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# Drought in the United States: Causes and Current Understanding

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## Summary

Drought is a natural hazard, often with significant societal, economic, and environmental consequences. Public policy issues related to drought range from how to identify and measure drought to how best to prepare for, mitigate, and respond to drought impacts, and who should bear associated costs. Severe droughts in 2011 and 2012 in Texas and the midcontinent region, the current drought in California and parts of other western states, and 15 years of dry conditions in the Southwest have fueled congressional interest in drought and its near-term effects on water supplies and agriculture, as well as in long-term issues, such as drought forecasting and possible links between drought and human-induced climate change.

Some part of the country is almost always experiencing drought at some level. Since 2000, no less than 6.6% of the land area of the United States has experienced drought of at least moderate intensity each year. The land area affected by drought of at least moderate intensity varies by year and also within a particular year. For example, since 2000, the total U.S. land area affected by drought of at least moderate intensity has varied from as little as 6.6% (July 6, 2010) to as much as 55% (September 25, 2012). Based on weekly estimates of drought conditions since 2000, the average amount of land area across the United States affected by at least moderate-intensity drought has been 27%.

What is drought? Drought has a number of definitions; the simplest may be a deficiency of precipitation over an extended time period, usually a season or more, compared with average conditions. Higher demand for water for human activities and vegetation in areas of limited water supply, and warmer conditions, increase the severity of drought. For example, drought during the growing season may be considered more severe—in terms of its impacts—than similar conditions when cropland lies fallow.

Some scientists refer to severe drought as a recurring natural disaster in North America. Reconstructions of drought conditions that extend back over 1,000 years—based on observations, historical and instrumental records, and tree rings—illustrate that portions of the conterminous United States have experienced periods of severe and long-lasting drought termed *megadroughts*. For example, drought reconstructions from tree rings document that severe multi-decadal drought occurred in the American Southwest during the 13<sup>th</sup> century. These megadroughts have affected flows in major western rivers. For example, during the years 1130-1154, estimated Colorado River flows were less than 84% of normal. Recent data suggest that Colorado River flows since 2000 are approaching those previous lows—flows have been below average for 13 of the 15 years between 2000 and 2014.

One question is whether the parts of the United States, in particular the American Southwest, including California, may be experiencing the beginning of a modern-era megadrought. Because such megadroughts occurred previously, there is the possibility of a return to the long-term drought conditions experienced in previous centuries. Further, some postulate that droughts could be exacerbated if the future climate is warmer due to the buildup of greenhouse gases in the atmosphere. Predicting the severity and persistence of severe drought over a specific region of the country, however, is not yet possible more than a few months in advance because of the many factors that influence drought (e.g., precipitation, heat, soil moisture). The prospect of extended droughts and more arid baseline conditions—possibly exacerbated by greenhouse gas-driven warmer temperatures—in parts of the United States may challenge existing public policy responses for preparing for and responding to drought.

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## Introduction

This report discusses how drought is defined (e.g., why drought in one region of the country is different from drought in another region) and why drought occurs in the United States. It also discusses how droughts are classified and what is meant by moderate, severe, and extreme drought classifications. The report briefly describes periods of drought in the country's past that equaled or exceeded drought conditions experienced during the 20<sup>th</sup> century. This description is followed by a discussion of the nature and extent of recent droughts that affected Texas and the U.S. midcontinent and the current drought in California. Last, the report discusses prospects for a climate in the western United States that might be drier than the average 20<sup>th</sup>-century climate and the possible influence of human-induced climate change.

The likelihood of extended periods of severe drought, similar to conditions experienced centuries ago, and its effects on 21<sup>st</sup>-century society in the United States raise several issues for Congress. These issues include how to respond to recurrent drought incidents, how to prepare for future drought, and how to coordinate federal agency actions, among other policy choices. A discussion of these issues is beyond the scope of this report.<sup>1</sup>

## Drought in the United States—Overview

Drought has affected portions of North America throughout history. Severe, long-lasting droughts may have been a factor in the disintegration of Pueblo society in the Southwest during the 13<sup>th</sup> century and in the demise of central and lower Mississippi Valley societies in the 14<sup>th</sup> through 16<sup>th</sup> centuries.<sup>2</sup> In the 20<sup>th</sup> century, droughts in the 1930s (Dust Bowl era) and 1950s were particularly severe and widespread. In 1934, 65% of the contiguous United States was affected by severe to extreme drought,<sup>3</sup> resulting in widespread economic disruption and displacement of populations from the U.S. heartland—many relocating to California's Central Valley—and revealing shortcomings in agricultural and land-use practices.

Drought conditions are broadly grouped into five categories: (D0) abnormally dry, (D1) moderate, (D2) severe, (D3) extreme, and (D4) exceptional.<sup>4</sup> Some part of the country is almost always experiencing drought at some level. Since 2000, no less than 6.6% of the land area of the United States has experienced drought of at least moderate intensity each year (See **Figure 1**).<sup>5</sup> The land area affected by drought of at least moderate intensity varies by year and also within a particular year. For example, since 2000, the total U.S. land area affected by drought of at least

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<sup>1</sup> For a discussion of various policy issues regarding drought, see, for example, CRS Report IF10196, *Drought Policy, Response, and Preparedness*, by (name redacted) and (name redacted); CRS Report IF10133 *California Drought: Water Supply and Conveyance Issues*, by (name redacted); CRS Report R43408 *Emergency Water Assistance During Drought: Federal Non-Agricultural Programs*, by (name redacted), (name redacted), and (name redacted), among others.

<sup>2</sup> Edward R. Cook, et al., "North American drought: reconstructions, causes, and consequences," *Earth-Science Reviews*, vol. 81 (2007): pp. 93-134. Hereinafter, referred to as Cook et al., 2007.

<sup>3</sup> Donald A. Wilhite, et al., *Managing Drought: A Roadmap for Change in the United States* (Boulder, CO: The Geological Society of America, 2007), p. 12, at <http://www.geosociety.org/meetings/06drought/roadmap.pdf>.

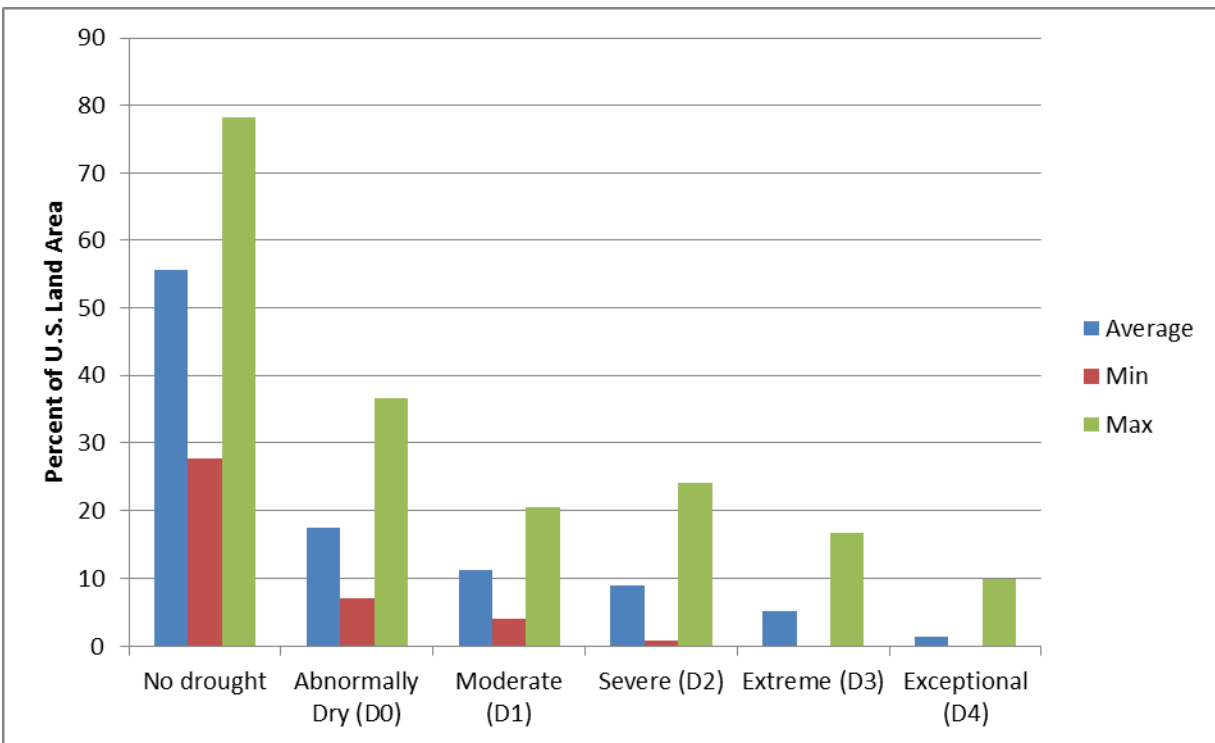
<sup>4</sup> These are the categories used by the National Drought Mitigation Center (NDMC). The NDMC helps prepare the U.S. Drought Monitor and maintains its website.

