methodology and results of a study on the relationships between the PDO and New Mexico seasonal and annual precipitation are detailed below.

**Table 3**

**Recent PDO Cycles**

| | |
|---|---|
| 1923-1944 | Positive Phase |
| 1944-1977 | Negative Phase |
| 1977-1998 | Positive Phase |
| 1998-2030? | Negative Phase |

**Methodology**

The relationship between the PDO and New Mexico precipitation was studied in several ways. Data sets for the PDO (as well as Figure 7) were obtained from the University of Washington web page. An annual PDO average was calculated for each year from 1900 through 1999. Average precipitation for each of eight climate divisions (Figure 8) was calculated, for each of those years, using data obtained from the National Climatic Data Center (NCDC). Precipitation was also calculated for each of the seasons. Years were determined for which the PDO varied substantially from zero. In this paper, one standard deviation of PDO values (1900-1999) was centered about the mean value (+0.04) to represent normal conditions. Outside of this range, the PDO was categorized as "significantly negative" or "significantly positive." "Significant Negative PDO years" were determined to be years in which the average PDO was less than -0.73. "Significant Positive PDO years" were determined to be years in which the average PDO was greater than +0.82. Years were determined for which the average PDO was outside of the range from -0.73 to +0.82. The positive and negative PDO years are shown in Table 4, along with the PDO average for those years:

**Table 4**

| Negative PDO Years | Average PDO | Positive PDO Years | Average PDO |
|---|---|---|---|
| 1920 | -0.907 | 1926 | +1.160 |
| 1948 | -0.874 | 1934 | +1.183 |
| 1949 | -1.228 | 1936 | +1.731 |
| 1950 | -1.810 | 1940 | +1.769 |
| 1951 | -0.769 | 1941 | +1.994 |
| 1952 | -0.866 | 1981 | +0.918 |
| 1955 | -1.948 | 1983 | +1.648 |
| 1956 | -1.804 | 1984 | +0.838 |
| 1961 | -0.818 | 1986 | +1.239 |
| 1962 | -1.158 | 1987 | +1.821 |
| 1964 | -0.770 | 1992 | +0.928 |
| 1967 | -0.734 | 1993 | +1.417 |
| 1971 | -1.291 | 1997 | +1.461 |
| 1972 | -0.922 | | |
| 1973 | -0.804 | | |
| 1975 | -1.102 | | |
| 1999 | -1.063 | | |

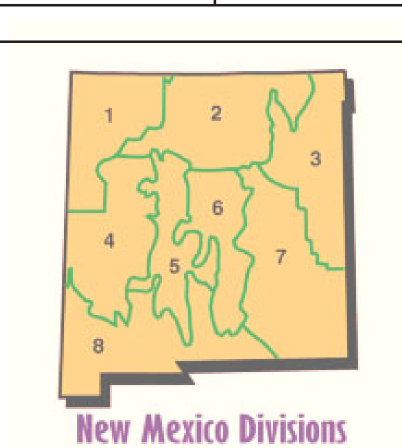


**Figure 8**

For the one hundred years included in the study, 30 years were determined to be either "significantly positive" or "significantly negative." Of those 30 years, 13 were determined to be "significantly positive," and 17 years were "significantly negative."

An average annual precipitation was computed for each climate division based on data obtained from the National Weather Service's cooperative observer network, and any aviation observation stations with long-term records. Approximately 175 stations were used in these calculations. Precipitation was considered to be normal for years in which the average for the division was within one half standard deviation of the long-term average. The remainder of the years were classified according to "above-normal" or "below-normal" status. This was also done for a "statewide" composite of all the climate divisions. The same methodology was employed for seasonal precipitation, with values plus or minus half a standard deviation designated "normal."

An attempt was also made to quantify precipitation during significantly positive or negative years. Average precipitation was calculated for each year and compared to long term averages. Ratios were also computed to compare the average precipitation during significantly negative and significantly positive years. The same methodology was employed to investigate seasonal precipitation for each of the eight climate divisions.

**Results for Annual Precipitation**

Tables 5 and 6 show the number of years with normal, above-normal, and below-normal precipitation for each climate division during the significantly positive and negative PDO years.

