Drought Indices

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Drought indices assimilate thousands of bits of data on rainfall, snowpack, streamflow, and other water supply indicators into a comprehensible big picture. A drought index value is typically a single number, far more useful than raw data for decision making.

There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms. Although none of the major indices is inherently superior to the rest in all circumstances, some indices are better suited than others for certain uses. For example, the Palmer Drought Severity Index http://www.cpc.ncep.noaa.gov/products/analysis_monitoring-/cdus/palmer_drought/, has been widely used by the U.S. Department of Agriculture to determine when to grant emergency drought assistance, but the Palmer is better when working with large areas of uniform topography. Western states, with mountainous terrain and the resulting complex regional microclimates, find it useful to supplement Palmer values with other indices such as the Surface Water Supply Index http://drought.unl.edu/whatis/indices.htm#swsi, which takes snowpack and other unique conditions into account.

The National Drought Mitigation Center http://www.drought.unl.edu/-index.htm, is using a newer index, the Standardized Precipitation Index http://lwf.ncdc.noaa.gov/oa/climate/-research/prelim/drought/spi.html, to monitor moisture supply conditions. Distinguishing traits of this index are that it identifies emerging droughts months sooner than the Palmer Index and that it is computed on various time scales.

Most water supply planners find it useful to consult one or more indices before making a decision. What follows is an introduction to

each of the major drought indices in use in the United States and in Australia.

1 Percent of Normal

The percent of normal precipitation is one of the simplest measurements of rainfall for a location. Analyses using the percent of normal are very effective when used for a single region or a single season. Percent of normal is also easily misunderstood and gives different indications of conditions, depending on the location and season. It is calculated by dividing actual precipitation by normal precipitation—typically considered to be a 30-year mean—and multiplying by 100%. This can be calculated for a variety of time scales. Usually these time scales range from a single month to a group of months representing a particular season, to an annual or water year. Normal precipitation for a specific location is considered to be 100%.

One of the disadvantages of using the percent of normal precipitation is that the mean, or average, precipitation is often not the same as the median precipitation, which is the value exceeded by 50% of the precipitation occurrences in a long-term climate record. The reason for this is that precipitation on monthly or seasonal scales does not have a normal distribution. Use of the percent of normal comparison implies a normal distribution where the mean and median are considered to be the same. An example of the confusion this could create can be illustrated by the long-term precipitation record in Melbourne, Australia, for the month of January. The median January precipitation is 36.0 mm (1.4 in.), meaning that in half the years less than 36.0 mm is recorded, and in half the years more than 36.0 mm is recorded. However, a monthly January total of 36.0 mm would be only 75% of normal when compared to the mean, which is often considered to be quite dry. Because of the variety in the precipitation records over time and location, there is no way to determine the frequency of the departures from normal or compare different locations. This makes it difficult to link a value of a departure with a specific impact occurring as a result of the departure, inhibiting attempts to mitigate the risks of drought based on the departures from normal and form a plan of response.

2 Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is a relatively new drought index based only on precipitation. The SPI can be used to monitor conditions on a variety of time scales. This temporal flexibility allows the SPI to be useful in both short-term agricultural and long-term hydrological applications.

The SPI values are given in Table 1.

The understanding that a deficit of precipitation has different impacts on groundwater, reservoir storage, soil moisture, snowpack, and streamflow led T. B. McKee, N. J. Doesken, and J. Kleist Colorado State University, to develop the Standardized Precipitation Index (SPI) in 1993. The SPI was designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of the different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short scale. Groundwater, streamflow, and reservoir storage reflect the longer-term precipitation anomalies. For these reasons, McKee et al. originally calculated the SPI for 3-, 6-, 12-, 24-, and 48-month time scales.

The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero. Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. Because the SPI is normalized, wetter and drier climates can be represented in the same way, and wet periods can also be monitored using the SPI.

McKee et al. used the classification system shown in the SPI values table to define drought intensities resulting from the SPI. McKee et al. also defined the criteria for a drought event for any of the time scales. A drought event occurs any time the SPI is continuously negative and reaches an intensity of –1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and an intensity for each month that the event continues. The positive sum of the SPI for

all the months within a drought event can be termed the drought's "magnitude".

