Drought

Identification

1. Indicator Description

This indicator measures drought conditions in the United States using several different indices. Drought can affect agriculture, water supplies, energy production, and many other aspects of society. Drought relates to climate change because rising average temperatures alter the Earth's water cycle, increasing the overall rate of evaporation from soil and transpiration from plants. An increase in evapotranspiration makes more water available in the air for precipitation, but contributes to drying over some land areas, leaving less moisture in the soil. As the climate continues to change, many historically wet areas are likely to experience an increased level of moisture and a higher risk of flooding. Historically dry areas are likely to experience less precipitation and an increased risk of drought (Marvel et al., 2023).

Components of this indicator include:

- Average drought conditions in the contiguous 48 states since 1895 based on the Palmer Drought Severity Index (Figure 1).
- Average drought conditions in the contiguous 48 states since 1900 based on the five-year-timescale Standardized Precipitation-Evapotranspiration Index, or SPEI (Vicente-Serrano et al., 2010) (Figure 2).
- Trend in the five-year SPEI in the contiguous 48 states, 1900 to 2023 (Figure 3).
- Percent of U.S. lands classified under drought conditions in recent years, based on an index called the U.S. Drought Monitor (Figure 4).

The data for Figure 3 are shown for climate divisions, as defined by the National Oceanic and Atmospheric Administration (NOAA).

2. Revision History

April 2010:	Indicator published.
December 2012:	Added Figure 1, based on the Palmer Drought Severity Index. Updated indicator with data through 2011.
August 2013:	Updated indicator with data through 2012.
May 2014:	Updated indicator with data through 2013.
June 2015:	Updated indicator with data through 2014.
August 2016:	Updated indicator with data through 2015.
April 2021:	Updated indicator with data through 2020; added Figures 2 and 3 based on the SPEI; renumbered previous Figure 2 (Drought Monitor) as Figure 4.
June 2024:	Updated indicator with data through 2023.

3. Data Sources

Data for Figure 1 were obtained from the National Oceanic and Atmospheric Administration's (NOAA's) National Centers for Environmental Information (NCEI), formerly National Climatic Data Center (NCDC), which maintains a large collection of climate data online.

Data for Figures 2 and 3 were obtained from the WestWide Drought Tracker, which is a collaboration between the University of Idaho, the Western Regional Climate Center, and the Desert Research Institute. The WestWide Drought Tracker based all calculations on measurements and models from Oregon State University's Parameter-elevation Regressions on Independent Slopes Model (PRISM) Climate Mapping Program—specifically the AN81m and AN81d data sets.

Data for Figure 4 were provided by the U.S. Drought Monitor, which maintains current and archived data at: https://droughtmonitor.unl.edu.

4. Data Availability

Figure 1. Average Drought Conditions in the Contiguous 48 States According to the Palmer Index, 1895–2023

NCEI's Climate at a Glance interface provides access to monthly values of the PDSI averaged across the entire contiguous 48 states, which EPA downloaded for this indicator. These data are available at: www.ncei.noaa.gov/access/monitoring/climate-at-a-glance. This website also provides access to monthly PDSI values for nine broad regions, individual states, and 357 smaller regions called climate divisions (each state has one to 10 climate divisions, except Alaska, which has 13). For accompanying metadata, see: www1.ncdc.noaa.gov/pub/data/cirs/climdiv/divisional-readme.txt.

PDSI values are calculated from precipitation and temperature measurements collected by weather stations within each climate division. Individual station measurements and metadata are available through NCEI's website (www.ncei.noaa.gov/products/land-based-station).

Figures 2 and 3. Average Drought Conditions and Average Change in Drought in the Contiguous 48 States According to the SPEI, 1900–2023

EPA obtained the SPEI data in raster format directly from the WestWide Drought Tracker archive, at both the five-year (i.e., "60 months") and one-year (i.e., "12 months") timescales. The data sets are publicly available at a variety of spatial extents at: https://wrcc.dri.edu/wwdt/batchdownload.php. The PRISM data are also made publicly available, via Oregon State University's PRISM Climate Group, by the Northwest Alliance for Computational Science and Engineering: www.prism.oregonstate.edu. Additional information on the SPEI can be found at: https://spei.csic.es/home.html.

Figure 4. U.S. Lands Under Drought Conditions, 2000–2023

U.S. Drought Monitor data can be obtained from: https://droughtmonitor.unl.edu/DmData/DataTables.aspx. Select "U.S. States and Puerto Rico" to view the historical data that were used for this indicator. For each week, the data table shows what percentage of land area was under the following drought conditions:

1. None
2. D0–D4
3. D1–D4
4. D2–D4
5. D3–D4
6. D4 alone

This indicator covers the time period from 2000 to 2023. Although data were available for parts of 2024 at the time EPA last updated this indicator, EPA chose to report only full years.

Drought Monitor data are based on a wide variety of underlying sources. Some are readily available from public websites; others might require specific database queries or assistance from the agencies that collect and/or compile the data. For links to many of the data sources, see: https://droughtmonitor.unl.edu/nadm/Home.aspx.