**Table 5 (Significantly Negative PDO Years)**

| Precip. | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| Above | 1 | 1 | 3 | 2 | 2 | 2 | 2 | 2 | 15 |
| Below | 6 | 8 | 7 | 5 | 6 | 9 | 8 | 9 | 58 |
| Norm. | 10 | 8 | 7 | 10 | 9 | 6 | 7 | 6 | 63 |

**Table 6 (Significantly Positive PDO Years)**

| Precip. | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| Above | 7 | 5 | 6 | 10 | 6 | 7 | 8 | 7 | 56 |
| Below | 0 | 1 | 4 | 0 | 1 | 1 | 2 | 1 | 10 |
| Norm. | 6 | 7 | 3 | 3 | 6 | 5 | 3 | 5 | 38 |

It's readily obvious that significantly positive PDO years favor above-normal precipitation, and significantly-negative PDO years favor below-normal precipitation. During negative PDO years, the dry years outnumbered the wet years nearly four to one, when all divisions were considered for those years in which precipitation varied from normal. During positive PDO years, wet years outnumbered dry years between five and six to one, when all divisions were considered for those years in which precipitation varied from normal.

Table 7 shows the average precipitation for each climate division during significantly positive and significantly negative PDO years, as well as long-term average precipitation for all years (1900-1999). The table also shows the ratio of precipitation between the negative and positive PDO years.

**Table 7 (Precipitation averages and percentage of normal during positive/negative PDO years)**

| Precip. | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| + PDO | 13.78 | 18.07 | 18.31 | 16.17 | 11.45 | 19.50 | 17.19 | 13.18 | 15.96 |
| %Normal | 122.7 | 110.7 | 115.5 | 124.7 | 122.7 | 116.3 | 127.8 | 122.2 | 119.6 |
| - PDO | 9.90 | 14.92 | 14.77 | 11.88 | 8.34 | 15.18 | 11.80 | 8.95 | 11.97 |
| %Normal | 88.1 | 91.4 | 93.1 | 91.6 | 89.3 | 90.6 | 87.7 | 83.0 | 89.7 |
| Norm. | 11.23 | 16.32 | 15.86 | 12.97 | 9.33 | 16.76 | 13.45 | 10.78 | 13.34 |
| -/+ Ratio | 71.8% | 82.5% | 80.7% | 73.5% | 72.8% | 77.8% | 68.6% | 67.9% | 75.0% |

It's readily apparent every climate division received more precipitation than normal during the positive PDO years, and less precipitation during the negative PDO years. Climate divisions 1, 4, 5, 7, and 8 all averaged more than 120 percent of the normal precipitation during the positive PDO years. Least affected was climate division 2, the north-central mountains bordering Colorado. The statewide average for positive PDO years was 119.6 percent of normal.

During negative PDO years, the state has averaged 89.7 percent of normal precipitation. It appears that climate division 8 (southwest desert) suffered greatest, with precipitation averaging only 83 percent of normal.

By looking at the ratio of negative PDO years to positive PDO years, one might be able to get a sense of the magnitude of change that can be expected when the cycle reverses. Looking at the ratio, it's apparent the amount of change increases southward in New Mexico. Ratios of slightly more than 80 percent along the Colorado border from north-central through northeast New Mexico (divisions 2 and 3) show less dramatic effects of the PDO cycle compared to climate divisions farther south. In divisions 7 and 8 (the southeast and southwest), precipitation during negative PDO years averages less than 70 percent of the average during positive PDO years. The statewide average ratio of precipitation between the negative and positive PDO years is 75 percent.

**Results for Seasonal Precipitation**

Seasonal precipitation was investigated for each climate division and determined to be normal, above-normal, or below-normal. The long-term average centered about one standard deviation provided the range of normal precipitation. For each climate division, the number of years for each season was determined for each category. For winter, two calculations were made for each climate division. One calculation was for those winters that were in progress at the beginning of a year determined to be a positive or negative PDO year. Another calculation was made for those winters that were determined to begin at the end of a year determined to be a positive or negative PDO year. For purposes of this paper, the seasons were determined in the following manner: Spring was March through May; Summer was June through August; Autumn was September through November; and Winter was December through February. Tables 8-17 show the results of the seasonal analyses.