<sup>5</sup> NDMC data collected since 2000. U.S. Drought Monitor at the NDMC in Lincoln, NE. See <http://droughtmonitor.unl.edu/MapsAndData/DataTables.aspx>.

moderate intensity (D1-D4) has varied from as little as 6.6% (July 6, 2010) to as much as 55% (September 25, 2012). Based on weekly estimates of drought conditions since 2000, on average about 27% of the land area across the United States has been affected by at least moderate-intensity drought.

While the previous percentages refer to the extent of drought nationally, there is particular concern about those locations experiencing the most intense drought conditions: *extreme* and *exceptional* drought. Nearly every year, extreme drought (D3) affects some portion of the country. Since 2000, extreme drought or drier conditions have affected approximately 6.5% of the nation on average.<sup>6</sup> (See **Figure 1.**) Since 2000, exceptional drought (D4) conditions have affected approximately 1.4% of the nation on average. Of particular note were the conditions between June 2011 and October 2011: exceptional drought occurred over the largest land area—greater than 9%—during those months, with the affected areas concentrated in Texas. The following year, during August 2012, extreme and exceptional drought extended over 20% of the country and was concentrated in the midsection of the United States.

**Figure 1. Average, Minimum, and Maximum Percentage of the U.S. Land Area by Drought Category**  
(January 4, 2000, through May 19, 2015)



**Source:** U.S. Drought Monitor, Tabular Data Archive, <http://droughtmonitor.unl.edu/MapsAndData/DataTables.aspx>. Modified by CRS.

**Notes:** Including Alaska, Hawaii, and Puerto Rico.

<sup>6</sup> In some years or months, however, no part of the country was under extreme or exceptional drought. For example, from January 2000 through early April 2000, extreme or exceptional drought did not affect any portion of the country.

## What Is Drought?

Drought has a number of definitions; the simplest may be a deficiency of precipitation over an extended period of time, usually a season or more.<sup>7</sup> Drought is usually considered relative to some long-term average condition or balance between precipitation, evaporation, and transpiration by plants (evaporation and transpiration are typically combined into one term: *evapotranspiration*).<sup>8</sup> An imbalance could result from a decrease in precipitation, an increase in evapotranspiration (from drier conditions, higher temperatures, higher winds), or both. It is important to distinguish between drought, which has a beginning and an end, and aridity, which is restricted to low-rainfall regions and is a relatively permanent feature of an area's climate (e.g., deserts are regions of relatively permanent aridity).<sup>9</sup>

Higher demand for water for human activities and vegetation in areas of limited water supply increases the severity of drought. For example, drought during the growing season likely would be considered more severe—in terms of its impacts—than similar conditions when cropland lies fallow. For policy purposes, drought often becomes an issue when it results in a water supply deficiency. With deficiencies, less than the average amount of water is available for irrigation, municipal and industrial (M&I) supply, energy production, preservation of endangered species, and other needs. These impacts can occur through multiple mechanisms, such as decreased precipitation and soil moisture affecting dryland farming; low reservoir levels decreasing allocations for multiple purposes (including irrigation, navigation, energy production, recreation, fish and wildlife needs, and other water supplies); low stream flows limiting withdrawals for multiple purposes, including M&I supplies, among others; and decreased exchange of water in lakes resulting in water quality problems limiting recreation (e.g., blue-green algae restrictions in multiple lakes in Oklahoma and Texas during 2011 and 2012 drought conditions). At the national level, drought is monitored and reported by the National Drought Mitigation Center in an index known as the U.S. Drought Monitor, which synthesizes various drought indices and impacts, and represents a consensus view between academic and federal scientists of ongoing drought conditions. Drought also can relate and contribute to other phenomena, such as fires and heat waves.<sup>10</sup>

## Drought Classification

To assess and classify the intensity and type of drought, certain measures, or drought indices, are typically used. Drought intensity, in turn, is the trigger for local, state, and federal responses that can lead to the flow of billions of dollars in relief to drought-stricken regions.<sup>11</sup> The classification

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<sup>7</sup> NDMC, “What Is Drought?” at <http://www.drought.unl.edu/DroughtBasics/WhatIsDrought.aspx>.

<sup>8</sup> Evapotranspiration may be defined as the loss of water from a land area through transpiration from plants and evaporation from the soil and surface water bodies such as lakes, ponds, and man-made reservoirs.

<sup>9</sup> Permanently arid conditions reflect the *climate* of the region, which is the composite of the day-to-day weather over a longer period of time. Climatologists traditionally interpret climate as the 30-year average. See NDMC, “What is Climatology?” at <http://www.drought.unl.edu/DroughtBasics/WhatIsClimatology.aspx>.

<sup>10</sup> For more on fire, see CRS Report R43077, *Wildfire Management: Federal Funding and Related Statistics*, by (name redacted) and (name redacted).

<sup>11</sup> For example, the Palmer Drought Index has been widely used by the U.S. Department of Agriculture to determine when to grant emergency drought assistance. See NDMC, <http://drought.unl.edu/Planning/Monitoring/ComparisonofIndicesIntro/PDSI.aspx>.