Methodology

5. Data Collection

Figure 1. Average Drought Conditions in the Contiguous 48 States According to the Palmer Index, 1895–2023

The PDSI is calculated from daily temperature measurements and precipitation totals collected at thousands of weather stations throughout the United States. These stations are overseen by NOAA, and they use standard instruments to measure temperature and precipitation. Some of these stations are automated stations operated by NOAA's National Weather Service. The remainder are Cooperative Observer Program (COOP) stations operated by other organizations using trained observers and equipment and procedures prescribed by NOAA. For an inventory of U.S. weather stations and information about data collection methods, see the technical reports and peer-reviewed papers cited at: www.ncei.noaa.gov/products/land-based-station, and the National Weather Service technical manuals at: www.weather.gov/coop. This indicator is derived from a specific quality-controlled subset of long-term stations that NCEI has designated as its *n*ClimDiv data set (www.ncei.noaa.gov/access/monitoring/reference-maps/conus-climate-divisions).

Figures 2 and 3. Average Drought Conditions and Average Change in Drought in the Contiguous 48 States According to the SPEI, 1900–2023

The PRISM Climate Mapping Program by Oregon State University's PRISM Climate Group is an ongoing effort to produce and disseminate accurate, high-resolution climate data sets (Daly et al., 1994). PRISM uses point data, a digital elevation model, and other spatial data sets to generate grid-based estimates of monthly precipitation and temperature from 1895 to the present day at a scale of about 4 kilometers (2.5 arc-minutes). Surface stations used to collect point data number nearly 10,000 for temperature and 13,000 for precipitation (Daly et al., 2008). PRISM is frequently updated to map climate in complex terrain, including rain shadows, high mountains, coastal regions, temperature inversions, and associated complex mesoscale climate processes. More information about the data set can be found at: www.prism.oregonstate.edu/documents/PRISM_datasets.pdf.

The WestWide Drought Tracker collects and analyzes monthly data from the PRISM Climate Mapping Program. Monthly data are aggregated to create a five-year-timescale data series. Updated data are processed at the beginning of each month and are available for download in multiple formats at: https://wrcc.dri.edu/wwdt/about.php.

Figure 4. U.S. Lands Under Drought Conditions, 2000–2023

Figure 4 is based on the U.S. Drought Monitor, which uses a comprehensive definition of drought that accounts for a large number of different physical variables. Many of the underlying variables reflect weather and climate, including daily precipitation totals collected at weather stations throughout the United States, as described above for Figure 1. Other parameters include measurements of soil moisture, streamflow, reservoir and groundwater levels, and vegetation health. These measurements are generally collected by government agencies following standard methods, such as a national network of stream gauges that measure daily and weekly flows, comprehensive satellite mapping programs, and other systematic monitoring networks. Each program has its own sampling or monitoring design. The Drought Monitor and the other drought indices that contribute to it have been formulated to rely on measurements that offer sufficient temporal and spatial resolution.

The U.S. Drought Monitor has five primary inputs:

- The PDSI.
- The Soil Moisture Model, from NOAA's Climate Prediction Center.
- Weekly streamflow data from the U.S. Geological Survey.
- The Standardized Precipitation Index (SPI), compiled by NOAA and the Western Regional Climate Center.
- A blend of objective short- and long-term drought indicators (short-term drought indicator blends focus on one- to three-month precipitation totals; long-term blends focus on six to 60 months).

At certain times and in certain locations, the Drought Monitor also incorporates one or more of the following additional indices, some of which are particularly well-suited to the growing season and others of which are ideal for snowy areas or ideal for the arid West:

- A topsoil moisture index from the U.S. Department of Agriculture's National Agricultural Statistics Service.
- The Keetch-Byram Drought Index.
- Vegetation health indices based on satellite imagery from NOAA's National Environmental Satellite, Data, and Information Service.
- Snow water content.
- River basin precipitation.
- The Surface Water Supply Index.
- Groundwater levels.
- Reservoir storage.
- Pasture or range conditions.

For more information on the other drought indices that contribute to the Drought Monitor, including the data used as inputs to these other indices, see: https://droughtmonitor.unl.edu/About/WhatistheUSDM.aspx.

To find information on underlying sampling methods and procedures for constructing some of the component indices that go into determining the U.S. Drought Monitor, one will need to consult a variety of additional sources. For example, as described above for Figure 1, NCEI has published extensive documentation about methods for collecting precipitation data.

6. Indicator Derivation

Figure 1. Average Drought Conditions in the Contiguous 48 States According to the Palmer Index, 1895–2023

PDSI calculations are designed to reflect the amount of moisture available at a particular place and time, based on the amount of precipitation received as well as the temperature, which influences evaporation rates. The formula for creating this index was originally proposed in the 1960s (Palmer, 1965). Since then, the methods have been tested extensively and used to support hundreds of published studies. The PDSI is the most widespread and scientifically vetted drought index in use today.

The PDSI was designed to characterize long-term drought (i.e., patterns lasting a month or more). Because drought is cumulative, the formula takes precipitation and temperature data from previous weeks and months into account. Thus, a single rainy day is unlikely to cause a dramatic shift in the index.

PDSI values are normalized relative to long-term average conditions at each location, which means this method can be applied to any location regardless of how wet or dry it typically is. NOAA currently uses 1931–1990 as its long-term baseline. The index essentially measures deviation from normal conditions. The PDSI takes the form of a numerical value, generally ranging from -6 to +6. A value of zero reflects average conditions. Negative values indicate drier-than-average conditions and positive values indicate wetter-than-average conditions. NOAA provides the following interpretations for specific ranges of the index:

- 0 to -0.5 = normal
- -0.5 to -1.0 = incipient drought
- -1.0 to -2.0 = mild drought
- -2.0 to -3.0 = moderate drought
- -3.0 to -4.0 = severe drought
- < -4.0 = extreme drought

Similar adjectives can be applied to positive (wet) values.