**Table 8 (Spring Season - Negative PDO Years)**

| Precip. | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| Above | 3 | 3 | 3 | 2 | 3 | 1 | 1 | 3 | 19 |
| Below | 8 | 7 | 8 | 9 | 8 | 7 | 8 | 8 | 63 |
| Norm. | 6 | 7 | 6 | 6 | 6 | 9 | 8 | 6 | 54 |

**Table 9 (Spring Season - Positive PDO Years)**

| Precip. | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| Above | 7 | 2 | 3 | 5 | 6 | 6 | 6 | 6 | 41 |
| Below | 0 | 2 | 1 | 0 | 2 | 1 | 0 | 1 | 7 |
| Norm. | 6 | 9 | 9 | 8 | 5 | 6 | 7 | 6 | 56 |

**Table 10 (Summer Season - Negative PDO Years)**

| Precip. | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| Above | 4 | 4 | 6 | 4 | 3 | 5 | 5 | 4 | 35 |
| Below | 7 | 6 | 7 | 9 | 8 | 7 | 7 | 8 | 59 |
| Norm. | 6 | 7 | 4 | 4 | 6 | 5 | 5 | 5 | 42 |

**Table 11 (Summer Season - Positive PDO Years)**

| Precip. | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| Above | 4 | 2 | 7 | 7 | 4 | 3 | 4 | 4 | 35 |
| Below | 2 | 5 | 4 | 3 | 4 | 5 | 3 | 5 | 31 |
| Norm. | 7 | 6 | 2 | 3 | 5 | 5 | 6 | 4 | 38 |

**Table 12 (Autumn Season - Negative PDO Years)**

| Precip. | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| Above | 3 | 2 | 3 | 5 | 4 | 3 | 2 | 4 | 26 |
| Below | 8 | 11 | 9 | 6 | 9 | 9 | 8 | 9 | 69 |
| Norm. | 6 | 4 | 5 | 6 | 4 | 5 | 7 | 4 | 41 |

**Table 13 (Autumn Season - Positive PDO Years)**

| Precip. | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| Above | 6 | 6 | 4 | 6 | 5 | 6 | 5 | 5 | 43 |
| Below | 2 | 3 | 4 | 2 | 4 | 2 | 4 | 3 | 24 |
| Norm. | 5 | 4 | 5 | 5 | 4 | 5 | 4 | 5 | 37 |

**Table 14 (Winter Season (a) - Negative PDO Years)**

| Precip. | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| Above | 2 | 4 | 4 | 3 | 2 | 5 | 5 | 2 | 27 |
| Below | 8 | 9 | 4 | 8 | 8 | 7 | 6 | 9 | 59 |
| Norm. | 7 | 4 | 9 | 6 | 7 | 5 | 6 | 6 | 50 |

**Table 15 (Winter Season (b) Negative PDO Years)**

| Precip. | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| Above | 3 | 3 | 2 | 4 | 2 | 5 | 3 | 4 | 26 |
| Below | 6 | 8 | 4 | 8 | 7 | 6 | 9 | 7 | 55 |
| Norm. | 8 | 6 | 11 | 5 | 8 | 6 | 5 | 6 | 55 |

**Table 16 (Winter Season (a) Positive PDO Years)**

| Precip. | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| Above | 5 | 6 | 5 | 7 | 6 | 5 | 5 | 5 | 44 |
| Below | 4 | 3 | 2 | 3 | 3 | 5 | 3 | 4 | 27 |
| Norm. | 4 | 4 | 6 | 3 | 4 | 3 | 5 | 4 | 33 |

**Table 17 (Winter Season (b) Positive PDO Years)**

| Precip. | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| Above | 9 | 7 | 3 | 8 | 7 | 6 | 5 | 6 | 51 |
| Below | 1 | 2 | 5 | 2 | 3 | 3 | 5 | 2 | 23 |
| Norm. | 3 | 4 | 5 | 3 | 3 | 4 | 3 | 5 | 30 |

**Table 18 (All Seasons for Negative PDO Years)**

| Precip. | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| Above | 15 | 16 | 18 | 18 | 14 | 19 | 16 | 17 | 133 |
| Below | 37 | 41 | 32 | 40 | 40 | 36 | 38 | 41 | 305 |
| Norm. | 33 | 28 | 35 | 27 | 31 | 30 | 31 | 27 | 242 |