Based on an analysis of stations across Colorado, McKee determined that the SPI is in mild drought 24% of the time, in moderate drought 9.2% of the time, in severe drought 4.4% of the time, and in extreme drought 2.3% of the time. Because the SPI is standardized, these percentages are expected from a normal distribution of the SPI. The 2.3% of SPI values within the "Extreme Drought" category is a percentage that is typically expected for an "extreme" event (Wilhite 1995). In contrast, the Palmer Index reaches its "extreme" category more than 10% of the time across portions of the central Great Plains. This standardization allows the SPI to determine the rarity of a current drought, as well as the probability of the precipitation necessary to end the current drought.

The SPI has been used operationally to monitor conditions across Colorado since 1994. Monthly maps of the SPI for Colorado can be found on the Colorado State University website http://ccc.atmos.colostate.edu/standardizedprecipitation.php, It is also being monitored at the climate division level for the contiguous United States by the National Drought Mitigation Center and the Western Regional Climate Center (WRCC).

3 Palmer Drought Severity Index (PDSI)

In 1965, W.C. Palmer developed an index to measure the departure of the moisture supply. See Table 2. The Palmer Drought Index is based on a supply-and-demand model of soil moisture. Supply is comparatively straightforward to calculate, but demand is more complicated as it depends on many factors - not just temperature and the amount of moisture in the soil but hard-to-calibrate factors including evapotranspiration and recharge rates. Palmer tried to overcome these difficulties by developing an algorithm that approximated them based on the most readily available data —precipitation and temperature. See also *Evapotranspiration*.

The PDSI is a meteorological drought index, and it responds to weather conditions that have been abnormally dry or abnormally wet. When conditions change from dry to normal or wet, for example, the drought measured by the PDSI ends without taking into account streamflow, lake and reservoir levels, and other longer-term

hydrologic impacts. The PDSI is calculated based on precipitation and temperature data, as well as the local Available Water Content (AWC) of the soil. From the inputs, all the basic terms of the water balance equation can be determined, including evapotranspiration, soil recharge, runoff, and moisture loss from the surface layer. Human impacts on the water balance, such as irrigation, are not considered. Complete descriptions of the equations can be found in the original study by Palmer and in the more recent analysis by Alley.

Palmer developed the PDSI to include the duration of a drought (or wet spell). His motivation was as follows: an abnormally wet month in the middle of a long-term drought should not have a major impact on the index, or a series of months with near-normal precipitation following a serious drought does not mean that the drought is over. Therefore, Palmer developed criteria for determining when a drought or a wet spell begins and ends, which adjust the PDSI accordingly. Palmer described this effort and gave examples, and it is also described in detail by Alley. In near-real time, Palmer's index is no longer a meteorological index but becomes a hydrological index referred to as the Palmer Hydrological Drought Index (PHDI) because it is based on moisture inflow (precipitation), outflow, and storage, and does not take into account the long-term trend.

In 1989, a modified method to compute the PDSI was begun operationally. This modified PDSI differs from the PDSI during transition periods between dry and wet spells. Because of the similarities between these Palmer indices, the terms *Palmer Index* and *Palmer Drought Index* have been used to describe general characteristics of the indices.

The Palmer Index varies roughly between –6.0 and +6.0. Palmer arbitrarily selected the classification scale of moisture conditions based on his original study areas in central Iowa and western Kansas. Ideally, the Palmer Index is designed so that a –4.0 in South Carolina has the same meaning in terms of the moisture departure from a climatological normal as a –4.0 in Idaho. The Palmer Index has typically been calculated on a monthly basis, and a long-term archive of the monthly PDSI values for every climate division in the United States exists with the National Climatic Data Center from 1895 through the present. In addition, weekly Palmer Index values (actually modified PDSI values) are calculated for the climate divisions

during every growing season and are available in the *Weekly Weather and Crop Bulletin*. These weekly Palmer Index maps are also available on the World Wide Web from the Climate Prediction Center at http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/-regional_monitoring/palmer.gif.