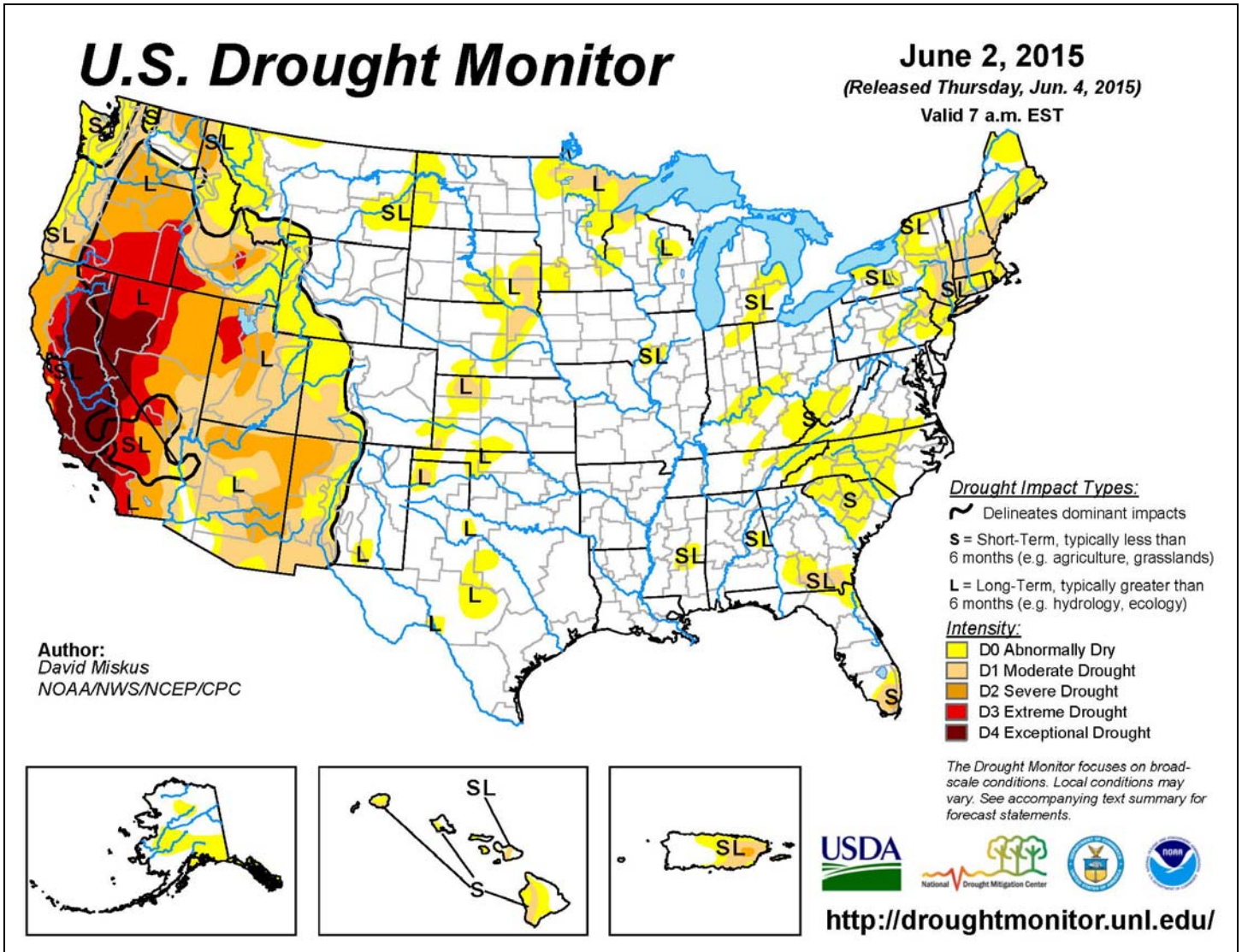
of drought intensity, such as that shown in **Figure 2**, may depend on a single indicator or several indicators, often combined with expert opinion from the academic, public, and private sectors. The U.S. Drought Monitor uses five key indicators,<sup>12</sup> together with expert opinion, with indices to account for conditions in the West where snowpack is relatively important and with other indices used mainly during the growing season.<sup>13</sup> The U.S. Drought Monitor intensity scheme—D0 to D4—is used to depict broad-scale conditions but not necessarily drought circumstances at the local scale. For example, the large regions depicted as red in **Figure 2** faced extreme to exceptional drought conditions for the week of June 2, 2015, but they may have contained local areas and individual communities that experienced less (or more) severe drought.

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<sup>12</sup> The five key indicators include the Palmer Drought Index, the Climate Prediction Center soil moisture model, U.S. Geological Survey weekly streamflow data, the Standardized Precipitation Index, and short- and long-term drought indicator blends. For a discussion of drought indices, see NDMC, <http://droughtmonitor.unl.edu/AboutUs/ClassificationScheme.aspx>.

<sup>13</sup> Ibid.

Figure 2. Example of a U.S. Drought Monitor Map



Source: U.S. Drought Monitor, <http://droughtmonitor.unl.edu/>.

Note: The U.S. Drought Monitor national maps are updated weekly.

## Drought Is Relative

Drought and “normal” conditions can vary considerably from region to region. For example, the U.S. Drought Monitor shows that Sacramento, California, faced exceptional drought in June 2015. Similarly, the city of Reno, Nevada, was in exceptional drought during the same time period. However, Reno receives on average a total of 3.77 inches of precipitation over the five-month period of January through May.<sup>14</sup> In contrast, Sacramento receives on average 11.69 inches

<sup>14</sup> National Weather Service Forecast Office, Observed Weather Reports, Reno, NV, at <http://www.nws.noaa.gov/climate/index.php?wfo=rev>.



of precipitation over the same period.<sup>15</sup> During the first five months of 2015, Sacramento received 4.99 inches of precipitation, only 43% of its average amount. However, that same amount, 4.99 inches, would constitute almost 132% of the amount Reno typically receives over the same period. Both cities faced exceptional drought in June 2015, but what is “normal” for Sacramento is different from what is “normal” for Reno.<sup>16</sup>

To deal with these differences, meteorologists use the term *meteorological drought*—usually defined as the degree of dryness relative to some average amount of dryness and relative to the duration of the dry period. Meteorological drought is region-specific because atmospheric conditions creating precipitation deficiencies vary from region to region, as described above for Reno and Sacramento.

## Drought Is Multifaceted

In addition to the color-coded D0-D4 designations, U.S. Drought Monitor maps often include an “S” and “L” designation to provide additional information about the nature of drought. (See **Figure 2**.) The “S” designation is intended to indicate existence of short-term effects: a combination of different drought indices that approximates responses to precipitation over days up to a few months. These effects would include impact to agriculture, topsoil moisture, unregulated streamflows, and aspects of wildfire danger. The “L” designation indicates the existence of long-term effects; it approximates responses to precipitation over several months up to a few years. These effects would include reservoir levels, groundwater, and lake levels. As **Figure 2** shows, some regions of the United States include both an “S” and “L” designation, indicating that in early June 2015 those regions are experiencing both short- and long-term impacts.

## What Causes Drought in the United States?

The immediate cause of drought is

the predominant sinking motion of air (subsidence) that results in compressional warming or high pressure, which inhibits cloud formation and results in lower relative humidity and less precipitation. Regions under the influence of semipermanent high pressure during all or a major portion of the year are usually deserts, such as the Sahara and Kalahari deserts of Africa and the Gobi Desert of Asia.<sup>17</sup>

Prolonged droughts occur when these atmospheric conditions persist abnormally for months or years over a certain region.<sup>18</sup>

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<sup>15</sup> National Weather Service Forecast Office, Observed Weather Reports, Sacramento, CA, at <http://w2.weather.gov/climate/index.php?wfo=sto>.

<sup>16</sup> Also, while drought may affect one region at a given time, other regions may experience too much water, and possibly flooding, at the same time. Water-related disasters, drought and flood, may occur simultaneously in different regions of the country.

<sup>17</sup> See NDMC, “Predicting Drought: High Pressure,” at <http://drought.unl.edu/DroughtBasics/PredictingDrought.aspx>.

<sup>18</sup> *Ibid.*

Predicting drought is difficult because the ability to forecast surface temperature and precipitation depends on a number of key variables, such as air-sea interactions, topography, soil moisture, land surface processes, and other weather system dynamics.<sup>19</sup> Scientists seek to understand how all these variables interact and to further the ability to predict sustained and severe droughts beyond a season or two, which is the limit of drought forecasting abilities today.

In the tropics, a major portion of the atmospheric variability over months or years seems to be associated with variations in sea surface temperatures (SSTs). Since the mid- to late 1990s, scientists have increasingly linked drought in the United States to SSTs in the tropical Pacific Ocean. Cooler-than-average SSTs in the eastern tropical Pacific region—“La Niña-like” conditions—have been shown to be correlated with persistently strong drought conditions over parts of the country, particularly the West.<sup>20</sup> A number of studies have made the connection between cooler SSTs in the eastern Pacific and the 1998-2004 western drought,<sup>21</sup> three widespread and persistent droughts of the late 19<sup>th</sup> century,<sup>22</sup> and past North American megadroughts that recurred between approximately 900 and 1300 A.D.<sup>23</sup> The precolonial megadroughts apparently lasted longer and were more extreme than any U.S. droughts since 1850, when instrumental records began. Some modeling studies suggest that within a few decades the western United States may again face higher base levels of dryness, or aridity, akin to the 900-1300 A.D. period.<sup>24</sup> The Southwest as a whole, in fact, has experienced a drought of fluctuating severity for the past 15 years, possibly foreshadowing conditions that could become more common in the coming decades.<sup>25</sup>

Although the relationship between cooler-than-normal eastern tropical Pacific SSTs (La Niña-like conditions) and drought in the United States is becoming more firmly established, meteorological drought is probably never the result of a single cause. Weather is inherently variable, and accurately predicting drought for one region in the United States for more than a few months or seasons in advance is not yet possible because so many factors influence regional drought. What is emerging from the scientific study of drought is an improved understanding of global linkages—called teleconnections by scientists—among interacting weather systems, such as the El Niño-Southern Oscillation, or ENSO. (See box for a description of ENSO.) For example, some scientists link La Niña conditions between 1998 and 2002 to the occurrence of near-simultaneous drought in the southern United States, Southern Europe, and Southwest Asia.<sup>26</sup>

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<sup>19</sup> Ibid.

