AUBURN UNIVERSITY
ALABAMA AGRICULTURAL EXPERIMENT STATION
Water Resources Center

extension
ALABAMA A&M & AUBURN UNIVERSITIES

NATIONAL INTEGRATED DROUGHT INFORMATION SYSTEM
NIDIS
Drought.gov
U.S. Drought Portal

TRIGGERS AND INDICATORS

TOOLS FOR IDENTIFYING AND MANAGING DROUGHT

The purpose of this module is to present drought management techniques, especially those pertaining to triggers and indicators. The article explores various approaches to monitoring, forecasting, identifying, and responding to drought and attempts to highlight the benefits of available tools while pointing out some of their limitations.

Authors:
Ryan McGehee, M.S., E.I.
Puneet Srivastava, Ph.D., P.E.

What is Drought?

Although it may be surprising to hear, there is no single definition of drought. However, perhaps the simplest definition is ***an event or action that causes a shortage of water*** (less than is normally needed to supply the needs of the environment and society for a given area). This is a very broad definition because water needs range from precipitation to streamflow to irrigation to storage or even just moisture in the soil and in the atmosphere. Drought can be caused by natural climate and weather events impacting the amount of precipitation and moisture in any given area or by human action through excessive use.

Drought is usually categorized as one of the three types: ***meteorological drought*** (low precipitation or humidity; high temperatures and low cloud cover; high evapotranspiration and winds; etc.), ***agricultural drought*** (low soil moisture; withered vegetation; low yields; etc.), or ***hydrologic drought*** (low runoff and streamflow; low groundwater and recharge; decreased water tables and lake levels; etc.). Some droughts can be more of one of these types depending on how the water shortage has developed. For instance, large and infrequent storms may lead to low soil moisture between events causing agricultural drought while still maintaining lake levels and streamflows.

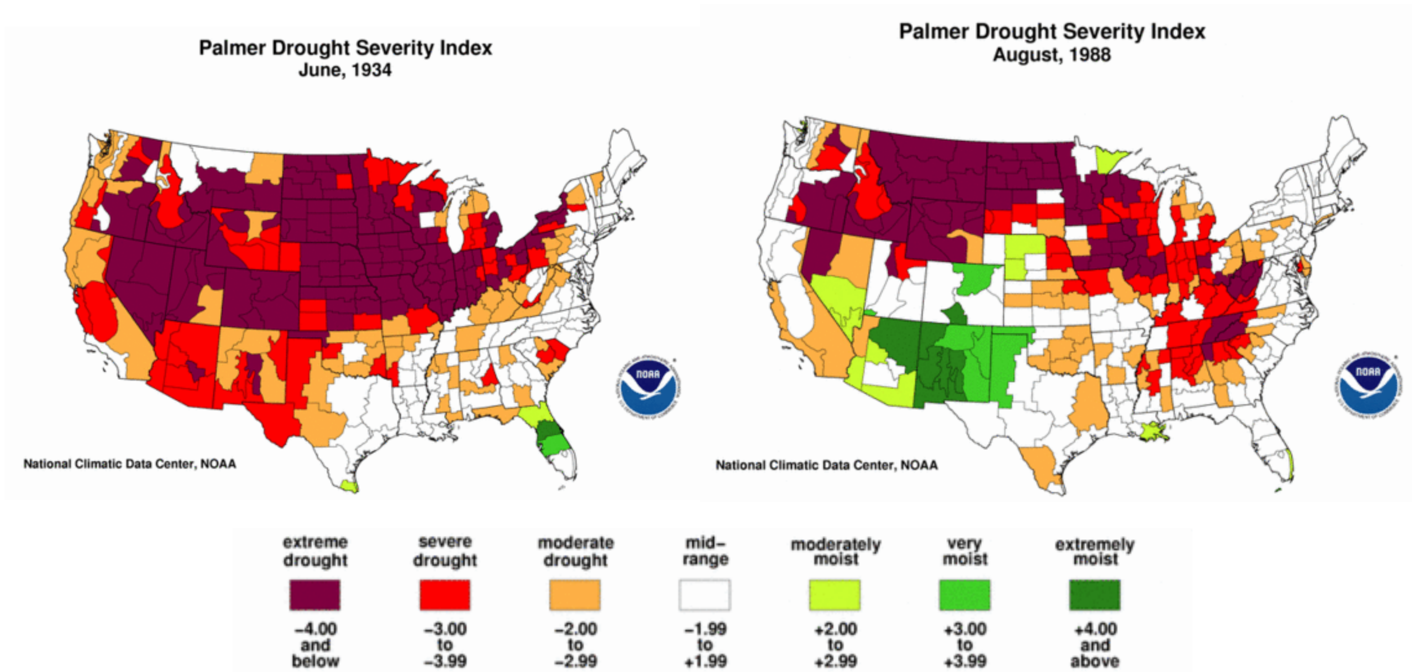
Why Manage Drought?

Drought is expensive! In terms of economic cost, drought frequently registers among other major natural disasters like floods, blizzards, and hurricanes that can run in the billions of dollars! Drought also comes with significant environmental costs and societal impacts. These range from added burden on endangered species, reduced water quality and supply, and worsened human health and increased fatalities from heat waves and dehydration. Therefore, ***we manage drought to mitigate (reduce) the negative impacts of drought on the economy, the environment, and society as a whole***.