The Palmer Index is popular and has been widely used for a variety of applications across the United States. It is most effective measuring impacts sensitive to soil moisture conditions, such as agriculture. It has also been useful as a drought monitoring tool and has been used to trigger actions associated with drought contingency plans. Alley identified three positive characteristics of the Palmer Index that contribute to its popularity: (1) it provides decision makers with a measurement of the abnormality of recent weather for a region; (2) it provides an opportunity to place current conditions in historical perspective; and (3) it provides spatial and temporal representations of historical droughts. Several states, including New York, Colorado, Idaho, and Utah, use the Palmer Index as one part of their drought monitoring systems.

There are considerable limitations when using the Palmer Index, and these are described in detail by Alley and Karl and Knight. Drawbacks of the Palmer Index include:

· The values quantifying the intensity of drought and signaling the beginning and end of a drought or wet spell were arbitrarily selected based on Palmer's study of central Iowa and western Kansas and have little scientific meaning.

· The Palmer Index is sensitive to the AWC of a soil type. Thus, applying the index for a climate division may be too general.

· The two soil layers within the water balance computations are simplified and may not be accurately representative of a location.

· Snowfall, snow cover, and frozen ground are not included in the index. All precipitation is treated as rain, so that the timing of PDSI or PHDI values may be inaccurate in the winter and spring months in regions where snow occurs.

· The natural lag between when precipitation falls and the resulting runoff is not considered. In addition, no runoff is allowed to take place in the model until the water capacity of the surface and subsurface soil layers is full, leading to an underestimation of runoff.

· Potential evapotranspiration is estimated using the Thornthwaite method. This technique has wide acceptance, but it is still only an approximation.

Several other researchers have presented additional limitations of the Palmer Index. McKee et al. suggested that the PDSI is designed for agriculture but does not accurately represent the hydrological impacts resulting from longer droughts. Also, the Palmer Index is applied within the United States but has little acceptance elsewhere. One explanation for this is provided by Smith et al., who suggested that it does not do well in regions where there are extremes in the variability of rainfall or runoff. Examples in Australia and South Africa were given. Another weakness in the Palmer Index is that the "extreme" and "severe" classifications of drought occur with a greater frequency in some parts of the country than in others. "Extreme" droughts in the Great Plains occur with a frequency greater than 10%. This limits the accuracy of comparing the intensity of droughts between two regions and makes planning response actions based on a certain intensity more difficult.

4 Surface Water Supply Index (SWSI)

The Surface Water Supply Index (SWSI; pronounced "Swazee") was developed by Shafer and Dezman to complement the Palmer Index for moisture conditions across the state of Colorado. The Palmer Index is basically a soil moisture algorithm calibrated for relatively homogeneous regions, but it is not designed for large topographic variations across a region and it does not account for snow accumulation and subsequent runoff. Shafer and Dezman designed the SWSI to be an indicator of surface water conditions and described the index as "mountain water dependent", in which mountain snowpack is a major component.

The objective of the SWSI was to incorporate both hydrological and climatological features into a single index value resembling the Palmer Index for each major river basin in the state of Colorado (Shafer and Dezman 1982). These values would be standardized to allow comparisons between basins. Four inputs are required within the SWSI: snowpack, streamflow, precipitation, and reservoir storage. Because it is dependent on the season, the SWSI is computed with only snowpack, precipitation, and reservoir storage in the

winter. During the summer months, streamflow replaces snowpack as a component within the SWSI equation.

The procedure to determine the SWSI for a particular basin is as follows: monthly data are collected and summed for all the precipitation stations, reservoirs, and snowpack/streamflow measuring stations over the basin. Each summed component is normalized using a frequency analysis gathered from a long-term data set. The probability of non-exceedence—the probability that subsequent sums of that component will not be greater than the current sum—is determined for each component based on the frequency analysis. This allows comparisons of the probabilities to be made between the components. Each component has a weight assigned to it depending on its typical contribution to the surface water within that basin, and these weighted components are summed to determine a SWSI value representing the entire basin. Like the Palmer Index, the SWSI is centered on zero and has a range between –4.2 and +4.2.

The SWSI has been used, along with the Palmer Index, to trigger the activation and deactivation of the Colorado Drought Plan. One of its advantages is that it is simple to calculate and gives a representative measurement of surface water supplies across the state. It has been modified and applied in other western states as well. These states include Oregon, Montana, Idaho, and Utah. Monthly SWSI maps for Montana are available from the Montana Natural Resource Information System http://nris.state.mt.us/wis/SWSInteractive/.