NOAA calculates monthly values of the PDSI for each of the 344 climate divisions within the contiguous 48 states. These values are calculated from weather stations reporting both temperature and precipitation. As part of its *n*ClimDiv analysis, NOAA uses station data and interpolation between stations to create a 5-kilometer grid across the contiguous 48 states for each variable in the data set, including PDSI. Divisional averages are derived by averaging the grid cells within each climate division. NOAA also combines PDSI values from all climate divisions, weighted by area, to derive a national average for every month. These methods ensure that PDSI values are not biased towards areas that happen to have more stations clustered close together.

Although NOAA has divided Alaska into 13 climate divisions, PDSI calculations are not available for Alaska.

EPA obtained monthly national PDSI values from NOAA's website, then calculated annual averages. To smooth out some of the year-to-year variability, EPA applied a nine-point binomial filter, which is plotted at the center of each nine-year window. For example, the smoothed value from 2002 to 2010 is plotted at year 2006. NOAA NCEI recommends this approach. Figure 1 shows both the annual values and the smoothed curve.

EPA used endpoint padding to extend the nine-year smoothed lines all the way to the ends of the period of record. As recommended by NCEI, EPA calculated smoothed values as follows: if 2023 was the most recent year with data available, EPA calculated smoothed values to be centered at 2020, 2021, 2022, and 2023 by inserting the 2023 data point into the equation in place of the as-yet-unreported annual data points for 2024 and beyond. EPA used an equivalent approach at the beginning of the time series.

For more information about NOAA's processing methods, see the metadata file at: www1.ncdc.noaa.gov/pub/data/cirs/climdiv/divisional-readme.txt. NOAA's website provides additional information regarding the PDSI at: www.ncei.noaa.gov/access/monitoring/monthly-report/drought/202401.

In March 2013, NOAA corrected minor errors in the computer code used to process soil moisture values, which feed into the computation of the PDSI. This change caused slight revisions to historical data compared with what EPA presented in Figure 1 prior to August 2013. Although most data were not substantially changed, minor but discernible differences appeared in data after 2005. NOAA discusses these improvements in full at: www.ncei.noaa.gov/access/monitoring/monthly-report/national/2013/3/supplemental/page-7.

Figures 2 and 3. Average Drought Conditions and Average Change in Drought in the Contiguous 48 States According to the SPEI, 1900–2023

This indicator shows multi-year (five-year) climatological drought/moisture patterns via the SPEI and examines potential multi-scalar drought trends, spatially and temporally. The SPEI's multi-scalar characteristics allow for spatial and temporal comparison of drought severity over a wide array of climates (Vicente-Serrano et al., 2010). Some of the advantages of the SPEI over other drought metrics are:

- The index combines multi-timescale aspects of the SPI with information about evapotranspiration. This ability to represent moisture conditions arguably makes the SPEI a more complete representation of drought than indices that rely predominantly on temperature.
- The statistically based index requires only climatological information, without assumptions about the characteristics of the underlying system.

The SPEI is statistically based and can easily be derived with a concise and customizable calculation procedure. Using the SPEI enables the analysis of a multitude of drought types (i.e., ecological, agricultural, meteorological, hydrological, etc.) as well as the potential impacts of climate change

(Vicente-Serrano et al., 2010). Notably, the SPEI is sensitive to the method used to calculate potential evapotranspiration, or PET (Stagge et al., 2014). The WestWide Drought Tracker's SPEI calculation uses the Thornthwaite method (Thornthwaite, 1948), due to data limitations of the PRISM data set at time of download and the requirements of other PET calculations. See "Indicator Development" below for further discussion of PET methods.

Classifications of the SPEI values are defined by McKee et al. (1993). More information on the calculation and standardization of the SPEI is available at: https://spei.csic.es/home.html and https://climatedataguide.ucar.edu/climate-data/standardized-precipitation-evapotranspiration-index-spei. The WestWide Drought Tracker's method for calculating SPEI is further documented in Abatzoglou et al. (2017).

Figure 2 of this indicator shows average drought conditions from 1900 to 2023 for the contiguous 48 states, based on the five-year-timescale SPEI values on a July to June time span. For example, the 2023 SPEI values contain the mean SPEI values per 4-kilometer pixel within the contiguous 48 states from July 2018 to June 2023, inclusive. EPA chose to analyze the SPEI values and trends with a five-year timescale for added perspective in assessing long-term drought conditions in the United States. A multi-year drought index is less affected by interannual variability. Consequently, it may better reflect changes in long-term dry/wet cycles, which is especially relevant when considering climate trends and potential connections of drought to climate change (Abatzoglou et al., 2017; Koch et al., 2012). Negative SPEI values indicate more prevalent drought conditions over the preceding five-year time period. Conversely, positive SPEI values indicate that higher moisture levels were more prevalent over the preceding five-year time period.

Figure 3 presents a map of the change in the five-year SPEI values by NOAA climate division over the time period of 1900 to 2023 (Vose et al., 2014). EPA calculated these trends by conducting ordinary least squares regressions of the five-year SPEI values for each climate division over the full time period. As with Figure 1, the five-year SPEI values are based on a July-to-June time span (e.g., the 2023 value considers SPEI from July 2018 to June 2023). Climate divisions in brown display a trend toward lower SPEI values; blue represents a trend toward higher SPEI. Each pixel's average annual rate of change (regression slope) has been multiplied by the length of the period of record (123 years) to derive and depict an estimate of total change.