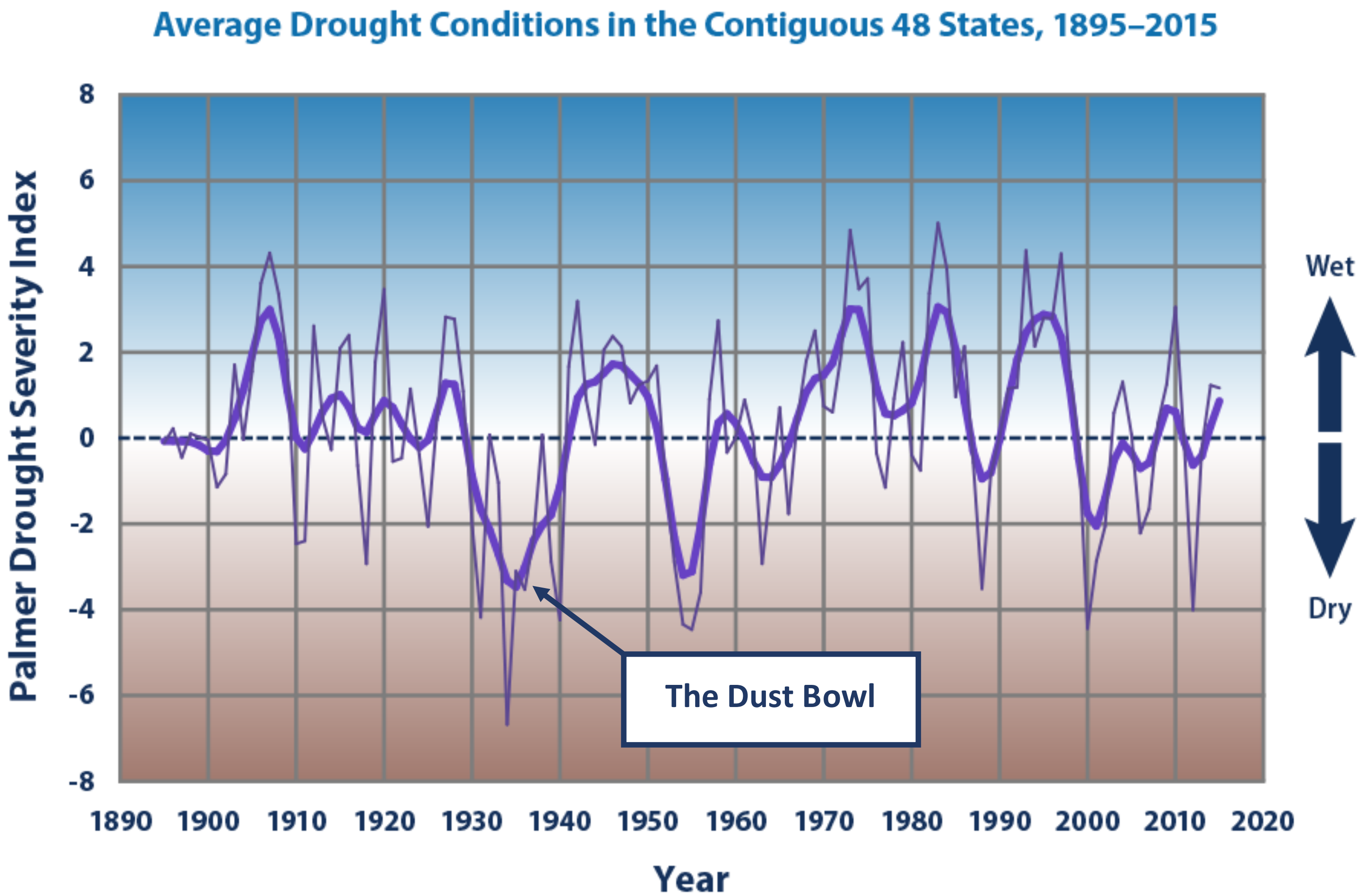
Historical Drought

Drought has occurred in the United States regularly as far back as records can indicate. Droughts vary in their severity (how intense they are), area (how widespread they are) and frequency (how often they occur). Some droughts like in the 1930's were widespread, intense, and occurred in multiple waves. Others impacted specific areas of the country with varying intensity, such as the droughts of 1980, 1988, 2007, 2012, and many more. The figure below shows the extent and severity of two well-known droughts in June of 1934 and August of 1988. This figure uses the Palmer Drought Severity Index (PDSI) to represent drought conditions (explained later). The drought in 1934 was part of several waves of drought that hit the country between 1930 and 1940. Combined with poor agricultural practices and the unique dry, windy climate of the Great Plains, this drought led to the Dust Bowl. The drought in 1988 is known because of its economic impact of 39 billion dollars—a sum of more than 80 billion dollars today!

Although we only mention a few notable droughts in this module, an important point for the reader to understand is that droughts occur almost continuously in the United States. Many times drought occurs only as one or two of the types of drought or only in a particular location or with moderate severity. Even mild droughts, if they occur frequently over several years, can have a highly damaging effect on ecology and the environment. Excluding low-intensity and regional droughts, the United States still sees widespread drought almost every decade. This is illustrated in the figure on the following page, which shows the PDSI for the contiguous United States for the years 1895 to 2011. In this figure, drought severity and frequency (for the contiguous 48 states) are easy to see. The country is equally wet and dry when PDSI equals zero.



Palmer Drought Severity Index (PDSI) for two well-known droughts in the United States: the drought of the 1930's (linked to the Dust Bowl) and the drought of 1988 (costliest drought in United States history). Note differences in severity and extent. (Adapted from NOAA NCEI).



Average drought conditions represented by the Palmer Drought Severity Index (PDSI) from 1895 to 2011. Negative values indicate that the contiguous 48 states were more dry than wet overall. Annual PDSI is shown in thin red with time-averaged PDSI in bold. (Credit: NOAA NCEI).

Drought Management Strategy

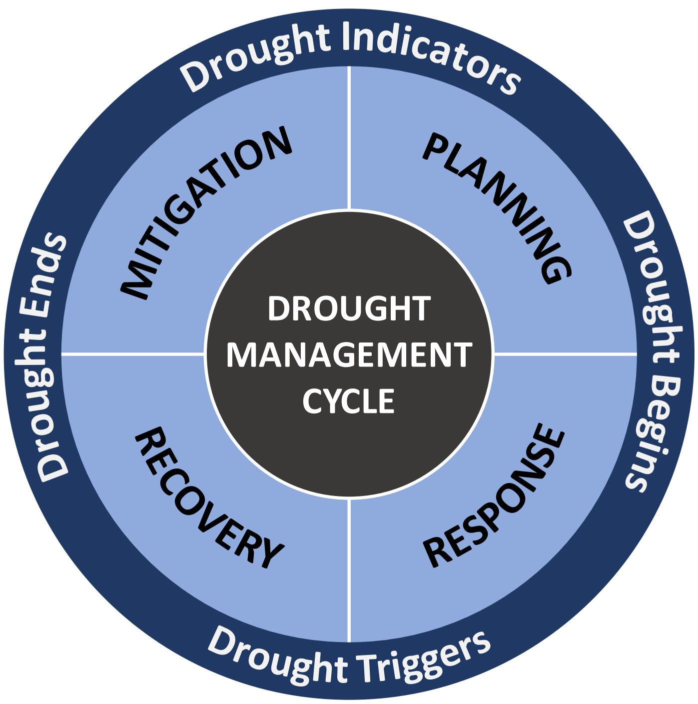
There are four steps in a disaster management cycle including: response, recovery, mitigation, and planning. This section is included to point out differences in general disaster management and drought management, which can be quite different from each other. ***The two largest differences in most disaster management and drought management are a prolonged response phase and a recovery phase beginning during the drought event itself.***

In the case of most disasters, an event (e.g. a flood event) is quick and most of the damage occurs in a very short period of time. However, in the case of drought, the event itself can last for months or years, and there is usually a rather slow onset before a state of drought is declared. Thus, the response phase of drought management can be much longer than that of other disasters. Also, recovery is generally a long process for most disasters. For drought, this is also true although the damage to infrastructure is usually not as significant, but damage to the environment and ecosystem is significant. Recovery in drought management is usually referring to recovering lake levels or soil moisture, which may recover quickly. However, it is easy to forget ecological damage caused by drought and these aspects of environmental recovery should also be considered.

The other two phases of management are identical for both drought and other disasters. When we develop in ways that are resilient to drought and disasters, it is called mitigation.

Planning refers to pre-event preparedness and policy changes that reduce impacts of drought or disaster during and post-event. Mitigation and planning phases always take place between events. The following figure displays the phases of drought management in the context of a hypothetical drought event.

In addition to the generic phases of drought management, there are two essential tools used in drought management. These include what we call triggers and indicators. Triggers are primarily used in response to developing or receding drought conditions, and indicators are used almost continuously (although they are mostly used to communicate current drought conditions and future drought outlooks or risk).



A generic drought management cycle including the four phases of management: Response-Recovery-Mitigation-Planning. The primary use of indicators and triggers are shown respective to the development and recession of a drought.

Drought Indicators

The first of the two drought management tools are called indicators. As mentioned above, indicators play a significant role in monitoring and communicating drought, but they are often confused with drought indices. To eliminate this confusion, we have included the definition of each of these below.

***Indicators** are variables or parameters used to describe drought conditions.*

Examples of indicators include precipitation, temperature, evapotranspiration, soil moisture, streamflow, lake levels, groundwater levels, snowpack, and drought indices (which are also indicators of drought themselves).