Several characteristics of the SWSI limit its application. Because the SWSI calculation is unique to each basin or region, it is difficult to compare SWSI values between basins or regions. Within a particular basin or region, discontinuing any station means that new stations need to be added to the system and new frequency distributions need to be determined for that component. Additional changes in the water management within a basin, such as flow diversions or new reservoirs, mean that the entire SWSI algorithm for that basin needs to be redeveloped to account for changes in the weight of each component. Thus, it is difficult to maintain a homogeneous time series of the index. Extreme events also cause a problem if the events are beyond the historical time series, and the index will need to be reevaluated to include these events within the frequency distribution of a basin component.

5 Reclamation Drought Index

The Reclamation Drought Index (RDI) (Table 3) was recently developed as a tool for defining drought severity and duration, and for predicting the onset and end of periods of drought. The impetus to devise the RDI came from the Reclamation States Drought Assistance Act of 1988, which allows states to seek assistance from the Bureau of Reclamation to mitigate the effects of drought.

Like the SWSI, the RDI is calculated at a river basin level, and it incorporates the supply components of precipitation, snowpack, streamflow, and reservoir levels. The RDI differs from the SWSI in that it builds a temperature-based demand component and a duration into the index. The RDI is adaptable to each particular region and its main strength is its ability to account for both climate and water supply factors.

Oklahoma has developed its own version of the RDI and plans to use the index as one tool within the monitoring system designated in the state's drought plan. The RDI values and severity designations are similar to the SPI, PDSI, and SWSI.

6 Deciles

Arranging monthly precipitation data into deciles is another drought-monitoring technique. It was developed by Gibbs and Maher to avoid some of the weaknesses within the "percent of normal" approach. The technique they developed divided the distribution of occurrences over a long-term precipitation record into tenths of the distribution. They called each of these categories a *decile*. The first decile is the rainfall amount not exceeded by the lowest 10% of the precipitation occurrences. The second decile is the precipitation amount not exceeded by the lowest 20% of occurrences. See Table 4. These deciles continue until the rainfall amount identified by the tenth decile is the largest precipitation amount within the long-term record. By definition, the fifth decile is the median, and it is the precipitation amount not exceeded by 50% of the occurrences over the period of record. The deciles are grouped into five classifications.

The decile method was selected as the meteorological measurement of drought within the Australian Drought Watch System because

it is relatively simple to calculate and requires less data and fewer assumptions than the Palmer Drought Severity Index. In this system, farmers and ranchers can only request government assistance if the drought is shown to be an event that occurs only once in 20–25 years (deciles 1 and 2 over a 100-year record) and has lasted longer than 12 months. This uniformity in drought classifications, unlike a system based on the percent of normal precipitation, has assisted Australian authorities in determining appropriate drought responses. One disadvantage of the decile system is that a long climatological record is needed to calculate the deciles accurately.

NOTE: This article is a US Government work and, as such, is in the public domain in the United States of America.

Additional Reading

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Table 1. SPI Values

2.0+	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
–.99 to .99	near normal
–1.0 to –1.49	moderately dry
–1.5 to –1.99	severely dry
–2 and less	extremely dry

Table 2. Palmer Classifications

4.0 or more	extremely wet
3.0 to 3.99	very wet
2.0 to 2.99	moderately wet
1.0 to 1.99	slightly wet
0.5 to 0.99	incipient wet spell
0.49 to –0.49	near normal
–0.5 to –0.99	incipient dry spell
–1.0 to –1.99	mild drought
–2.0 to –2.99	moderate drought
–3.0 to –3.99	severe drought
–4.0 or less	extreme drought

Table 3. RDI Classifications

4.0 or more	extremely wet
1.5 to 4.0	moderately wet
1 to 1.5	normal to mild wetness
0 to –1.5	normal to mild drought
–1.5 to –4.0	moderate drought
–4.0 or less	extreme drought

Table 4. Decile Classifications

Deciles 1–2: lowest 20%	much below normal
Deciles 3–4: next lowest 20%	below normal
deciles 5–6: middle 20%	near normal
deciles 7–8: next highest 20%	above normal
deciles 9–10: highest 20%	much above normal