<sup>20</sup> Cook et al., 2007.

<sup>21</sup> Martin Hoerling and Arun Kumar, “The perfect ocean for drought,” *Science*, vol. 299 (January 31, 2003), pp. 691-694. Hereinafter referred to as Hoerling and Kumar, 2003.

<sup>22</sup> Celine Herweiger, Richard Seager, and Edward Cook, “North American droughts of the mid to late nineteenth century: a history, simulation and implication for Mediaeval drought,” *The Holocene*, vol. 15, no. 2 (January 31, 2006), pp. 159-171. Hereinafter referred to as Herweiger et al., 2006.

<sup>23</sup> Cook et al., 2007.

<sup>24</sup> Richard Seager et al., “Model projections of an imminent transition to a more arid climate in southwestern North America,” *Science*, vol. 316 (May 25, 2007): pp. 1181-1184.

<sup>25</sup> Richard Seager, Columbia University, quoted in Justin Gillis, “Science Linking Drought to Global Warming Remains Matter of Dispute,” *New York Times*, February 16, 2014, p. A11.

<sup>26</sup> Hoerling and Kumar, 2003.

### El Niño-Southern Oscillation (ENSO)

Under normal conditions, the trade winds blow toward the west in the tropical Pacific Ocean, piling up the warm surface waters so that the ocean surface off Indonesia is one-half meter higher than the ocean off Ecuador. As a result, deep and cold water flows up to the surface (upwelling) off the west coast of South America. The upwelling waters are 8 degrees Celsius (14.4 degrees Fahrenheit) cooler than waters in the western Pacific. During El Niño, the trade winds relax, upwelling off South America weakens, and sea surface temperatures rise. The El Niño events occur irregularly at intervals of 2-7 years, and they typically last 12-18 months. These events often occur with changes in the Southern Oscillation, a see-saw of atmospheric pressure measured at sea level between the western Pacific and Indian Ocean, and the eastern Pacific. Under normal conditions, atmospheric pressure at sea level is high in the eastern Pacific and low in the western Pacific and Indian Oceans. As implied by its name, the atmospheric pressure oscillates, or see-saws, between east and west, and during El Niño the atmospheric pressure builds up to abnormally high levels in the western tropical Pacific and Indian Oceans—the El Niño-Southern Oscillation, or ENSO. During a La Niña, the situation is reversed: abnormally high pressure builds up over the eastern Pacific, the trade winds are abnormally strong, and cooler-than-normal sea surface temperatures occur off tropical South America. La Niña-like conditions have been shown to be correlated with persistently strong drought conditions over parts of the country, particularly the West. Scientists use the terms *ENSO* or *ENSO cycle* to include the full range of variability observed, including both El Niño and La Niña events.

It is widely recognized that ENSO drives substantial variability in rainfall and severe weather, including drought. Some recent studies indicate that human-forced changes in climate may alter the spatial pattern of ENSO-driven variability in precipitation and temperature, for example increasing El Niño drying in the western Pacific Ocean and increasing rainfall in the central and eastern equatorial Pacific. Other studies, including a 2014 Intergovernmental Panel on Climate Change (IPCC) report, point to a lack of consensus over global warming-related changes in the timing, intensity, and spatial pattern of El Niño-driven events, and they suggest that it is not yet possible to say that ENSO activity will be enhanced or damped and whether the frequency of ENSO events will change. The 2014 IPCC report, in fact, states that changes in ENSO intensity for the 21<sup>st</sup> century are uncertain, but that there is *high confidence* that ENSO will remain the dominant mode of natural climate variability in the tropical Pacific, with global effects in the 21<sup>st</sup> century. Some scientists share the opinion that the instrumental record is too short to document the spectrum of ENSO variability and there is little knowledge of how variability alters with changes in the climate.

**Source:** Tropical Ocean Atmosphere Project, Pacific Marine Environmental Laboratory, at [http://www.pmel.noaa.gov/tao/proj\\_over/ensodefs.html](http://www.pmel.noaa.gov/tao/proj_over/ensodefs.html); Scott Power et al., “Robust Twenty-First-Century Projections of El Niño and Related Precipitation Variability,” *Nature*, published online October 13, 2013; J. H. Christensen et al., “Climate Phenomena and their Relevance for Future Regional Climate Change,” in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, T. F. Stocker et al., eds., Cambridge University Press, Cambridge, United Kingdom and New York, NY; Mat Collins et al., “The Impact of Global Warming on the Tropical Pacific Ocean and El Niño,” *Nature Geoscience*, published online May 23, 2010; Pascale Braconnot et al., “Editorial: El Niño-Southern Oscillation-Observations and Modeling,” *PAGES news*, vol. 21, no. 2, August 2013, p. 48.

## Prehistorical and Historical Droughts in the United States

Some scientists refer to severe drought as “the greatest recurring natural disaster to strike North America.”<sup>27</sup> That claim stems from a reconstruction of drought conditions that extends back over 1,000 years, based on observations, historical and instrumental records where available, and tree-ring records or other proxies in the absence of direct measurements.<sup>28</sup> What these reconstructions illustrate is that the conterminous United States has experienced periods of severe and long-

<sup>27</sup> Cook et al., 2007.

<sup>28</sup> Proxies are indirect measurements typically used where direct measurements are unavailable. Tree rings can be used as a proxy for measuring dryness and drought. Similarly, ice cores from glaciers and polar caps can be used as proxies for measuring atmospheric temperatures and carbon dioxide concentrations from thousands of years ago.

lasting drought in the western states and also in the more humid East and Mississippi Valley. Drought reconstructions from tree rings document that severe multi-decadal drought occurred in the American Southwest during the 13<sup>th</sup> century, which anthropologists and archeologists suspect profoundly affected Pueblo society. Tree-ring drought reconstructions also document severe drought during the 14<sup>th</sup>, 15<sup>th</sup>, and 16<sup>th</sup> centuries in the central and lower Mississippi Valley, possibly contributing to the disintegration of societies in that region.<sup>29</sup>

More recently, a combination of tree-ring reconstructions and other proxy data, historical accounts, and some early instrumental records identify three periods of severe drought in the 19<sup>th</sup> century: 1856-1865 (the “Civil War drought”), 1870-1877, and 1890-1896.<sup>30</sup> The 1856-1865 drought was centered on the Great Plains and Southwest and was the most severe drought to strike the region over the last two centuries, according to one study.<sup>31</sup> The 1890-1896 drought coincided with a period in U.S. history of federal encouragement of large-scale efforts to irrigate the relatively arid western states under authority of the Carey Act.<sup>32</sup> At that time, congressional debate also occurred over a much larger federal role in western states’ irrigation. This debate led to the Reclamation Act of 1902, which was enacted largely to “reclaim the arid West.”<sup>33</sup>

In the 20<sup>th</sup> century, the 1930s “Dust Bowl” drought and the 1950s Southwest drought are commonly cited as the two most severe multiyear droughts in the United States.<sup>34</sup> (In addition, the 1987-1989 drought was widespread and severe, mainly affecting the Great Plains and California but also instigating extensive western forest fires, including the widespread Yellowstone fire of 1988.) According to several studies, however, the 19<sup>th</sup> and 20<sup>th</sup> century severe droughts occurred during a regime of relatively less arid conditions compared with the average aridity in the American West during the 900 to 1300 megadroughts. One study indicates that the drought record from 900 to 1300 A.D. shows similar variability—drought periods followed by wetter periods—compared with today, but the average climate conditions were much drier and led to more severe droughts.<sup>35</sup>

## **Droughts Affect Flows in Major Western Rivers**

Paleoclimate reconstructions using precipitation proxies like tree rings have enabled researchers to estimate and plot the history of flows for important western rivers such as the Colorado River

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<sup>29</sup> Cook et al., 2007.

<sup>30</sup> Herweiger et al., 2006.