Physically-Based Indicators

Indicators can be either directly measured or indirectly measured. Those which are indirectly measured have been converted into numerical representations of one or more indicators and are discussed more thoroughly below. Those that are directly measured we call physically-based because they are readily observable in the physical world. There are many of these types of indicators, but the two most popular physically-based indicators are water level measurements for lakes / reservoirs and depth to groundwater.

Physically-based indicators (and triggers for that matter) are preferred for their ease of use, understanding, and communication of drought. They are relatively easy to monitor, especially since water markers and groundwater wells are commonly employed in water monitoring and management. A third and equally widespread physical indicator is rain. Rain is observed and recorded using rain gauges. The problem with using rain as opposed to groundwater or lake water is that rain is not a good indicator of long-term drought or human-induced drought. In addition to the logistical issue of keeping up with previous rainfall / precipitation (most of these gauges only keep 24 hours of rainfall), precipitation can be more difficult for the public to understand due to unfamiliarity with typical precipitation amounts and lower visibility than other measures. This is not very surprising since most people, even those involved in these areas, cannot distinguish a 0.5-inch storm event from a 2-inch event. Even groundwater can be a difficult concept for some, since most have never seen it. Therefore, the most visible of the physically-based indicators which also does a fairly good job communicating lasting effects of drought is lake water level. The following figures show how each of these physical indicators are 'directly' measureable.

A water marker (left), USGS groundwater well (right), and NCAR precipitation gauge (bottom), which are used to measure surface water levels, depth to groundwater, and rainfall (or precipitation), respectively (Image Credit: USGS and NCAR).

Indices as Indicators of Drought

Remember that drought indices are themselves indicators of drought. So, what distinguishes drought indices from their physically-based counterparts?

***Indices** are computed numerical representations of a drought's intensity (they are not directly measured).*

From these definitions, we can understand that drought indicators are used to compute drought indices, and indices are themselves an indicator of drought. In other words, ***drought indices are based on drought indicators***. According to Zargar et al. (2011), drought indices can serve any of the following purposes:

- Detecting / Monitoring Drought in Real-Time
- Declaring Beginning and Ending of Drought
- Declaring Drought Levels and Responses
- Evaluating Drought Parameters
- Representing Regional Drought Concepts
- Correlating Drought with Associated Impacts
- Communicating Drought to Various Entities

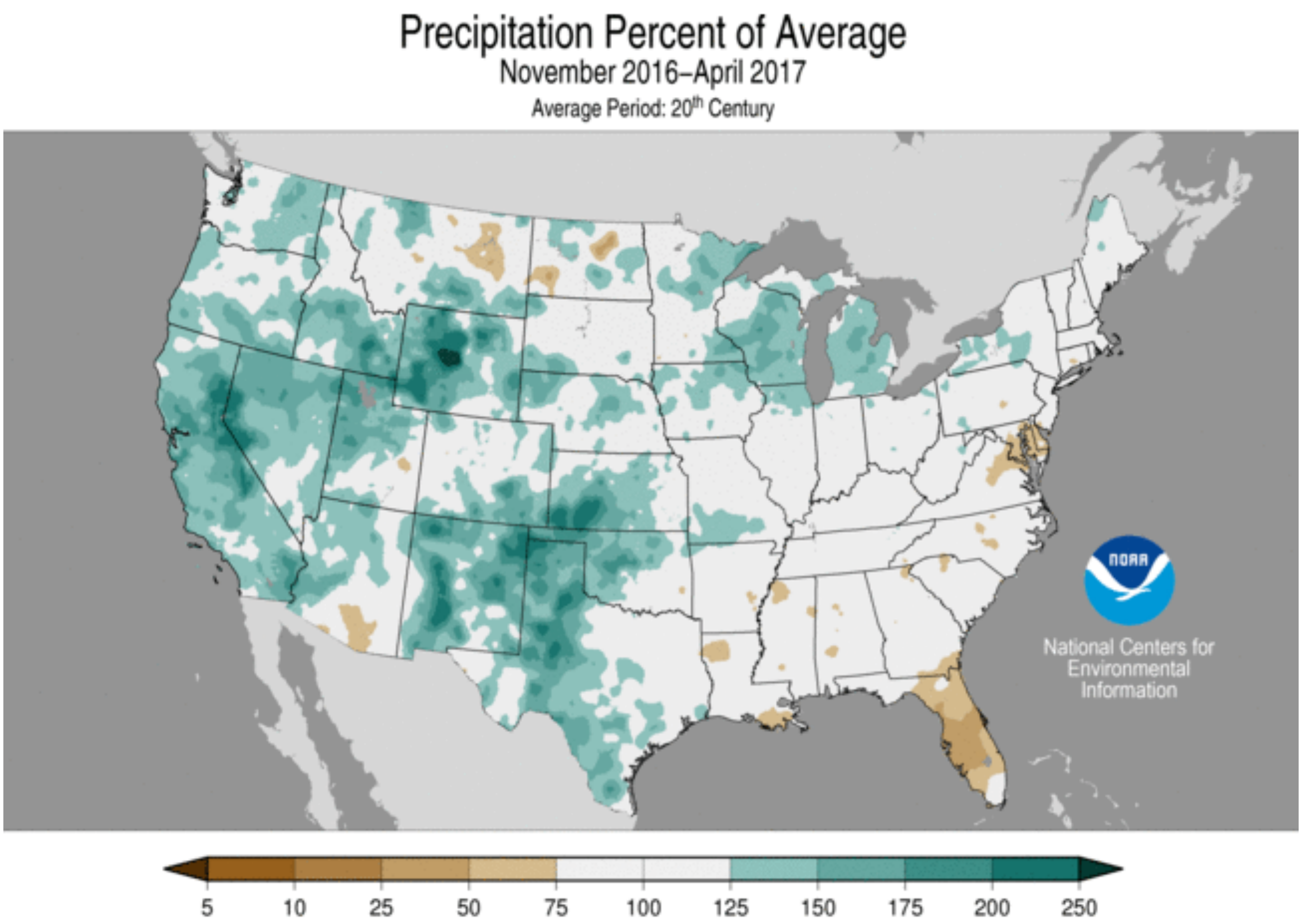
There are at least 150 unique drought indices at the time of this writing. Many of these unique indices are based on the same indicators. The most popular indicator used in many indices may be obvious to you because we generally associate a lack of it to drought—and that is precipitation. There are dozens of indices that use this one variable in their computation. Some use only this variable while others use a wide variety. These indices also vary in their complexity. Five of the most popular drought indices are summarized on the following pages (with related figures to help visualize different methods used to represent the same period—November 2016 to April 2017). Each indice is followed by a brief discussion of its advantages and disadvantages. You will see that there is no single indice that is best in every scenario, but you will also see that some are much more popular than others due to their various strengths and/or applicability.

Percent of Normal Precipitation

The simplest meteorological drought index is the percent of normal precipitation. This index describes drought as a percent deviation from normal—the last 30 years or longer. This index is calculated by dividing observed precipitation by the average of the last 30 years for the same time period. Thus, this measure can be used at different time scales (i.e. monthly, seasonal, annual, decadal, etc.). The same analysis can be applied to any meteorological, hydrological, agricultural, or other type of variable. However, precipitation is the most common.

Pros: The method is simple. Most of the public understands precipitation and what is normal. Thus, this measure is ideal to communicate drought to the public.

Cons: Precipitation is not normally distributed (it is skewed right—meaning that there are many more small events than large ones), and differences in the mean and median values can impact its accuracy. Since every region and time of the year have unique distributions, this method is not robust (it cannot be applied in a wide range of distributions).