Over the complete period of record, EPA aggregated the 4-kilometer SPEI pixel values within each climate division as well as the contiguous 48 states, for both one- and five-year-timescale calculations. For each one- and five-year SPEI raster, EPA used the "Calculate Zonal Statistics as Table" tool in ESRI ArcGIS with the NOAA climate division layer as zone data to determine SPEI values per climate division. Because SPEI value output is multiplied by 100, as per WestWide Drought Tracker settings, EPA divided the "mean" values by 100 using the "Calculate Field" tool in ESRI ArcGIS. Analysis at the climate division level can provide more insight into regional drought trends. Climate division data were obtained from NOAA's NCEI.

Figure 4. U.S. Lands Under Drought Conditions, 2000–2023

The National Drought Mitigation Center at the University of Nebraska–Lincoln produces the U.S. Drought Monitor with assistance from many other climate and water experts at the federal, regional, state, and local levels. For each week, the Drought Monitor labels areas of the country according to the intensity of any drought conditions present. An area experiencing drought is assigned a score ranging from D0, the least severe drought, to D4, the most severe. For definitions of these classifications, see: https://droughtmonitor.unl.edu/About/WhatistheUSDM.aspx.

Drought Monitor values are determined from the five major components and other supplementary factors listed in Section 5. A table on the Drought Monitor website (https://droughtmonitor.unl.edu/About/WhatistheUSDM.aspx) explains the range of observed values for each major component that would result in a particular Drought Monitor score. The final index score is based to some degree on expert judgment, however. For example, expert analysts resolve discrepancies in cases where the five major components might not coincide with one another. They might assign a final Drought Monitor score based on what the majority of the components suggest, or they might weight the components differently according to how well they perform in various parts of the country and at different times of the year. Experts also determine what additional factors to consider for a given time and place and how heavily to weight these supplemental factors. For example, snowpack is particularly important in the West, where it has a strong bearing on water supplies.

From the Drought Monitor's public website, EPA obtained data covering the contiguous 48 states plus Alaska, Hawaii, and Puerto Rico, then performed a few additional calculations. The original data set reports cumulative categories (for example, "D2–D4" and "D3–D4"), so EPA had to subtract one category from another in order to find the percentage of land area belonging to each individual drought category (e.g., D2 alone). EPA also calculated annual averages to support some of the statements presented in the "Key Points" for this indicator.

No attempt has been made to portray data outside the time and space in which measurements were made. Measurements are collected at least weekly (in the case of some variables like precipitation and streamflow, at least daily) and used to derive weekly maps for the U.S. Drought Monitor. Values are generalized over space by weighting the different factors that go into calculating the overall index and applying expert judgment to derive the final weekly map and the corresponding totals for affected area.

For more information about how the Drought Monitor is calculated, including percentiles associated with the occurrence of each of the D0–D4 classifications, see Svoboda et al. (2002), along with the documentation provided on the Drought Monitor website at: http://droughtmonitor.unl.edu.

Indicator Development

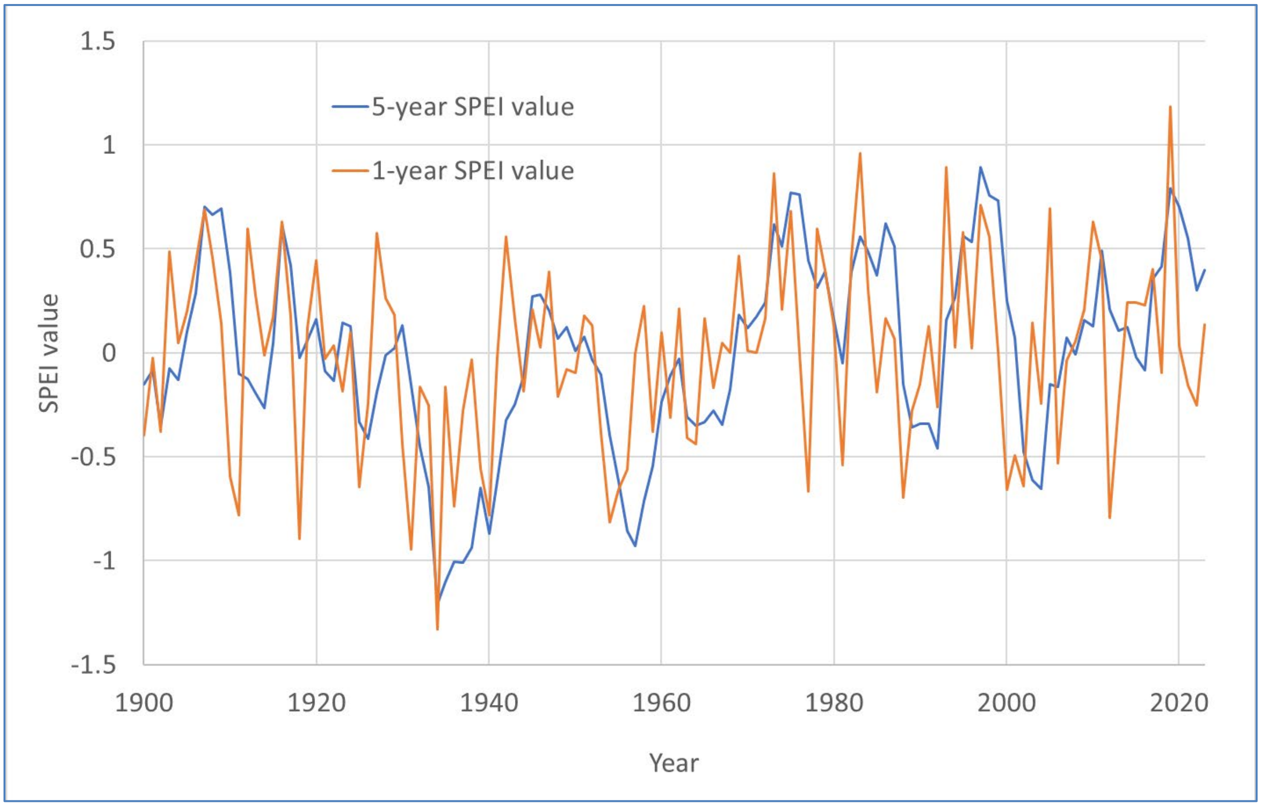
EPA has conducted several analyses to compare methods and metrics at the national scale:

- Figure TD-1 shows the influence of timeframe on the SPEI, with a comparison of one- and five-year SPEI values derived from the same source using the same underlying PET method (Thornthwaite). Broad patterns are highly similar; the one-year version just shows more year-to-year variability, as one would likely expect.
- Figure TD-2 compares the PDSI and SPEI, both at one-year timescales over the same spatial and temporal extent. Visually, this graph shows general agreement between the indices as far as national-scale patterns are concerned.
- Figure TD-2 also shows two versions of the one-year SPEI, reflecting different methods of accounting for PET: Thornthwaite, as used in this indicator, and another commonly used method, Penman-Monteith (Allen et al., 1998). The two methods are correlated for the period of overlap, with $R^2 = 0.92$.

- Figure TD-3 compares the influence of PET method on SPEI at a four-year timescale—the longest timeframe readily available from the source that provided SPEI based on Penman-Monteith. Here, the correlation has $R^2 = 0.86$.

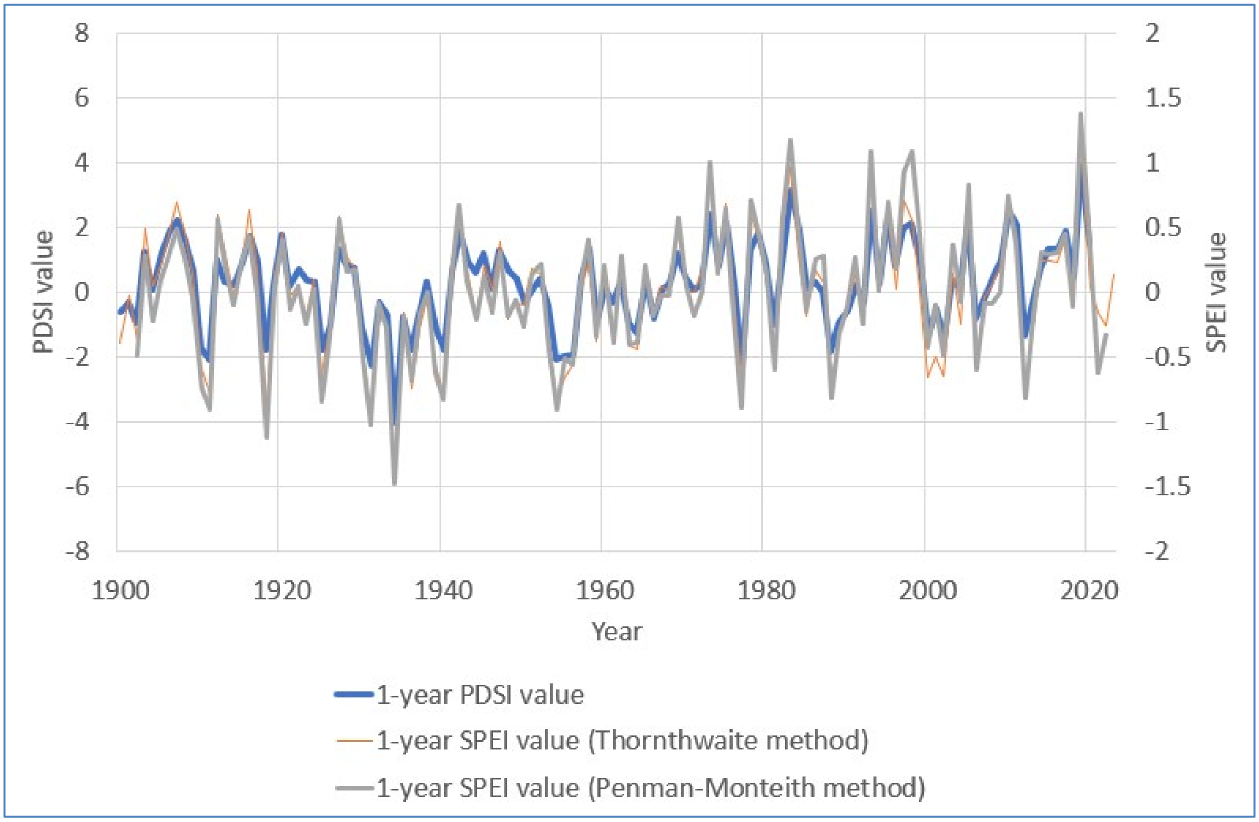
These results all reflect national aggregation. It is very possible that differences between methods will be wider at smaller spatial scales and for shorter specific time periods.