**Table 19 (All Seasons for Positive PDO Years)**

| Precip. | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| Above | 31 | 23 | 22 | 33 | 28 | 26 | 25 | 26 | 214 |
| Below | 9 | 15 | 16 | 10 | 16 | 16 | 15 | 15 | 112 |
| Norm. | 25 | 27 | 27 | 22 | 21 | 23 | 25 | 24 | 194 |

**Discussion of Seasonal Results**

*Spring*

When looking at the amount of time precipitation falls into categories of normal, above, and below normal, it's apparent that the spring weather during positive PDO years was significant. When the precipitation was outside of the normal range, wet springs outnumbered the dry years 41 to 7 for all divisions. Precipitation fell in the normal range 56 seasons, or 54 percent of the time. Divisions 1, 4, and 7 experienced no (zero) dry years during positive PDO years. Division 2 (north-central mountains near the Colorado border) was the only division to show no effect, with 2 wet springs, 2 dry ones, and 9 in the normal category.

Negative PDO years produced dry springs more often than not by a ratio of over three to one. For all climate divisions combined, dry springs outnumbered wet ones 63 to 19. Fifty-four seasons were considered normal, which was approximately 40 percent of the time. Divisions 6 and 7, constituting roughly the southeast quarter of the state, exhibited the greatest effect from negative PDO years, with dry springs outnumbering wet springs 15 to 2 in those divisions combined.

*Summer*

Of all the seasons, summer was least affected by whether the PDO was positive or negative for the year. Positive PDO years favored above-normal precipitation, but by a small margin. Wet summers outnumbered dry ones 35 to 31, with 38 falling into the normal range. Divisions 2, 6 and 8 (the mountains and southwest desert) actually had more dry summers than wet ones during positive PDO years, while division 5 (central valley) broke even.

The tendency for dry summers during negative PDO years was a bit more apparent, with dry summers outnumbering the wet ones 59 to 35 for all divisions combined. Forty-two summers fell into the normal range.

*Autumn*

Tables12 and 13 show the effect of positive and negative PDO years on autumn precipitation. For all climate divisions, dry years outnumber wet ones 69 to 26, with 41 seasons falling in the normal range. The effect of negative PDO years on autumn precipitation was especially apparent in division 2 (north-central mountains), where dry years outnumbered wet ones 11 to 2. Meanwhile, division 4 (west-central mountains) was relatively balanced between the wet and dry years.

During positive PDO years, wet autumns outnumbered dry ones nearly two to one. However, there appeared to be little effect in the Eastern Plains (divisions 3 and 7), as well as the Central Valley (division 5).

*Winter*

Recall winter precipitation was determined for those winters which were already in progress at the beginning of the negative/positive PDO year, as well as those winters that began at the end of a negative/positive PDO year. These two winters are referred to, respectively, as winter (a) and winter (b) in tables 14 through 17.

For negative PDO years, winters (a) and (b) exhibited little difference. For both winters (tables 14 and 15), dry seasons outnumbered wet ones slightly more than two to one. For winter (a), the least difference was noted in divisions 3, 6, and 7. This area comprises the Eastern Plains and central mountain chain, or roughly the eastern half of New Mexico. This pattern wasn't noted for winter (b), although division 6 (central mountains) exhibited more balance than the other divisions.

Tables 16 and 17 show that positive PDO years favored above-normal precipitation, especially in the winters (b) that began at the end of a positive PDO year. Winter (b) was especially interesting in that wet winters that began at the end of positive PDOs almost exclusively favored western and central New Mexico. Division 1 (northwest) only experienced one dry winter in 13 years. In divisions 1, 2, 4, 5, 6, and 8 (all of west and central New Mexico), wet winters outnumbered dry ones 43 to 13 for winter (b), with 22 falling into the normal range. This was in marked contrast to the Eastern Plains (divisions 3 and 7), where dry winters (b) actually outnumbered wet ones 10 to 8, with 8 falling in the normal range.

*All Seasons Combined*

Tables 18 and 19 show the results of all seasons combined. For negative PDO years (table 18), dry seasons outnumbered wet seasons approximately 2.3 to 1. The greatest ratio was in division 5 (central valley), where dry seasons outnumbered wet ones nearly three to one.