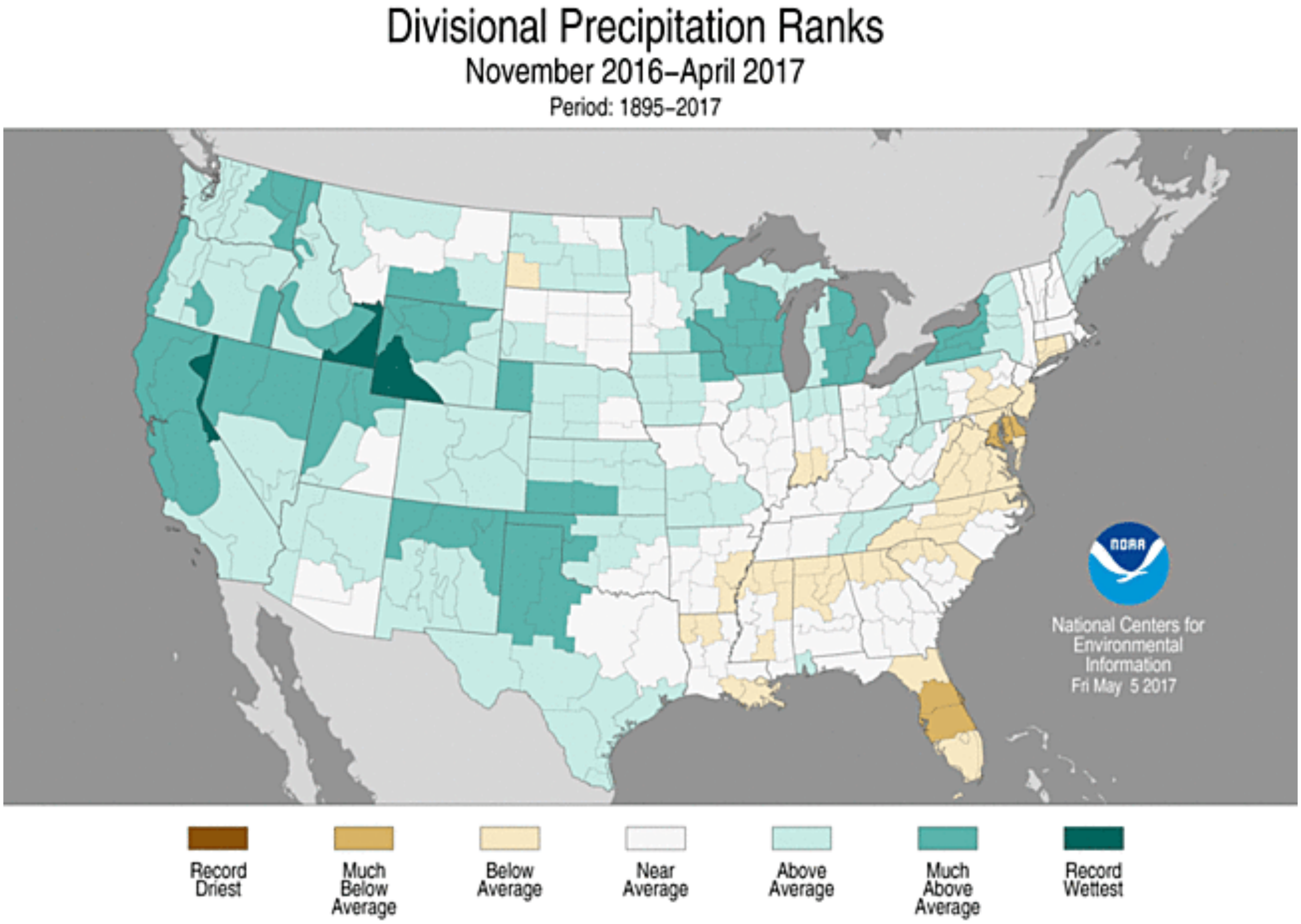
The percent of normal precipitation for November 2016 to April 2017 (1900 to 2000 was used as the 'normal' period for comparison). (Credit: NOAA NCEI).

Precipitation Deciles

The name deciles comes from dividing a data distribution into 10 equal parts of 10%. This measure can also be computed for other types of variables and for any time period preferred. Usually, the lowest 10% decile is of the most interest, and it may be divided into two parts: the lowest 5% (severe drought) and the second lowest 5% (serious drought), respectively. The United States does not currently produce true decile maps, but it produces a similar product called precipitation ranks. Rather than using 10% increments, this method simply uses the values rank. For a hypothetical drought, the precipitation decile method may report serious drought (falling in the 5% to 10% category—or the lowest decile), but the rank method would just report, for example, the 7th driest year on record (assuming about 100 years of data). Australia does produce true decile maps and can be found using a simple web search.

Pros: This method is still relatively simple, and it is based on a probabilistic distribution, which gives it an edge over the percent of normal.

Cons: An accurate calculation of deciles or ranks for any variable requires a significant amount of data.



The divisional precipitation ranks (similar to precipitation deciles) for November 2016 to April 2017 (1895 to 2017 was used as the ranking period). Ranks not shown. (Credit: NOAA NCEI).

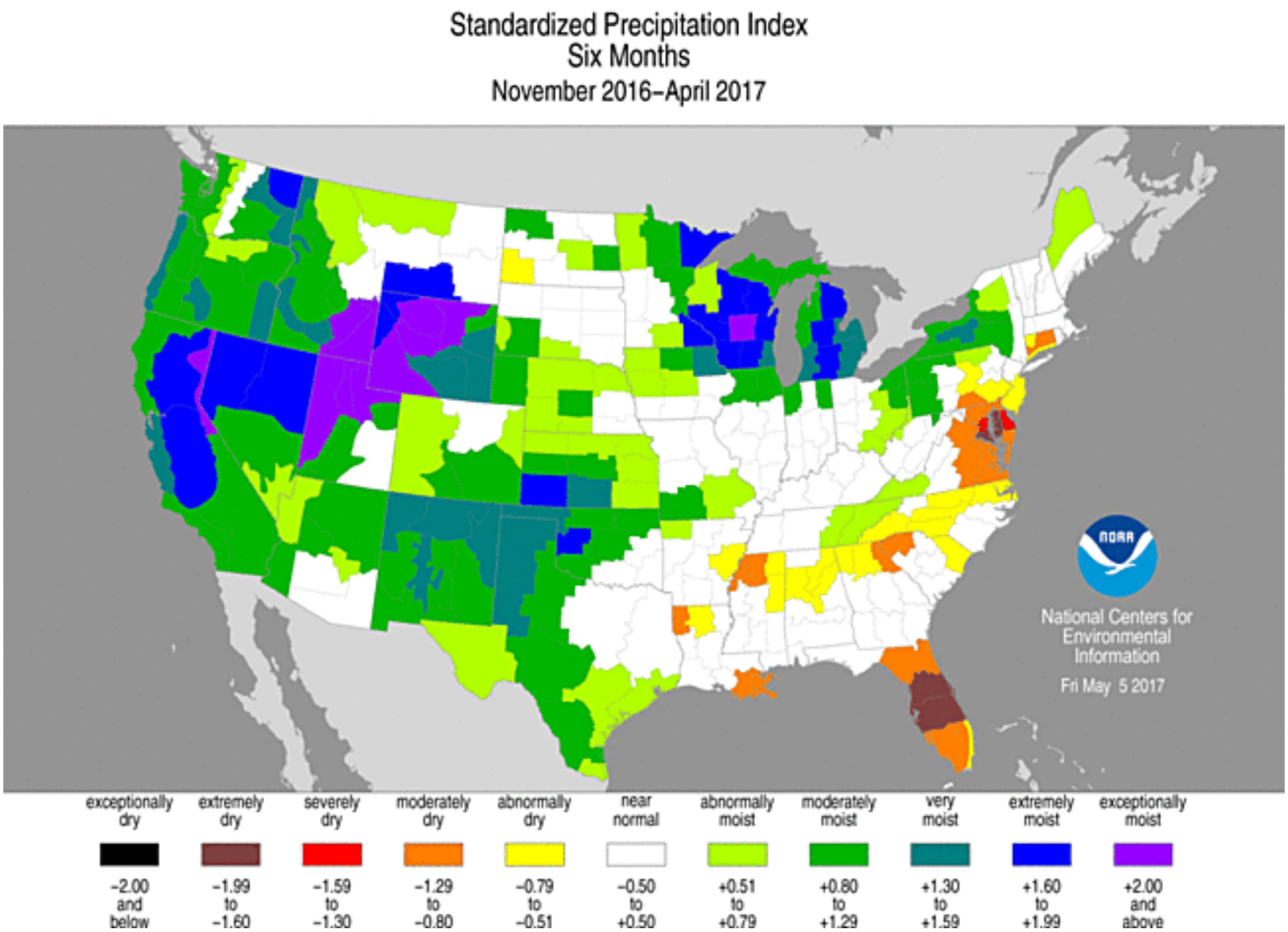
Standardized Precipitation Index (SPI)