Figure TD-1. Comparison of One- and Five-Year SPEI Values for the Contiguous 48 States, 1900–2023



Data source: WestWide Drought Tracker

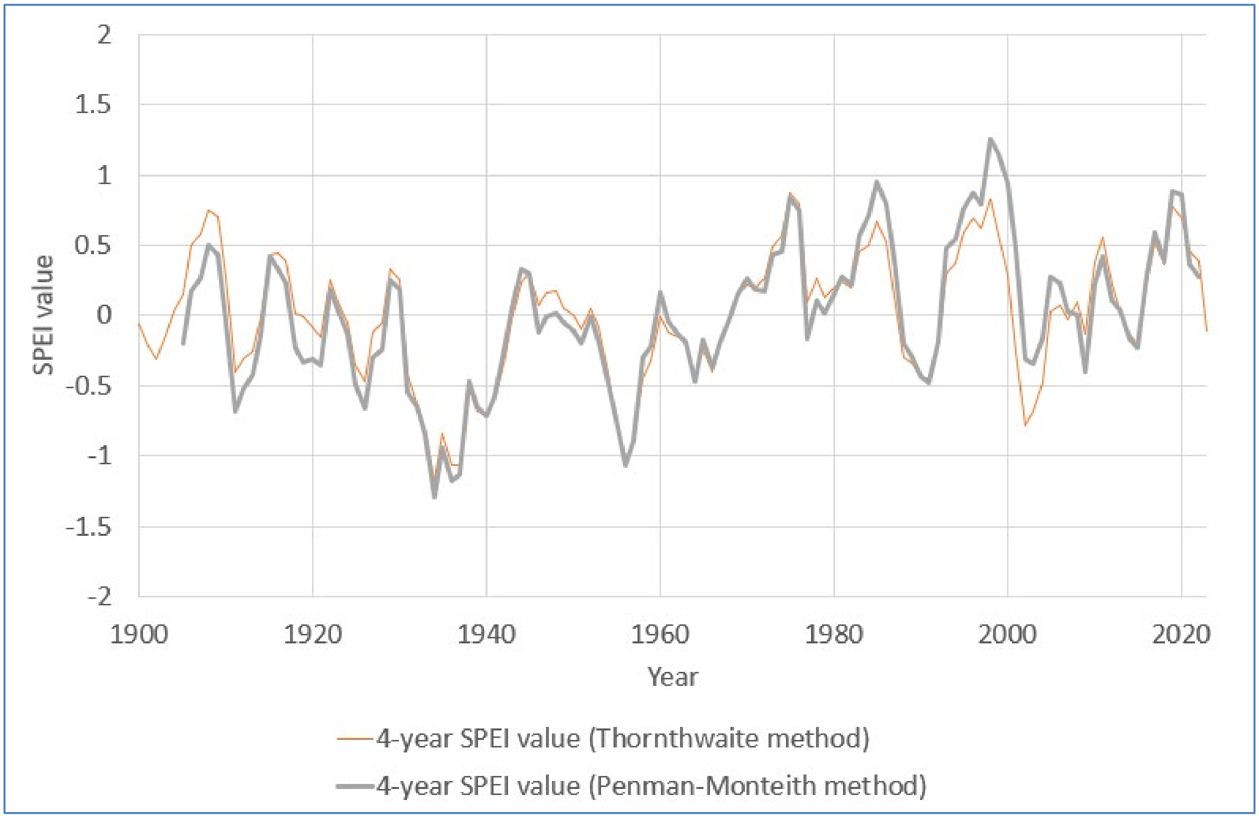
Figure TD-2. Comparison of One-Year PDSI and SPEI Values for the Contiguous 48 States, 1900–2023



Data sources:

- *PDSI from NOAA NCEI*
- *SPEI (Thornthwaite method) from WestWide Drought Tracker*
- *SPEI (Penman-Monteith method) from SPEIbase (https://spei.csic.es/database.html)*

Figure TD-3. Comparison of Four-Year SPEI Values for the Contiguous 48 States, 1900–2023



Data sources:

- *PDSI from NOAA NCEI*
- *SPEI (Thornthwaite method) from WestWide Drought Tracker*
- *SPEI (Penman-Monteith method) from SPEIbase (https://spei.csic.es/database.html)*

The Thornthwaite method estimates PET based on mean temperature, whereas the Penman-Monteith equation combines temperature with wind speed, relative humidity, and solar radiation. Because these other variables all influence evapotranspiration, studies and experts suggest a preference for using the Penman-Monteith method where it is available. For example, Stagge et al. (2014) conducted comparisons and sensitivity analyses and recommended using more robust options such as Penman-Monteith where possible, with the observation that PET calculations are particularly sensitive to the method of accounting for radiation. However, several key inputs to the Penman-Monteith equation (wind speed, relative humidity, and solar radiation) were not recorded during the first half of the 20th century, and even when they were measured actively during the second half of the century, the density of stations with complete data for analysis was sparse. SPEI data based on Penman-Monteith are nonetheless available—including the data shown in the figures above, which come from an international consortium website called SPEIbase (https://spei.csic.es/database.html). Yet these data do not have the high geographic resolution needed for the PRISM analysis that feeds into EPA's indicator, particularly when climate division mapping is concerned. Given the desired spatial and temporal coverage for this indicator, EPA elected to use a Thornthwaite-based SPEI data source.

