Drought

Identification

1. Indicator Description

This indicator measures drought conditions in the United States from 1895 to 2015. 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. An increase in evaporation 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 areas are likely to experience increased precipitation and increased risk of flooding, while areas far from storm tracks are likely to experience less precipitation and increased risk of drought.

Components of this indicator include:

- Average drought conditions in the contiguous 48 states over time, based on the Palmer Drought Severity Index (Figure 1).

- Percent of U.S. lands classified under drought conditions in recent years, based on an index called the U.S. Drought Monitor (Figure 2).

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 on EPA's website with data through 2012.
May 2014:	Updated indicator with data through 2013.
June 2015:	Updated indicator on EPA's website with data through 2014.
August 2016:	Updated indicator with data through 2015.

Data Sources

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 Figure 2 were provided by the U.S. Drought Monitor, which maintains current and archived data at: http://droughtmonitor.unl.edu.

4. Data Availability

Figure 1. Average Drought Conditions in the Contiguous 48 States, 1895–2015

NCEI 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: www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp. 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: ftp://ftp.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.ncdc.noaa.gov/data-access/land-based-station-data).

Figure 2. U.S. Lands Under Drought Conditions, 2000–2015

U.S. Drought Monitor data can be obtained from: http://droughtmonitor.unl.edu/MapsAndData/DataTables.aspx. Select "United States" 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 2015. Although data were available for parts of 1999 and 2016 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: http://droughtmonitor.unl.edu/SupplementalInfo/Links.aspx.

Methodology

5. Data Collection

Figure 1. Average Drought Conditions in the Contiguous 48 States, 1895–2015

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.ncdc.noaa.gov/data-access/land-based-station-data, and the National Weather Service technical manuals at: www.nws.noaa.gov/om/coop/training.htm. This indicator is derived from a specific quality-controlled subset of long-term stations that NCEI has designated as its *n*ClimDiv dataset (www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php).

Figure 2. U.S. Lands Under Drought Conditions, 2000–2015

Figure 2 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 (WRCC).
- A blend of objective short- and long-term drought indicators (short-term drought indicator blends focus on 1- to 3-month precipitation totals; long-term blends focus on 6 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 (NESDIS).
- Snow water content.
- River basin precipitation.
- The Surface Water Supply Index (SWSI).
- 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: http://drought.unl.edu/Planning/Monitoring/ComparisonofIndicesIntro.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, 1895–2015

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-km grid across the contiguous 48 states for each variable in the dataset, 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 2015 was the most recent year with data available, EPA calculated smoothed values to be centered at 2012, 2013, 2014, and 2015 by inserting the 2015 data point into the equation in place of the as-yet-unreported annual data points for 2016 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: ftp://ftp.ncdc.noaa.gov/pub/data/cirs/climdiv/divisional-readme.txt. NOAA's website provides additional information regarding the PDSI at: www.ncdc.noaa.gov/sotc/drought.

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.ncdc.noaa.gov/sotc/national/2013/3/supplemental/page-7.

Figure 2. U.S. Lands Under Drought Conditions, 2000–2015

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: http://droughtmonitor.unl.edu/AboutUs/ClassificationScheme.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 (http://droughtmonitor.unl.edu/AboutUs/ClassificationScheme.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.

7. Quality Assurance and Quality Control

Figure 1. Average Drought Conditions in the Contiguous 48 States, 1895–2015

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 dataset 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: http://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php. 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.

Figure 2. U.S. Lands Under Drought Conditions, 2000–2015

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, 1895–2015

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.

Figure 2. U.S. Lands Under Drought Conditions, 2000–2015

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 gives a broad overview of drought conditions in the United States. 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. 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.

5. The drought classification scheme used for Figure 2 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. 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. Both figures address spatial variability by presenting aggregate national trends. Figure 1 addresses temporal variability by using an index that is designed to measure long-term drought and is not easily swayed by short-term conditions. Figure 1 also provides an annual average, along with a nine-year smoothed average. Figure 2 smooths out some of the inherent variability in drought measurement by relying on many indices, including several with a long-term focus. While Figure 2 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.

Because data from the U.S. Drought Monitor are only available for the most recent decade, 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.

References

Karl, T.R., C.N. Williams, Jr., P.J. Young, and W.M. Wendland. 1986. A model to estimate the time of observation bias associated with monthly mean maximum, minimum, and mean temperatures for the Unites States. J. Clim. Appl. Meteorol. 25(1):145–160.

Palmer, W.C. 1965. Meteorological drought. Res. Paper No. 45. Washington, DC: U.S. Department of Commerce.

Svoboda, M., D. Lecomte, M. Hayes, R. Heim, K. Gleason, J. Angel, B. Rippey, R. Tinker, M. Palecki, D. Stooksbury, D. Miskus, and S. Stephens. 2002. The drought monitor. B. Am. Meteorol. Soc. 83(8):1181–1190.