SPI is perhaps the most widespread and most widely accepted meteorological drought indice in the world. Meteorological indices are the most common, especially since drought tends to develop meteorologically first. In 2009, the World Meteorological Organization selected SPI as the 'best meteorological index' so that a common index for drought could be compared among different countries, regions, and time periods (WMO, 2009).

SPI is similar to the percent of normal precipitation in that it is also based solely on precipitation data, but it is different in that it applies a transformation to the precipitation distribution—overcoming weaknesses of the percent of normal index. Precipitation data are fitted to a gamma distribution which is then transformed into a normal distribution using an equal probability transformation (McKee et al. 1993). The mean is set equal to zero with the SPI score representing standard deviations above or below the mean. Consistent values of -1 or lower are considered drought conditions. As with other methods, SPI can be calculated over different time scales with 3, 6, 12, 24, and 48 months the most popular options. Typically, 50 years of data is recommended, but 30 is sufficient when it is not available.

Pros: Due to the distribution transformation, SPI can be used in any climate or region, which is ideal when looking at large spatial scales or long spans of time (i.e. global climate change). SPI is also useful for describing wet periods in statistically relevant terms to drought. Still, SPI only uses precipitation data (keeping it simple compared to other more complicated methods).

Cons: The main limitation to SPI, like other meteorological methods, is that it is loosely connected to impacts since it only uses precipitation in its calculation. Consequently, other methods may be more suitable for assessing hydrologic and agricultural types of drought as well as impacts of drought.



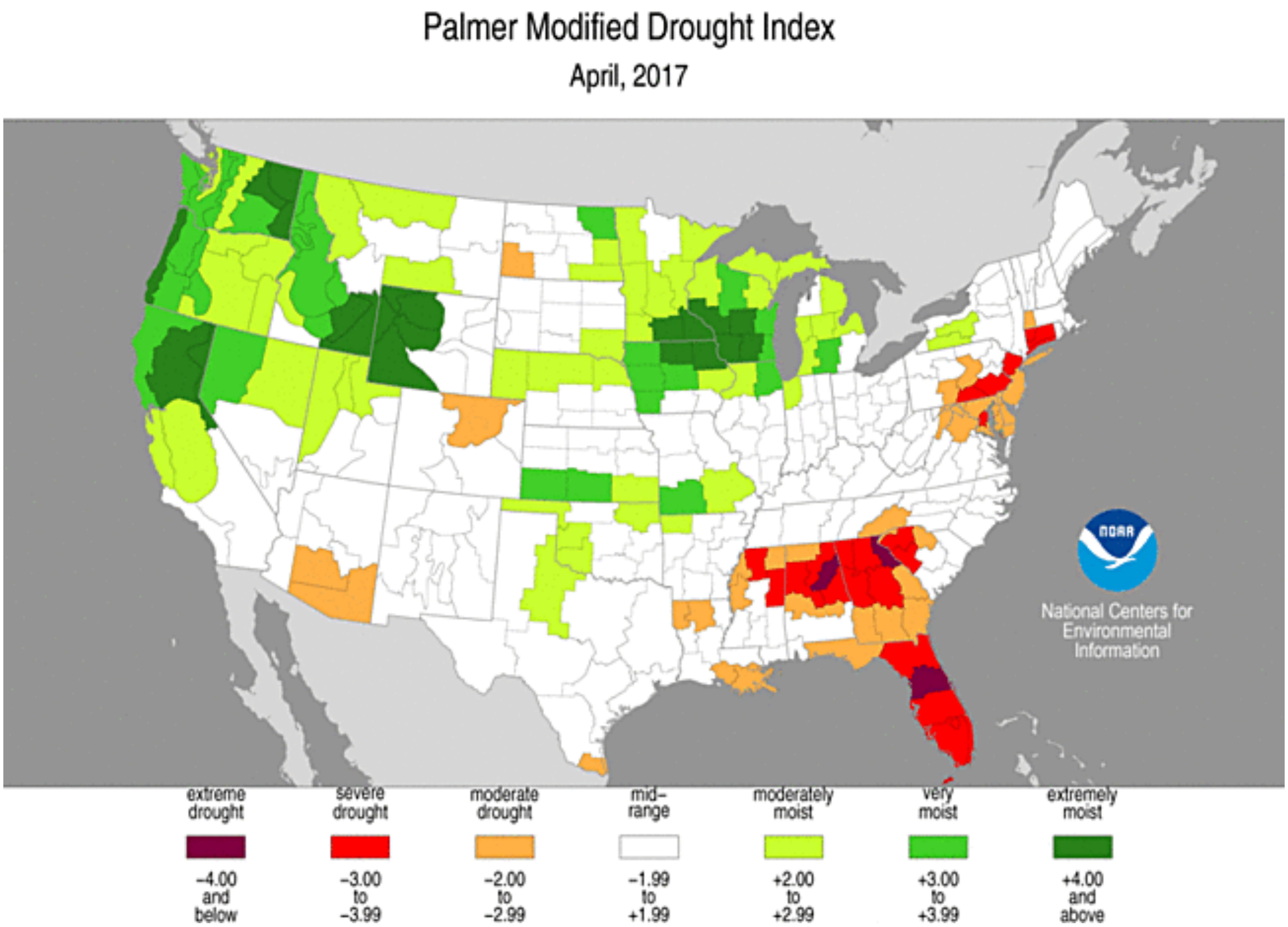
The 6-month Standardized Precipitation Index (SPI) for November 2016 to April 2017. (Credit: NOAA NCEI).

Palmer Drought Severity Index (PDSI)

A meteorological index that is popular in the United States is the Palmer Drought Severity Index (Palmer, 1965). PDSI is a comprehensive meteorological index (meaning that it considers more variables than just precipitation in its computation). Although the exact calculation of PDSI is too complicated and lengthy to include in this module, the most important variables used in its calculation include: precipitation, temperature, and local available water content (AWC). Additionally, calculated derivatives of these variables are used to determine PDSI, which include: runoff, evapotranspiration, soil recharge, and moisture. In short, PDSI looks at water availability and demand as opposed to just the precipitation anomaly (i.e. SPI).