EPA notes that temperature-based PET methods (such as Thornthwaite) have been shown to perform relatively well in climatological applications because air temperature is correlated with net radiation and humidity at weekly, monthly, and sub-annual timescales (Sheffield et al., 2012). The apparent similarities between methods at the scales shown in Figures TD-2 and TD-3 support this observation.

7. Quality Assurance and Quality Control

Figure 1. Average Drought Conditions in the Contiguous 48 States According to the Palmer Index, 1895–2023

Data from weather stations go through a variety of quality assurance and quality control (QA/QC) procedures before they can be added to historical databases in their final form. NOAA's *n*ClimDiv data set follows strict QA/QC procedures to identify errors and biases in the data and then either remove these stations from the time series or apply correction factors. Procedures for *n*ClimDiv are summarized at: www.ncei.noaa.gov/access/monitoring/reference-maps/conus-climate-divisions. Specific to this indicator, Karl et al. (1986) describe steps that have been taken to reduce biases associated with differences in the time of day when temperature observations are reported. Other procedures include:

- Removal of duplicate records.
- Procedures to deal with missing data.
- Testing and correcting for artificial discontinuities in a local station record, which might reflect station relocation or instrumentation changes.

Figures 2 and 3. Average Drought Conditions and Average Change in Drought in the Contiguous 48 States According to the SPEI, 1900–2023

QA/QC measures for temperature and precipitation data include the removal of duplicate records, missing data corrections, and testing and correcting for artificial discontinuities in a local station record, which might reflect station relocation or instrumentation changes. Monthly PRISM data follow a variety of QA/QC procedures before they are distributed in their final form. PRISM adjusts for complex terrain, including rain shadows, high mountains, coastal regions, temperature inversions, and associated complex mesoscale climate processes in the QA/QC procedure. All station data are spatially QCed, and all procedures are peer-reviewed. Methodology for the PRISM data set is described in further detail in Daly et al. (2008).

QA/QC procedures behind the WestWide Drought Tracker calculations are not readily available. Each underlying data source has an associated methodology, which typically includes some degree of QA/QC and is available online.

Figure 4. U.S. Lands Under Drought Conditions, 2000–2023

QA/QC procedures for the overall U.S. Drought Monitor data set are not readily available. Each underlying data source has its own methodology, which typically includes some degree of QA/QC. For example, precipitation and temperature data are verified and corrected as described above for Figure 1. Some of the other underlying data sources have QA/QC procedures available online, but others do not.

Analysis

8. Comparability Over Time and Space

Figure 1. Average Drought Conditions in the Contiguous 48 States According to the Palmer Index, 1895–2023

PDSI calculation methods have been applied consistently over time and space. In all cases, the index relies on the same underlying measurements (precipitation and temperature). Although fewer stations were collecting weather data during the first few decades of the analysis, NOAA has determined that enough stations were available starting in 1895 to calculate valid index values for the contiguous 48 states as a whole.

Figures 2 and 3. Average Drought Conditions and Average Change in Drought in the Contiguous 48 States According to the SPEI, 1900–2023

The calculation methods of the SPEI have been applied consistently over both dimensions. In all cases, the index relies on the same underlying measurements and calculations. The SPEI values used for this indicator are based on weighted PRISM data by location (Daly et al., 2008) including the 4-kilometer pixel grid values. PRISM calculates a climate–elevation regression for each digital elevation model grid cell, and stations entering the regression are assigned weights based primarily on the physiographic similarity of the station to the grid cell. Factors considered are location, elevation, coastal proximity, topographic facet orientation, vertical atmospheric layer, topographic position, and orographic effectiveness of the terrain (Daly et al., 2008).

A potential source of variability relates to aggregating the original resolution of the data (i.e., raster data). The PRISM temperature data model was revamped in late October of 2019. This change is made less important by natural data smoothing associated with temporal aggregation. Data in this indicator rely on the current model iteration, whereas future SPEI data will incorporate temperature data collected with the newer versions of the model and any associated changes to the parameters.

Figure 4. U.S. Lands Under Drought Conditions, 2000–2023

The resolution of the U.S. Drought Monitor has improved over time. When the Drought Monitor began to be calculated in 1999, many of the component indicators used to determine drought conditions were reported at the climate division level. Many of these component indicators now include data from the county and sub-county level. This change in resolution over time can be seen in the methods used to draw contour lines on Drought Monitor maps.

The drought classification scheme used for this indicator is produced by combining data from several different sources. Different locations may use different primary sources—or the same sources, weighted differently. These data are combined to reflect the collective judgment of experts and in some cases are adjusted to reconcile conflicting trends shown by different data sources over different time periods.

Though data resolution and mapping procedures have varied somewhat over time and space, the fundamental construction of the indicator has remained consistent.

9. Data Limitations

Factors that may impact the confidence, application, or conclusions drawn from this indicator are as follows:

1. The indicator focuses on a broad overview of drought conditions in the contiguous United States. The spatial averaging of drought metrics over such a large area can obscure drought extremes occurring at regional scales. It is not intended to replace local or state information that might describe conditions more precisely for a particular region. Local or state entities might monitor different variables to meet specific needs or to address local problems. As a consequence, there could be water shortages or crop failures within an area not designated as a drought area, just as there could be locations with adequate water supplies in an area designated as D3 or D4 (extreme or exceptional) drought.