For positive PDO years, divisions 1 (northwest) and 4 (west-central mountains) stood out, with wet seasons outnumbering dry ones over three to one. Effects of a positive PDO were least in divisions 2 (north-central mountains) and 3 (northeast plains). For all divisions combined, wet seasons outnumbered dry ones nearly two to one.

## Seasonal Precipitation Quantified

Monthly and seasonal precipitation in the Southwest U.S. exhibits great variability. During any "normal" year it's not unusual to have some months in which less than 20 percent of normal precipitation falls, and others with precipitation that exceeds 200 percent of normal. Consequently, besides examining the number of seasons with above-normal, below-normal, or normal precipitation, average precipitation was calculated for each climate division during positive and negative PDO years, and compared to the long-term averages.

Tables 20-24 show the percentage of normal precipitation for each climate division and each season, along with a ratio of averages during negative PDO years to averages during positive PDO years.

**Table 20 (Spring Season) (%)**

| | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| – PDO | 78.7 | 85.5 | 88.7 | 71.0 | 72.0 | 75.1 | 69.2 | 73.1 | 78.7 |
| + PDO | 142.9 | 115.7 | 130.7 | 160.4 | 141.6 | 142.8 | 163.4 | 175.0 | 142.2 |
| Ratio | 55.0 | 73.9 | 67.9 | 44.3 | 50.9 | 52.5 | 40.6 | 41.8 | 55.4 |

**Table 21 (Summer Season) (%)**

| | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| – PDO | 94.1 | 97.0 | 98.7 | 91.8 | 95.9 | 96.5 | 97.9 | 93.5 | 96.0 |
| + PDO | 106.2 | 98.5 | 101.0 | 104.8 | 103.8 | 95.6 | 107.6 | 101.9 | 101.8 |
| Ratio | 88.6 | 98.5 | 97.8 | 87.6 | 92.4 | 101 | 91 | 91.7 | 94.2 |

**Table 22 (Autumn Season) (%)**

| | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| – PDO | 90.2 | 82.7 | 85.0 | 97.9 | 87.5 | 85.6 | 80.8 | 93.0 | 87.5 |
| + PDO | 122.7 | 116.1 | 124.8 | 127.8 | 130.1 | 127.9 | 122.6 | 125.0 | 124.4 |
| Ratio | 73.7 | 71.2 | 68.1 | 76.6 | 67.4 | 67.0 | 65.9 | 74.4 | 70.4 |

**Table 23 (Winter (a)) (%)**

| | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| – PDO | 86.4 | 92.2 | 97.0 | 88.8 | 86.0 | 93.3 | 97.1 | 87.2 | 90.7 |
| + PDO | 124.3 | 117.3 | 133.1 | 130.4 | 134.9 | 112.7 | 137.7 | 136.7 | 126.5 |
| Ratio | 69.5 | 78.6 | 72.8 | 68.1 | 63.8 | 82.8 | 70.5 | 63.4 | 71.7 |

**Table 24 (Winter (b)) (%)**

| | Div 1 | Div 2 | Div 3 | Div 4 | Div 5 | Div 6 | Div 7 | Div 8 | ALL |
|---|---|---|---|---|---|---|---|---|---|
| – PDO | 80.2 | 91.9 | 86.3 | 90.2 | 82.9 | 92.3 | 82.6 | 93.2 | 88.1 |
| + PDO | 139.6 | 123.7 | 105.6 | 145.1 | 130.2 | 121.9 | 116.9 | 137.1 | 127.5 |
| Ratio | 57.5 | 74.3 | 81.8 | 62.1 | 63.4 | 75.7 | 70.7 | 68.0 | 69.1 |

## Discussion of Seasonal Precipitation Quantities

The effect of the PDO cycle is profound when one studies the quantity of precipitation New Mexico receives during the positive and negative phases of the cycle that lie outside one standard deviation of the mean value. Tables 20 through 24 show that this effect was most pronounced during the spring, and least noticeable during the summer.

Table 20 shows that the state received only 78.7% of the normal spring precipitation during the negative PDO years, but a whopping 142.2 percent of the normal spring precipitation during the positive PDO years. The ratio of precipitation between negative and positive PDO years was 55.4 percent for the state. This ratio is especially noteworthy in divisions 7 and 8. Spring rains are extremely important in these two divisions, because of the agriculture (ranching and farming) operations. The ratio between positive and negative PDO years in these divisions was, respectively, only 40.6 and 41.8 percent. Spring precipitation in these two divisions exemplify the "feast" and "famine" cycle. Meanwhile, there was less difference farther north between the dry and wet springs. The highest ratios between the dry and wet springs were in divisions 2 (north-central mountains) and 3 (northeast plains), where there are also agricultural activities at that time of year.