<sup>31</sup> Ibid.

<sup>32</sup> The Carey Act, signed into law on August 18, 1894 (Chapter 301, §4, 28 Stat. 422), initially made available up to 1 million acres of federal land in each state, provided that the state met several requirements for the eventual development of water resources for reclamation. Some observers have suggested that the failure of the Carey Act to foster irrigation projects in all the land made available, compounded in part by the 1890-1896 drought, led to the Reclamation Act of 1902 and the emergence of the Bureau of Reclamation in the 20<sup>th</sup> century. See Marc Reisner, *Cadillac Desert* (New York, New York, Penguin Books, 1986).

<sup>33</sup> Under the Reclamation Act of 1902, the federal government constructed hundreds of dams, reservoirs, and related facilities to provide water to local farmers to “reclaim” the arid West through irrigation of arid lands.

<sup>34</sup> Falko K. Fye, David W. Stahle, and Edward R. Cook, “Paleoclimate Analogs to Twentieth Century Moisture Regimes Across the United States,” *Bulletin of the American Meteorological Society*, vol. 84 (2003), pp. 901-909.

<sup>35</sup> For example, one report showed that 42% of the area studied in the American West was affected by drought during the years 900 to 1300, versus 30% between 1900 and 2003, a 29% reduction in the average area affected by drought between the two periods. See Cook et al., 2007.

in the Rockies, the Sacramento and San Joaquin Rivers draining the Sierra Nevada Mountains in California, and the Klamath River draining southern Oregon and northern California.<sup>36</sup> The Colorado River basin has experienced generally lower-than-normal flows for the past 15 years (based on roughly 100 years of observed flow records), affecting lake levels in Lake Mead and Lake Powell. Comparing previous low-flow periods compiled from other sources may indicate what could be in store for the Colorado River, Lake Powell, and Lake Mead. For example, a 2007 study showed that for the years 1130-1154, estimated Colorado River flows were less than 84% of normal (with *normal* defined as the mean annual flow between 1906 and 2004, about 15 million acre-feet, or MAF, measured at Lee's Ferry, Arizona).<sup>37</sup> Prior to the current dry period, the lowest 25-year mean of observed flows occurred between 1953 and 1977, but Colorado River flows were 87% of normal, still higher than the 1130-1154 period.<sup>38</sup> In addition, the 25-year period of exceptionally low flow in the mid-1100s occurred within a generally dry 62-year period, 1118-1179, that was characterized by a series of multiyear low-flow pulses and the absence of years with flow much above 15 MAF.

### **Colorado River: Approaching Historic Low Flows?**

Whether the current 15-year dry spell in the Colorado basin is creating low-flow levels on the Colorado River that are similar to the low-flow levels experienced in the mid-1100s—and how likely it is that the dry period could extend for years or even decades more—remains an outstanding question. Flow data seem to suggest that Colorado River flows since 2000 are approaching those historic low levels. According to Bureau of Reclamation data, during 12 of the 15 years between 2000 and 2014, the Colorado River flows at Lee's Ferry were below the 1906-2014 average, and the average amount of flow calculated for the 15-year period was about 12.3 MAF, or 83% of the 1906-2014 average.<sup>39</sup> The most recent flow data for 2013 and 2014 are provisional; however, if the numbers do not change appreciably, then Colorado River flows for the past 15-year period—83% of the 1906-2014 average—would be lower than for the 1130-1154 period. That outcome would suggest that dry conditions since 2000 may have rivaled the extreme dry periods during medieval times.<sup>40</sup>

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<sup>36</sup> See David M. Meko, et al., "Medieval Drought in the Upper Colorado River Basin," *Geophysical Research Letters*, vol. 34, no. 10 (May 24, 2007); and David M. Meko, Connie A. Woodhouse, and Ramzi Touchan, *Klamath/San Joaquin/Sacramento Hydroclimate Reconstructions from Tree Rings*, Draft Final Report to California Department of Water Resources, February 7, 2014, at [http://www.water.ca.gov/waterconditions/docs/tree\\_ring\\_report\\_for\\_web.pdf](http://www.water.ca.gov/waterconditions/docs/tree_ring_report_for_web.pdf).

<sup>37</sup> Meko et al., 2007.

<sup>38</sup> Ibid.

<sup>39</sup> U.S. Bureau of Reclamation, Lower Colorado Region, "Colorado River Basin Natural Flow and Salt Data-Current Natural Flow Data 1906-2012," at <http://www.usbr.gov/lc/region/g4000/NaturalFlow/current.html>. Data from the spreadsheet provided by Reclamation on that website were extracted from the AnnualWYTotal Natural Flow worksheet, column U, per recommendation of Dr. David Meko, University of Arizona, Laboratory of Tree-Ring Research, personal communication, June 10, 2015. Flow data for water years 2013 and 2014 were provided by Dr. James Prairie, Hydrologic Engineer, U.S. Bureau of Reclamation, personal communication, June 11, 2015. Data for water years 2013 and 2014 are provisional flow data, because of an at least 1.5-year lag between the end of current year data and the calculation of natural flows available in the upper Colorado River basin for that year. Documentation for the natural flow calculation methods is available at <http://www.usbr.gov/lc/region/g4000/NaturalFlow/NaturalFlowAndSaltComptMethodsNov05.pdf>.

<sup>40</sup> The 1130-1154 low-flow period lasted 25 years, so those flows and the current dry period and accompanying low flows for the 2000-2014 15-year period in the upper Colorado River are not directly comparable. For comparison, Colorado River flows at Lee's Ferry for the 25-year period between 1990 and 2014 were 90% of the 1906-2014 average, higher than the average flows during the 25-year period from 1130 to 1154, which averaged 84% of the 1906-2014 average.

## **California Rivers: Low Flows in the 16<sup>th</sup> and 20<sup>th</sup> Centuries**

For the Sacramento and San Joaquin Rivers, both of which are critical to California's water supply and the agricultural production in the Central Valley, paleoclimate reconstructions have shown that low flows in the 1920s and 1930s rank among the most extreme in the context of the last millennium.<sup>41</sup> However, 1580 was the driest single year. In 1580, flows on the Sacramento River were only 45% of the Sacramento River flow in 1924, and flows on the San Joaquin River were only 54% of the San Joaquin River flows for 1924, the second-driest single year of the entire reconstructed period. Thus, it appears that despite the severity of drought in the 1920s and 1930s, and more recent California droughts in the late 1980s to early 1990s and in 1975 to 1977, flows on both rivers were lower due to drought during the 1500s. An outstanding question is whether the current four-year California drought is affecting flows on the Sacramento and San Joaquin Rivers to a similar extent as did the 1920s-1930s drought or even the exceptionally dry year in 1580.

## **Recent Droughts: Texas, the Midcontinent, and California**

Over the past five years, portions of the country have been gripped with extensive and extreme to exceptional drought. As noted above, drought conditions nearly always occur in some part of the United States; however, the intensity of the Texas drought in 2011, the widespread nature of the midcontinent drought in 2012-2013, and the return of drought to California in 2012-2015 have focused national and congressional attention on those regions. The national importance of agriculture in those areas, combined with drought conditions (i.e., lack of precipitation, dry soil conditions, and farming and ranching needs), illustrates the nature of drought: namely, it is the combination of lack of precipitation and acute demand for water that poses challenges for water managers. The following section briefly describes these specific regional droughts.

### **Drought in Texas: 2011**

Texas experienced varying levels of drought from 2011 to late spring 2015, when record amounts of rain fell in parts of the state, essentially ending the multiyear drought.<sup>42</sup> However, the drought in Texas was most extensive and most severe in 2011. For example, mid-February 2011 conditions in Texas were dramatically different compared with mid-February 2010, when only about 7% of the total land area in Texas was abnormally dry and no part of the state was experiencing even moderate drought.<sup>43</sup>

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<sup>41</sup> Meko et al., 2014.

<sup>42</sup> As of June 2, 2015, only about 10% of Texas was experiencing abnormally dry or moderate drought conditions. One month earlier, 40% of the state was experiencing abnormally dry or drought conditions. Oklahoma also faced drought conditions earlier in 2015; as of May 5, 2015, nearly 60% of the state was in at least moderate drought conditions. As with Texas, late spring heavy rains have nearly eliminated the drought in Oklahoma.