2. Because this indicator focuses on national trends, it does not show how drought conditions vary by region. For example, even if half of the country suffered from severe drought, Figure 1 could show an average index value close to zero if the rest of the country was wetter than average. Thus, Figure 1 might understate the degree to which droughts are becoming more severe in some areas, while other places receive more rain as a result of climate change.

3. Although the PDSI is arguably the most widely used drought index, it has some limitations that have been documented extensively in the literature. While the use of just two variables (precipitation and temperature) makes this index relatively easy to calculate over time and space, drought can have many other dimensions that these two variables do not fully capture. For example, the PDSI loses accuracy in areas where a substantial portion of the water supply comes from snowpack.

4. This SPEI calculation uses the Thornthwaite PET equation, given the limitation on variables available from the monthly PRISM data set. With the Thornthwaite approach, variables other than temperature that can affect PET, such as wind speed, surface humidity, and solar radiation, are not considered. However, at present, these additional variables are not as widely available as temperature and precipitation for the same temporal and spatial scope of this multi-decadal period of record. As discussed in Section 6, the Thornthwaite method performs reasonably well at the scale of this indicator.

5. Some studies have found that the PRISM data set may report anomalous high-elevation warming trends. Some extreme warming observed at higher elevations is potentially the result of systematic artifacts and not climatic conditions (Oyler et al., 2015).

6. The extreme conditions associated with the Dust Bowl in the 1930s may unduly influence the long-term trends in some parts of the country. Widespread and exceptional drought in the early part of the time series may accentuate the appearance of a wetter trend more recently. This may be especially true for climate divisions in the center part of the country.

7. Indices such as the U.S. Drought Monitor seek to address the limitations of the PDSI by incorporating many more variables. The Drought Monitor is relatively new, however, and cannot yet be used to assess long-term climate trends.

8. The drought classification scheme used for Figure 4 is produced by combining data from several different sources. These data are combined to reflect the collective judgment of experts and in some cases are adjusted to reconcile conflicting trends shown by different data sources over different time periods.

10. Sources of Uncertainty

Error estimates are not readily available for national average PDSI, the U.S. Drought Monitor, or the underlying measurements that contribute to this indicator.

As far as the SPEI calculations are concerned, it is not clear how much uncertainty might be associated with the weighting of different parts of the PRISM model, as well as the accompanying calculation. However, an in-depth analysis of PRISM is conducted in Daly et al. (2008). Estimating the true levels of uncertainty associated with spatial climate data sets is challenging and influenced by its own set of errors. With the exception of a relatively small number of observations, the true climate field is largely unknown. Even the known observations are subject to uncertainties. For more information on uncertainty with respect to temperature and precipitation data, see Daly et al. (2008).

An additional source of uncertainty exists within the spatial aggregation at both the climate division and nationwide scales. The NOAA climate division layer resolution used by this indicator is finer than that used by the WestWide Drought Tracker (the source of SPEI data). This resulted in small differences in output, as certain pixels were attributed to differing climate divisions, thereby influencing aggregative SPEI values. In coastal areas, EPA excluded SPEI values from 4-kilometer grid cells if a majority of the area lay outside the climate division layer. On the border between two or more climate divisions, EPA attributed the grid cell values to the climate division that most contained the pixel.

It is not clear how much uncertainty might be associated with the component indices that go into formulating the Drought Monitor or the process of compiling these indices into a single set of weekly values through averaging, weighting, and expert judgment.

11. Sources of Variability

Conditions associated with drought naturally vary from place to place and from one day to the next, depending on weather patterns and other factors. This indicator addresses spatial variability by presenting trends by climate division as well as aggregate national trends. Figures 1, 2, and 3 address temporal variability by using indices that are designed to measure long-term drought and are not easily swayed by short-term conditions. Figure 1 provides an annual average, along with a nine-year smoothed average. Figures 2 and 3 use a multi-year drought index, which minimizes annual and monthly variability and helps to better reflect changes in long-term drought/wet cycles. Examining trends over the data set's full period of record (1900–2023) accounts for any sizable interannual variability. Figure 4 smooths out some of the inherent variability in drought measurement by relying on many indices, including several with a long-term focus. While Figure 4 shows noticeable week-to-week variability, it also reveals larger year-to-year patterns.

12. Statistical/Trend Analysis

This indicator does not report on the slope of the trend in PDSI values over time, nor does it calculate the statistical significance of this trend. This information is currently not available from NOAA's NCEI.

As a first-order screening tool, EPA applied an ordinary least-squares linear regression to the national five-year SPEI time-series in Figure 2 and identified an overall trend toward wetter conditions at a rate of +0.034 SPEI units per year. This trend is statistically significant ($p < 0.05$). EPA also applied an ordinary least-squares regression to the five-year SPEI index data from 1900 to 2023 for each NOAA climate division. The slopes of the trendlines (change in SPEI value per year) are transformed into total change and colorized in Figure 3. Of a total of 344 climate divisions, 75 display negative trends in SPEI values and 269 display positive trends. A total of 258 of these trends (75 percent of climate divisions) are significant to a 95 percent level ($p < 0.05$).

Because data from the U.S. Drought Monitor are only available since 2000, this metric is too short-lived to be used for assessing long-term climate trends. With continued data collection, future versions of this indicator should be able to paint a more statistically robust picture of long-term trends in Drought Monitor values.

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