Pros: The values calculated from PDSI are more relevant for impacts (especially for those linked to soil water availability). Another major benefit of this method is the incorporation of antecedent conditions.

Cons: PDSI calculations are significantly more complicated than other meteorological indices, which not only makes it more difficult to find enough data, but it also reduces transparency in communicating drought. The method has been heavily criticized for its simple calculation of evapotranspiration, runoff lag, and snow thaw as well as its exclusion of critical water management variables such as reservoirs, snowfall, and irrigation (Zargar et al., 2011).



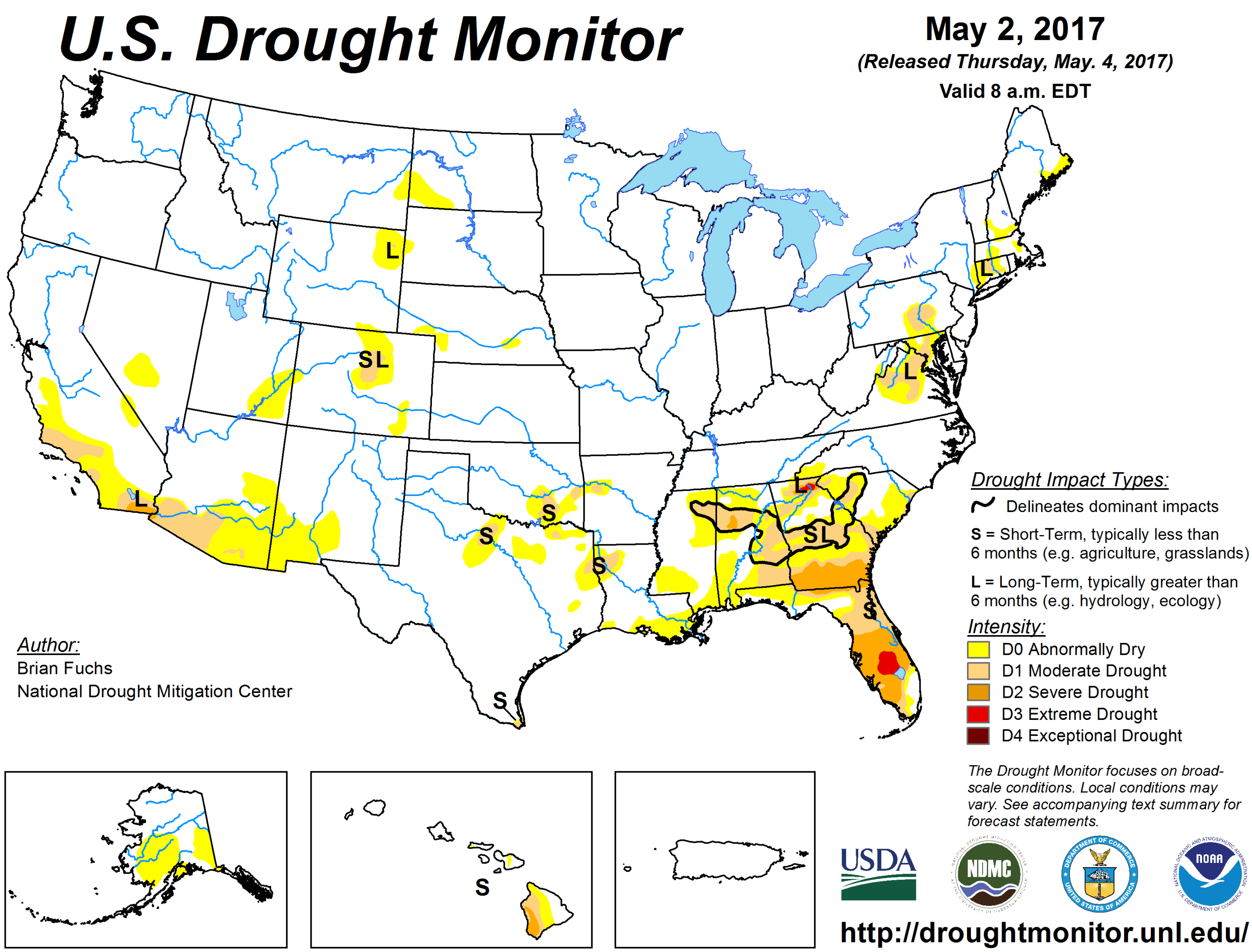
The Palmer Modified Drought Index (PMDI), which is similar to the Palmer Drought Severity Index (PDSI) for April 2017. The main difference in the two methods regards changing beginning and ending drought/wet periods. (Credit: NOAA NCEI).

U.S. Drought Monitor (USDM)

The most complicated and the only composite drought index summarized in this module is the U.S. Drought Monitor (USDM). The USDM is a composite index in the sense that it utilizes multiple indices in its computation and those indices are not solely meteorological in nature. Some USDM inputs are listed on the next page.

> ***[USDM] Numeric inputs include:*** *the Palmer Drought Severity Index (PDSI), the Standardized Precipitation Index (SPI), and other climatological inputs; the Keech-Byram Drought Index for fires, satellite-based assessments of vegetation health, and soil moisture from data assimilation systems and other models; and hydrologic data, particularly in the West, such as the Surface Water Supply Index and snowpack.*

USDM in particular is quite a unique index indeed. Not only does the USDM synthesize large amounts of and all types of data in its analysis, but it also diverges from other indices in that it ***"…relies on experts to synthesize the best available data from multiple sources and work with local observers to localize the information as much as possible."*** (NDMC, 2014). The USDM has also seen the most success in communicating drought severity and extent to the public.



The U.S. Drought Monitor (USDM) for the week of May 2, 2017. USDM is produced collaboratively by a large team of authors (11 who rotate responsibilities of the weekly map) and a long list of contributors who provide locally relevant portions of the data. The map (and associated data) are synthesized at the National Drought Mitigation Center (NDMC) who then provides the map and data to NOAA, USDA, and other associated agencies. (Credit: NDMC).

Pros: There is not a more comprehensive and locally relevant index of drought of which we are aware. This index incorporates all aspects of drought from meteorological to agricultural to hydrological indicators, indices, and impacts of drought. The USDM benefits from being the most publicly recognizable index of drought and most established index in US news media.

Cons: The USDM synthesizes large quantities and many types of data, and it is compiled by a team of 11 authors who rotate responsibilities bi-weekly. This effort is also supported by an extensive list of contributors headed by state climatologists in each state. Even with all the data and information available, no individual could reproduce this index. Also, since this index is exclusively for the United States, it cannot be extended to other parts of the world for comparing drought and drought impacts. Other indices may also better serve different scales, especially smaller scales, since USDM may be too coarse for smaller applications.

Drought Triggers

Even with reliable and accurate prediction and monitoring technology through which we could communicate the risks and realities of drought, there is no guarantee that this new knowledge could be translated to better management. That is where triggers come into the picture. Triggers are mostly used to establish actionable responses to observed drought conditions. This includes actions to reduce drought impacts by conserving resources during the development of drought as well as actions to transition back to normal management when drought recedes. So what exactly are triggers?

> ***Triggers*** *are thresholds of an indicator or index that initiate and/or terminate actions of a drought management plan.*

We can see from this definition that triggers are generally based on indicators, and just like indicators, they can be physically-derived or index-derived.