<sup>43</sup> U.S. Drought Monitor, February 16, 2010. For comparison, the U.S. Drought Monitor on February 15, 2011, reported that over 87% of the state was experiencing abnormally dry or drought conditions, and only 12.5% of the state was not abnormally dry or in drought, <http://droughtmonitor.unl.edu/MapsAndData/MapArchive.aspx>.

Drought conditions worsened in Texas through the beginning of October 2011, when 88% of the state experienced exceptional drought conditions and only 3% of the state was not classified as being in extreme or exceptional drought.<sup>44</sup> (See **Figure 3**.) Drought conditions generally improved throughout the rest of 2011, but large portions of the state were still affected by extreme or exceptional drought until late winter and early spring 2012, when the eastern portion of the state recovered to normal or abnormally dry conditions (the least severe category) because of above-normal rainfall from December 2011 through February 2012.<sup>45</sup> Drought conditions persisted in parts of Texas through early 2015, although the most severe, extreme, and exceptional conditions occurred in 2011.

According to Texas state climatologist John Nielsen-Gammon, 2011 may have been the worst one-year drought on record for Texas.<sup>46</sup> Compounding the effects of abnormally low precipitation, the June-August average temperature in Texas was approximately 2.5 degrees Fahrenheit higher than during any Texas summer since record keeping began in 1895 and 5 degrees Fahrenheit higher than the long-term average.<sup>47</sup>

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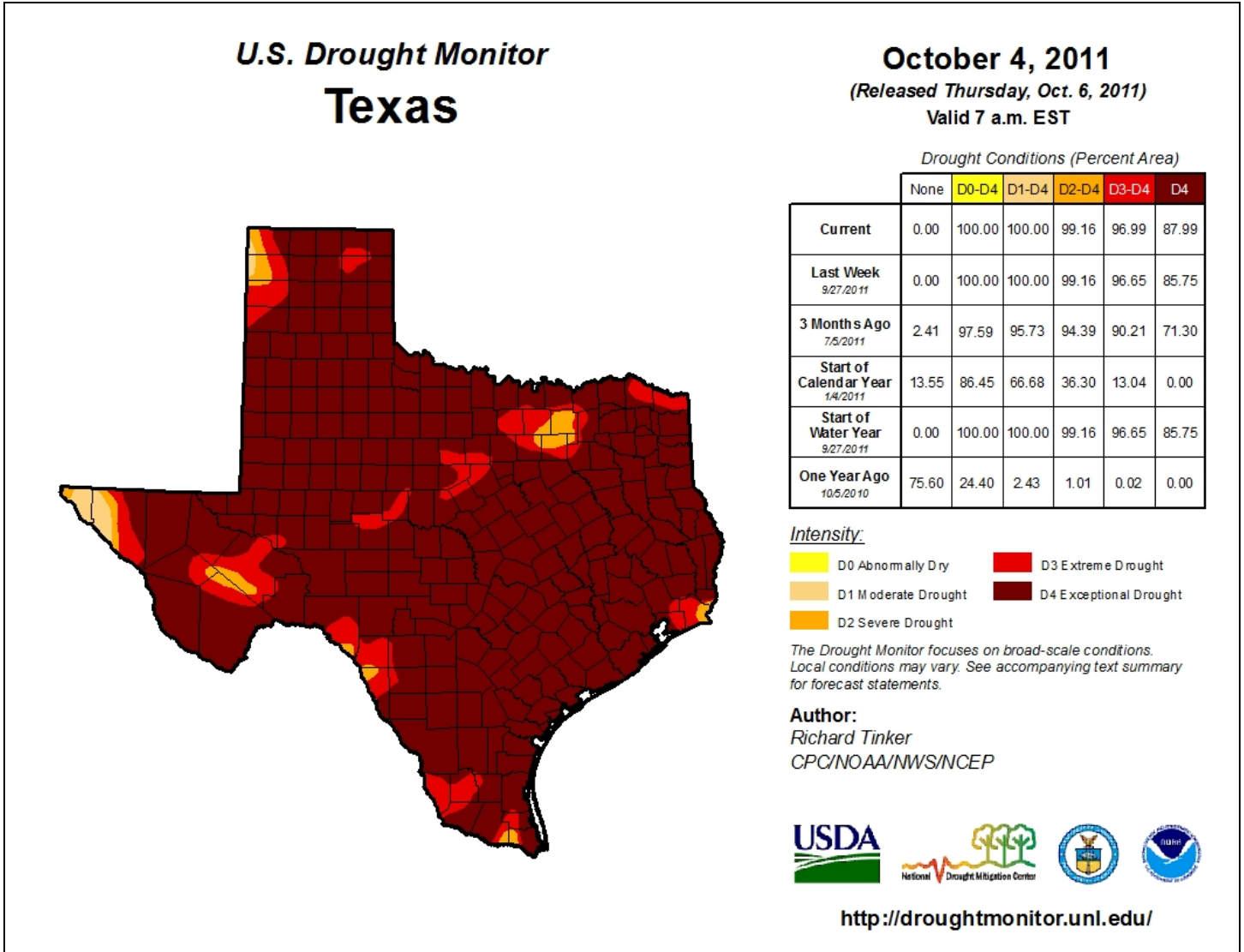
<sup>44</sup> See the U.S. Drought Monitor, Texas, on October 4, 2011, at <http://droughtmonitor.unl.edu/MapsAndData/DataTables.aspx>.

<sup>45</sup> “Climate Abyss: Weather and Climate Issues with John Nielsen-Gammon,” *Texas Drought Update*, March 23, 2012, <http://blog.chron.com/climateabyss/2012/03/texas-drought-update/>.

<sup>46</sup> Office of the Texas State Climatologist, “Texas Drought Officially the Worst Ever,” August 4, 2011, <http://tamunews.tamu.edu/2011/08/04/texas-drought-officially-the-worst-ever/>.

<sup>47</sup> John W. Nielsen-Gammon, *The 2011 Texas Drought: A Briefing Packet for the Texas Legislature*, October 31, 2011, p. 29, [http://climatexas.tamu.edu/files/2011\\_drought.pdf](http://climatexas.tamu.edu/files/2011_drought.pdf). Possibly the most severe Texas drought overall occurred from 1950 to 1957 and had substantial impacts on water supplies across the state because it lasted over many years. Because of the longevity and severity of the 1950s drought, municipal water supplies in Texas today are designed to withstand a drought of similar magnitude, according to the state climatologist. Long-term precipitation patterns in Texas—longer than year-to-year changes—are influenced by a configuration of sea surface temperatures known as the Pacific Decadal Oscillation (PDO). Similar conditions also prevailed from the 1940s through the 1960s, encompassing the Texas drought of record (1950-1957).