Divisions 4 (west-central mountains), 5 (central valley), 7 (southeast plains) and 8 (southwest desert) suffered most during negative PDO years. Precipitation averaged less than 75 percent of normal in those divisions. Divisions 2 and 3, in the north-central and northeast, suffered the least, with precipitation between 85.5 and 88.7 percent of normal. Those same two divisions (2 and 3) were also least affected during positive PDO years, especially division 2, which averaged 115.7 percent of normal precipitation. Meanwhile, some of the divisions that suffered the most during negative PDO years benefitted the most during positive PDO years. Divisions 4, 7, and 8 all averaged greater than 150 percent of normal spring precipitation during the positive PDO years. Division 8 averaged 175 percent of normal. Of course, one thing to keep in mind with the drier climate divisions in New Mexico is that normal precipitation is a small amount. Consequently, the range that division 8 exhibited between negative PDO and positive PDO years (73 to 175 percent of normal) translates into a difference of about one inch of precipitation. However, one inch of precipitation in the southwest desert is 10 to 15 percent of the average annual precipitation.

One effect of positive PDO years on spring precipitation in the mountainous climate divisions (primarily 2, 4, 6) would certainly be to increase the amount of spring snow melt for numerous applications. A complete study of this issue related to the PDO would need to include the climate divisions of southern Colorado. A good portion of the spring precipitation in division 2 (north-central mountains) is in the form of snow, although divisions 4 (west-central mountains) and 6 (central mountains) tend to see a change from snow to rain during the second half of the spring.

Summer exhibited less of a ratio between negative and positive PDO years than the other seasons. Most affected by the negative PDO years were the climate divisions in western New Mexico. Divisions 1 (northwest), 4 (west-central mountains), and 8 (southwest desert) all received less than 95 percent of the normal summer precipitation during negative PDO years. All divisions farther east received between 95 and 99 percent of the normal summer precipitation during negative PDO years. Divisions 1 (northwest), 4 (west-central mountains), and 7 (southeast plains) were most favored during positive PDO years. Even so, division 7, the most favored, received only 107.6 percent of normal precipitation during positive PDO years. Consequently, the only division with a ratio of less than 90 percent between negative and positive PDO years was division 1, with a ratio of 88.6 percent. One division (6) was actually slightly wetter during the negative PDO years. Divisions 2 (north-central mountains) and 6 (central mountains) actually have better (wetter) summers when the PDO is neither significantly negative or positive.

Table 22 shows the results of significant negative and positive PDO years on New Mexico autumn precipitation. Autumn precipitation differences between negative and positive PDO years was not as pronounced as spring, but far more noticeable than summer. It's apparent all divisions suffered less precipitation during negative PDO years and received more during positive PDO years. The ratios between the negative and positive PDO years averaged 70.4 percent, with a range from 65.9 percent in division 7 (southeast) to 76.6 percent in division 4 (west-central mountains). This was the smallest range of ratios of all the seasons.

The overall effect on the state of significantly negative and positive PDO years on winter precipitation was similar to autumn, regardless of looking at winters that were ending early in a PDO year or winters that had just begun at the end of a PDO year. Table 23 shows the results for winter (a), that is, those winters that were ending early in a significant PDO year. It's interesting to note the western portion of New Mexico suffered most during negative PDO years, with winter precipitation averaging less than 90 percent of normal. Meanwhile, the Eastern Plains faired best (divisions 3 and 7), averaging 97 percent of normal. During positive PDO years, all divisions received greater than 110 percent of normal precipitation, but divisions 3 (northeast), 4 (west-central mountains), 5 (central valley), 7 (southeast), and 8 (southwest desert) all exceeded 130 percent of normal. The greatest differences between the good and bad years were in divisions 5 (central valley) and 8 (southwest desert), where the ratios between negative and positive PDO years was between 63 and 64 percent.