Index-Derived Triggers

Any of the more than 150 drought indices can be used as the basis for a trigger. Often what this means is that a municipality or agency or some other entity finds that a particular index or a combination of several indices accurately and reliably capture drought conditions and/or impacts for their respective area. When this happens, that entity will devise actionable thresholds at which conservation plans or drought plans can be enacted in time to prevent or reduce major economic, environmental, or social impacts from drought. For example, a city may ban residential use of water to wash cars when SPI drops below a value of -1. The city may take further more drastic action as the SPI value continues to drop, and these uses may not necessarily be reestablished until SPI recovers to a value of -0.5 or 0 for a certain amount of time.

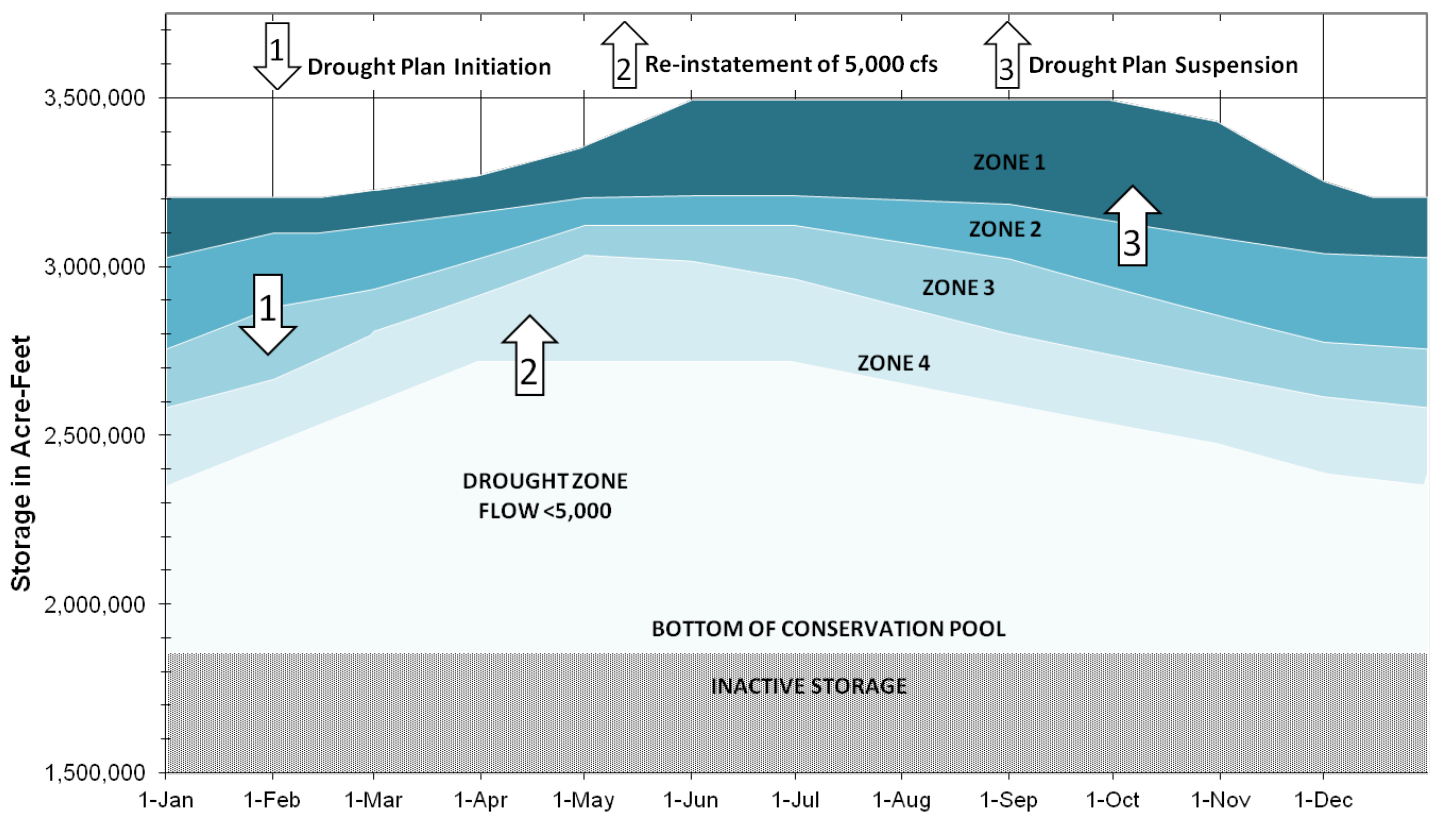
Pros: Triggers drawing on indices can be much more robust (successfully applied at larger spatial scales, over longer time periods, and across more diverse climate regions) than physical variables. These also benefit from the statistical transformations and or analyses that better connect them to real impacts of drought.

Cons: Index-based triggers may be much less visible to the public in particular since these are not usually a part of the typical person’s media diet. Fortunately, these are based at some point on physical variables, but it is generally harder to communicate those connections.

Physically-Derived Triggers

The second group of drought triggers includes those which can be physically measured or observed. Some of these can be measured more easily than others. The most popular of these is reservoir storage elevation (i.e. lakes). This is a popular measure because it is usually directly linked to municipal and industrial water supply as well as to recreational activities for the public (water access for boating, fishing, swimming, etc.). In almost all cases, governing authorities have a very good idea of how much water is normally available to meet the typical needs of their jurisdiction. Therefore, drought triggers based on physical water supply sources are highly effective for communicating drought impacts to decision-makers and those who commonly use those water resources.