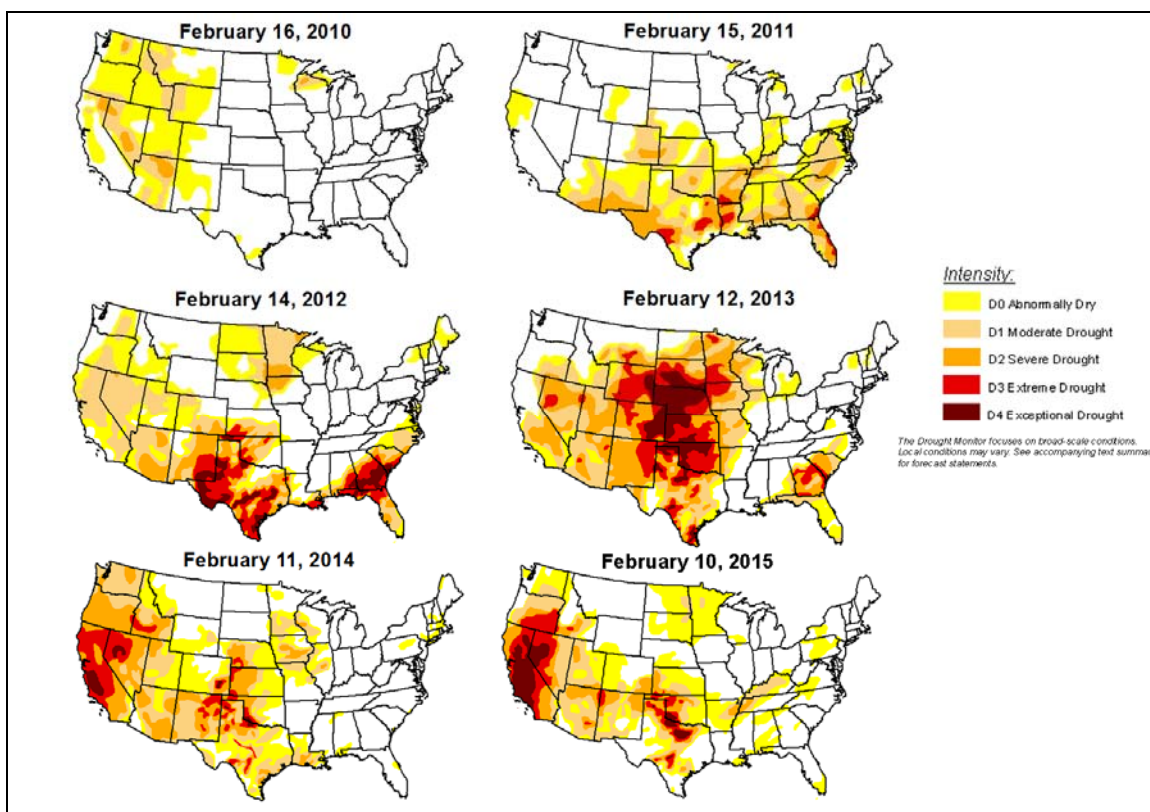
Figure 3. The Maximum Extent of Drought in Texas in 2011



**Source:** U.S. Drought Monitor, U.S. Drought Monitor Map Archive, October 4, 2011, <http://droughtmonitor.unl.edu/MapsAndData/MapArchive.aspx>.

**Note:** As shown in the table to the right of the map of Texas, 100% of the land area of the state was in drought and 97% of the state was in extreme to exceptional drought.



**Figure 4. Drought Conditions in the United States: 2010-2015**

**Source:** U.S. Drought Monitor, <http://droughtmonitor.unl.edu/MapsAndData/MapArchive.aspx>.

**Notes:** Alaska and Hawaii not shown.

## Drought in the Midcontinent: 2012-2013

In mid-August 2012, approximately 70% of the land area of the United States (including Alaska and Hawaii) was affected by abnormally dry and drought conditions.<sup>48</sup> The land area affected by abnormally dry or drought conditions stayed at or above 65% through February 2013. The intensity of the drought varied, with the regions of extreme and exceptional drought clustered across the Midwest, Great Plains, Southwest, and Southeast, particularly Georgia in 2012. (See **Figure 4**.)

**Figure 4** shows that Texas and portions of Florida and Georgia experienced exceptional drought conditions (the worst category of drought) in early 2012, while the upper Midwest, including most of the Mississippi Valley, experienced normal conditions. A year later, in early 2013, the drought had eased somewhat in portions of Georgia and Florida, but it had intensified throughout the center of the country from Texas to the Canadian border. Nearly 12% of the contiguous

<sup>48</sup> For the contiguous United States, nearly 80% of the land area was affected by abnormally dry or drought conditions. U.S. Drought Monitor, "U.S. Drought Monitor Map Archive," accessed August 14, 2012, at <http://droughtmonitor.unl.edu/MapsAndData/MapArchive.aspx>.

United States was in exceptional drought conditions from late June 2011 through October 2011, compared to approximately 6% of the country the following year.<sup>49</sup> However, exceptional drought conditions persisted over nearly 6% of the contiguous United States from mid-August 2012 through mid-February 2013. Although less severe for portions of the country, such as Texas and Florida, the 2012-2013 drought affected broader swaths of the agricultural heartland compared to 2011 (**Figure 4**). The 2012-2013 experience illustrates that the extent, timing, and particular features of areas affected by drought—dryland versus irrigated farm regions, regions that are still recovering from previous droughts, or regions with multiyear surface storage or ample groundwater resources—are important in addition to the relative severity of drought conditions.

### **Origin of the 2012-2013 Drought**

**Figure 4** shows a snapshot of drought conditions for mid-February in the United States for 2010-2015. In 2010, most of the United States was experiencing near-normal conditions. The extent and severity of the 2012-2013 drought raised questions regarding its origin and whether the drought was within the range of natural variability in the U.S. Midwest and Plains or whether it was linked to longer-term changes in the Earth's climate system, such as human-induced global warming.

Although the images presented in **Figure 4** may seem to indicate a steady progression of drought in the middle portion of the country from near-normal conditions in 2010 to widespread and intense drought in 2012-2013, a March 2013 analysis concluded that the 2012 intense drought in the midcontinent region was a discrete extreme event.<sup>50</sup> The report stated that “the event did not appear to be just a progression or a continuation of the prior year’s record drought event that developed in situ over the central U.S.”<sup>51</sup> Instead, the report asserted that the drought developed suddenly, with near-normal precipitation during winter and spring 2012 over the Great Plains. The drought resulted from an extreme lack of precipitation during the summer months: 2012 was the driest summer in the observed historical record for the region, experiencing even less rainfall than the years 1934 and 1936, when the central Great Plains were about 0.5 degrees Celsius warmer than 2012.<sup>52</sup> Essentially, the rains abruptly stopped in May over the central Great Plains and did not return for the summer.

The report further stated that the 2012 summer drought was a “climate surprise,” because summertime Great Plains rainfall has been trending upward since the early 20<sup>th</sup> century and the last major drought occurred in 1988.<sup>53</sup> Further, the report concluded that neither sea surface temperatures, which have been rising generally due to global warming, nor changes in greenhouse gases in the atmosphere were responsible for producing the anomalously dry conditions over the central Great Plains in 2012.<sup>54</sup> (See section on “Drought and Climate Change,” below.)

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<sup>49</sup> U.S. Drought Monitor, *Tabular Data Archive*, <http://droughtmonitor.unl.edu/MapsAndData/DataTables.aspx>.

<sup>50</sup> Martin Hoerling et al., *An Interpretation of the Origins of the 2012 Central Great Plains Drought*, National Oceanic and Atmospheric Administration, Assessment Report: NOAA Drought Task Force Narrative Team, March 20, 2013, at <ftp://ftp.oar.noaa.gov/CPO/pdf/mapp/reports/2012-Drought-Interpretation-final.web-041113.pdf>.

<sup>51</sup> *Ibid.*, p. 1.

<sup>52</sup> *Ibid.*, p. 4.

<sup>53</sup> *Ibid.*, p. 10.

<sup>54</sup> *Ibid.*, p. 22.

Although seasonal forecasts did not predict the summer 2012 drought in the Great Plains, a 2014 retrospective report stated that some modeling results indicated a regime shift toward warmer and drier western Great Plains and Southwest conditions during the 10 years to 15 years prior to the 2012 drought.<sup>55</sup> The report noted that the shift likely is due to natural decadal variability, but its existence would have increased the probability of a severe summer Great Plains drought, such as the 2012 event. The report concluded that the 2012 Great Plains drought resulted mostly from natural variations in weather.

## Four Years of Drought in California

As of October 1, 2014—the beginning of the 2015 *water year*<sup>56</sup>—nearly 60% of California was experiencing exceptional drought, the most severe U.S. federal drought classification. The dry conditions resulted, in part, because the 2014 water year was the third driest on record in terms of precipitation (2013 was the driest calendar year on record, whereas the 1924 water year was the driest on record).<sup>57</sup> California typically receives more than 80% of its annual precipitation in the November-to-April winter precipitation season, and the season between November 2013 and April 2014 for the state as a whole was the sixth driest since records began in 1895.<sup>58</sup>

The state is experiencing its fourth consecutive dry year. As of June 2, 2015—after the end of the winter precipitation season—nearly 47% of California still faced exceptional drought and nearly 94% of the state faced drought conditions that ranged from severe to exceptional (**Figure 5**).<sup>59</sup>

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<sup>55</sup> M. Hoerling et al., “Causes and Predictability of the 2012 Great Plains Drought,” *Bulletin of the American Meteorological Society*, vol. 95, no. 2 (February 2014), pp. 269-282.