Winter precipitation at the end of a significant PDO year (Table 24) showed a similar statewide average for the negative PDO years (88.1 percent versus 90.7 percent), but the pattern from east (wetter) to west (drier) did not hold true. Divisions 1 (northwest), 5 (central valley), and 7 (southeast) all averaged between 80.2 and 82.9 percent of normal precipitation during the negative PDO years. Divisions 6 and 8 (central mountains and southwest desert) faired a little better, with averages of 92.3 and 93.2 percent.

Winter precipitation averaged 126.5 percent (statewide) for winter (a), and 127.5 percent for winter (b), showing no appreciable difference.

## Summary/Conclusions

There is a strong relationship between the Pacific Decadal Oscillation and precipitation in New Mexico. From Table 5, it can be seen that dry years outnumbered wet years nearly four to one for significantly negative PDO years whenever precipitation was either above or below normal. For all divisions combined, dry division-years outnumbered wet ones 58 to 15, with 63 falling in the normal range (plus or minus one-half standard deviation from the mean precipitation). During significantly positive PDO years (Table 6), wet years outnumbered dry years between five and six to one. For all divisions combined, wet division-years outnumbered wet ones 56 to 10, while 38 fell into the normal range.

The effect of the PDO cycle increases generally from north to south in New Mexico. Ratios of negative to positive PDO precipitation averages shows this quite well. Table 7 shows that this ratio ranges from just above 80 percent in divisions 2 and 3 (north-central mountains and northeast plains) to less than 70 percent in divisions 7 and 8 (southeast plains and southwest desert). The statewide average is 75 percent.

Seasonal precipitation during significant PDO years is especially affected during the spring and least affected during the summer. Spring seasons during positive PDO years are especially noteworthy, with wet springs outnumbering the dry ones nearly six to one (table 9). The ratio between spring precipitation during negative and positive PDO years (Table 20) is very significant, with a statewide average of only 55 percent. This affect is especially noteworthy in the south and southwest, where divisions 4, 7, and 8 all had ratios of less than 45 percent. This has profound ramifications for the agricultural regions in those divisions.

If historical data from the 20th century can be used to forecast conditions in the 21st century, one might conclude the following: Precipitation totals during the next negative phase of the PDO will likely be approximately 75 percent of those during the most recent positive PDO cycle. If it is true that a negative phase of the PDO cycle began in the late 1990s, then it is likely precipitation totals for New Mexico between the late 1990s and the 2020s may only average 75 percent of those totals from the middle 1970s through the middle 1990s. If this forecast is accurate, it will have profound effects on New Mexico. Water issues in New Mexico have been significant throughout recent history, and the importance of these issues will increase dramatically as the population continues to grow. These figures are especially important during periods of rapid growth or great changes in the state. New Mexico experienced rapid changes and substantial population growth during the positive PDO phase that began in the middle 1970s. Anyone who judges the period from the middle 1970s through the middle 1990s to be "normal" may find the negative phase of the PDO cycle to be especially harsh in terms of water yield.

Water demands related to increased population along with changes in laws would alone suggest New Mexico will experience an escalation of water issues in the future. When the possible water budget cut of 25 percent is factored into the equation, problems are exacerbated.

There are certainly some caveats in this entire process of extrapolating history forward. The planet is not a static place. The atmosphere of 2002 is not the same as the one of 1950. One big issue of concern is certainly global warming. Some global warming models suggest New Mexico will continue to get wetter as the globe heats up. However, since we rely substantially on snow pack to produce water supply, global warming, even if it did produce more precipitation, would overall diminish the water supply by raising snow levels and decreasing the percentage of total precipitation that falls as snow. However, it is also possible that global warming is creating the increase in amplitude we are seeing in the PDO cycle. If this is true, it could lead to worse droughts during the negative phase and even wetter periods during the positive phase. In any case, considering the ramifications and huge impacts a drought similar to the 1950s (or worse) would have on the Southwest United States, it seems only prudent to plan for significant droughts in our future. We know they will occur. We're just not sure exactly when or how bad they will be. This study of the relationships between the PDO phase and New Mexico precipitation suggests the likelihood of a very significant drought that will be much higher during the next 20-30 years than it was over the past 20 years when we reaped the benefits of a positive PDO phase. If we are going to meet demands for water in our future, it will take a combination of excellent management, conservation, and the development of new, affordable technologies.

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