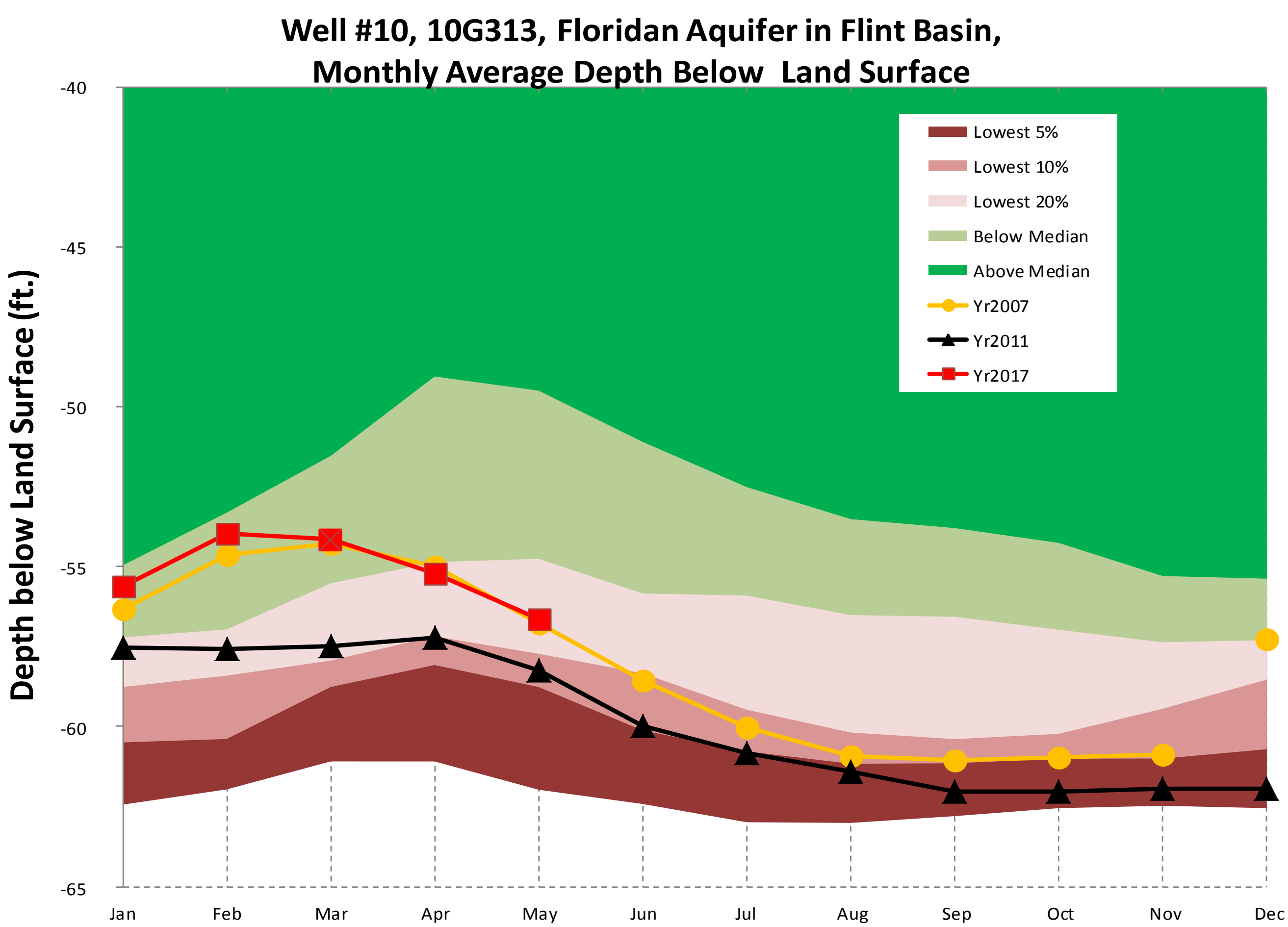
In the Apalachicola-Chattahoochee-Flint (ACF) River Basin, a highly contentious basin for water resource allocations, the US Army Corps of Engineers (USACE) utilizes reservoir levels to manage its water resources in both normal conditions and drought (see the figure below). What makes this a robust trigger is that their management of drought is based on water availability as opposed to meteorological conditions. Since drought can be caused by human actions (such as excessive use and inefficient management) as well as natural phenomena (i.e. low precipitation), this type of trigger will initiate conservation measures for natural drought or human-induced drought. Since most drought indices are meteorological in nature, ***triggers based on physically-based indicators rather than indices can more effectively respond to different types of drought, especially those that are agricultural and hydrologic in nature.***



The composite storage and composite action zones for the ACF River Basin, which act as drought triggers and are used to initiate and suspend the drought contingency plan (DCP) outlined in the Revised USACE Master Water Control Manual (USACE, 2017). In this example, the USACE initiates a drought management plan when storage drops into 'Zone 3'. Management becomes more extreme as the storage drops into the 'Drought Zone', and extreme drought measures are initiated if the 'Conservation Storage' is exhausted and 'Inactive Storage' is utilized. As conditions return to normal, a minimum flow of 5,000 cfs is reinstated in 'Zone 4' and the drought plan is suspended if storage returns to 'Zone 1'. Please reference the USACE Master Water Control Manual for more information about USACE management of water and drought in the ACF River Basin.

A less common alternative—yet still a highly effective one—is depth to groundwater. This is still relatively easy to measure/monitor and only slightly less transparent to the public. This is primarily useful where groundwater is used for water supply. The Flint River portion of the ACF serves a large percentage of agriculture in Georgia. Most of this agriculture is irrigated by groundwater/well fed pumping. Since drought can impact groundwater recharge, it can also reduce groundwater available for irrigation. Hence, drought triggers based on groundwater may prove to be highly effective for these areas of the state while informing users of drought as it relates to their businesses and livelihoods.

Georgia's Environmental Protection Division (EPD) publishes a special monthly report during times of drought called the "Drought Indicators Report" in which they monitor eight different drought indicators. Among these indicators, one is depth to groundwater (measured by groundwater wells). Most of the wells included in this report are located in the Flint River portion of the ACF, an area where groundwater may be an important indicator of drought. In this region, groundwater indicators are great candidates for drought triggers, especially those managing responses to agricultural and hydrological droughts, which tend to be slower to develop and slower to recover. Although Georgia EPD does not currently use groundwater triggers for management, the figure below is an example of what a potential groundwater trigger may look like.



Monthly measures of depth to groundwater for a groundwater well in the Floridan Aquifer system (in the Flint River Basin). More negative values indicate more severe drought. Similar to the previous figure, action zones could be established at, for example, the lowest 10% or 5% measures that would help to conserve water during drought (Image Credit: Georgia EPD).

Pros: Physically-derived triggers are highly visible. This is important to remember when communicating to the public. When most may or may not connect well with SPI, USDM, or even rainfall normals, there is still a common understanding of things like lake levels and streamflow.

Cons: Making connections between physical variables and economic impacts or drought severity can be difficult, especially in different regions. Imagine comparing a drop of several feet in lake elevation for one of the Great Lakes and for a relatively small lake in Georgia. Indices can take those differences into account, whereas the raw physical variables cannot.

Summary

The most important lesson to learn from this module is that drought, drought impacts, and drought management tools are unique; not all droughts are the same. Droughts can occur as a result of natural processes or human actions. They can be meteorological, agricultural, or hydrologic in nature (or a combination of the three). The tools we use must be capable of performing well under all types of drought and their respective impacts on the environment, the economy, and society. Therefore, the tools we use (including both triggers and indicators) must also be diverse and robust enough to handle these different circumstances. Although there is not a single solution for monitoring and managing drought, there are popular choices, and these management tools have varying strengths and weaknesses to address the many regions, climates, impacts, and droughts that we see every year around the world.

References

McKee, T.B., N.J. Doesken, and J. Kleist. 1993. The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference on Applied Climatology, Anaheim, Calif. 17–22 January 1993. American Meteorological Society.

National Center for Atmospheric Research (NCAR). Marshall Field Info. Available at: https://www.rap.ucar.edu/projects/winter/sites/marshall/show_instrument.php?inst=82

National Drought Mitigation Center (NDMC). 2014. What is the U.S. Drought Monitor? http://droughtmonitor.unl.edu/data/docs/USDMbrochure.pdf

National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI). State of the Climate: Drought Report (April 2017). https://www.ncdc.noaa.gov/sotc/drought/201704

State of Georgia, Department of Natural Resources (DNR), Environmental Protection Division (EPD). Drought Indicators Reports, June 2017. Available at: https://epd.georgia.gov/water-conservation

United States Army Corps of Engineers (USACE) Mobile District. 2017. Master Water Control Manual: Apalachicola-Chattahoochee-Flint (ACF) River Basin.

United States Geological Survey (USGS). California Water Science Center. Available at: https://ca.water.usgs.gov/sustainable-groundwater-management/images/manual-groundwater-level-measurements.jpg

World Meteorological Organization (WMO). 2009. Lincoln declaration on drought indices. www.wmo.int/pages/prog/wcp/agm/meetings/wies09/documents/Lincoln_Declaration_Drought_Indices.pdf

Zargar, A., R. Sadhiq, B. Naser, and F. I. Khan. 2011. A Review of drought indices. Environ. Rev. 19: 333–349 (2011). doi:10.1139/A11-013