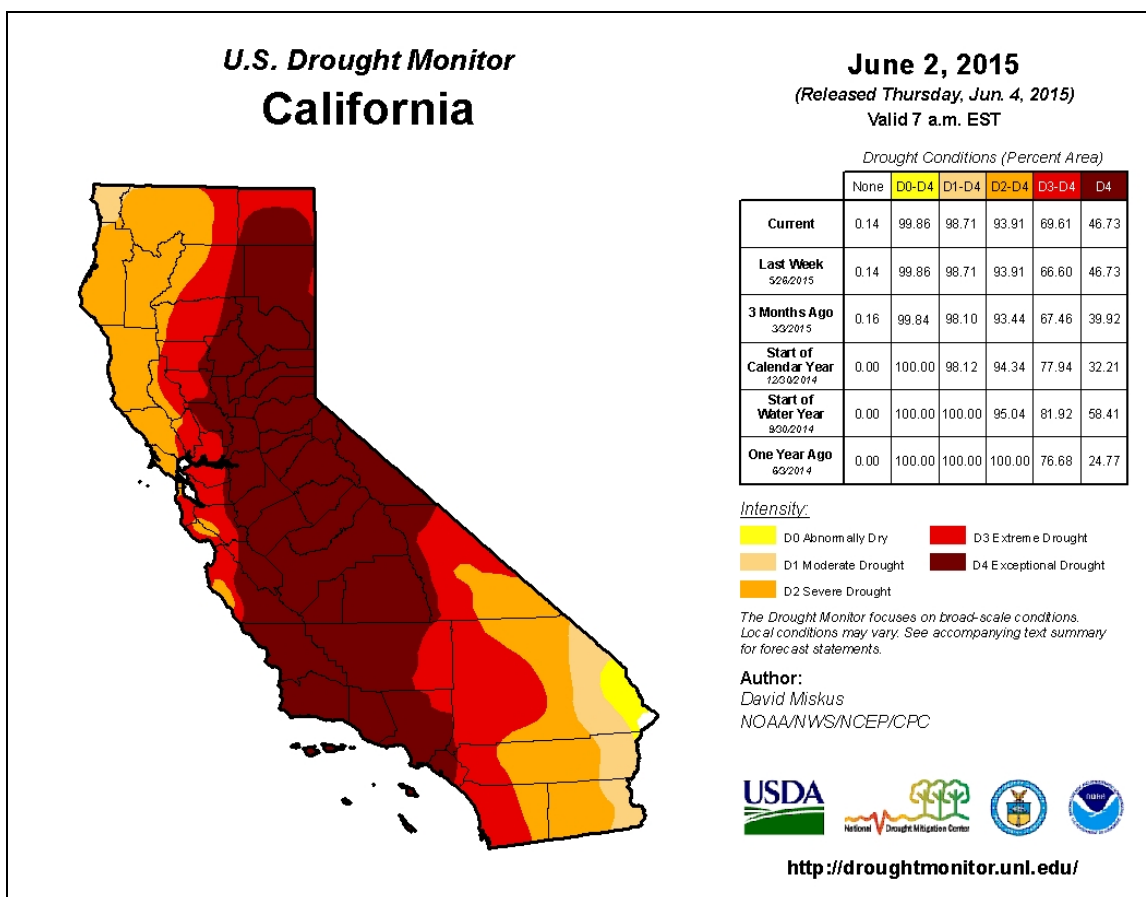
<sup>56</sup> For planning and water allocation purposes, water managers typically rely on “water-year” data. Each water year begins October 1 and ends September 30, thereby including the late-fall and winter months preceding winter/spring water allocation decisions. The media and others often use a calendar-year baseline, thus creating some confusion regarding “driest” years on record. For the purpose of this report, CRS relies on water-year data and water-year types defined by the Bureau of Reclamation and the California Department of Water Resources, not calendar-year data.

<sup>57</sup> California Department of Water Resources, “Water Year 2014 Ends as 3<sup>rd</sup> Driest in Precipitation,” press release, September 30, 2014, at <http://www.water.ca.gov/waterconditions/>.

<sup>58</sup> Richard Seager et al., *Causes and Predictability of the 2011-2014 California Drought*, National Oceanic and Atmospheric Administration, Assessment Report, December 2014, p. 3, at [http://cpo.noaa.gov/sites/cpo/MAPP/Task%20Forces/DTF/californiadrought/california\\_drought\\_report.pdf](http://cpo.noaa.gov/sites/cpo/MAPP/Task%20Forces/DTF/californiadrought/california_drought_report.pdf). Hereinafter referred to as NOAA Assessment Report 2014.

<sup>59</sup> U.S. Drought Monitor, June 2, 2015.

Figure 5. California Drought Conditions



**Source:** U.S. Drought Monitor, June 2, 2015, at <http://droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?CA>.

Water users that receive supplies from California state and federal water projects are experiencing unprecedented water supply shortages due to the drought. Severe water supply shortages also hampered the state during a recent three-year drought (2007-2009). Other severe droughts in California over the last 100 years include a six-year drought (1987-1992); a two-year drought (1976-1977); and an extended dry period during the 1920s and 1930s that included the single driest water year on record—1924. (The driest winter on record was 1976-1977.) Studies of relict tree stumps, tree rings, and other evidence indicate that parts of California have experienced numerous multiyear droughts, some of which lasted for decades or even centuries during the past 2,000 years.<sup>60</sup> Whether the current drought is the worst in California’s history currently is being debated. The role of human-induced climate change also is in debate, in particular whether the record high temperatures in California in 2014, combined with low precipitation, indicate a fingerprint of human influence on climate.

<sup>60</sup> Rachel Berkowitz, “A Dry State in the West,” *Physics Today*, July 2014, at <http://scitation.aip.org/content/aip/magazine/physicstoday/news/10.1063/PT.5.4004>. See also Scott Stine, “Extreme and Persistent Drought in California and Patagonia During Mediaeval Time,” *Nature*, vol. 369 (June 16, 1994), pp. 546-549.

## **Human Factors and Water Shortage Severity**

Although California experienced the driest calendar year on record in 2013, the severity of drought impacts is not solely related to the lack of precipitation and the duration of dryness. For example, drought risks to U.S. citizens generally increase in proportion to the population affected by drought, as well as in proportion to the resources and economic activity dependent upon average water supply and soil conditions. This principle is illustrated by the current situation in California, where more than 22 million people rely on water delivered from the Sacramento and San Joaquin Rivers' Delta confluence with San Francisco Bay (Bay-Delta)—also the home and nursery for several species of federal- and state-listed threatened and endangered species. Farms in the state's Central Valley also rely on water coming from the Bay-Delta, as well as runoff from the Sierra Mountains. Because the state is in its fourth year of drought, and because it is the top U.S. agricultural producer in terms of cash receipts, drought impacts in California could be felt nationwide.<sup>61</sup>

## **The 2007-2009 California Drought: Setting the Stage for the Current Drought?**

The 2007-2009 California drought<sup>62</sup> was complicated by decades of tension over water supply deliveries for irrigation and municipal and industrial uses and over the preservation of water flows to protect threatened and endangered species. Dry conditions that began in 2007 continued through the 2009 water year (October 2008 through September 2009) and into the fall of 2009. According to the California Department of Water Resources, the 2007-2009 drought was the 12<sup>th</sup>-driest three-year period in California's history since measurements began.<sup>63</sup> Hydrological conditions were classified as below normal in 2010, but they were classified as wet (well above average) in 2011 for California, and the drought was declared over in spring 2011.<sup>64</sup> However, the 2012 water year was classified as below normal for the Sacramento River basin and dry for the San Joaquin River basin,<sup>65</sup> and by August 2012 the U.S. drought monitor again showed increasing severity of drought in the eastern portion of the state. Although above-average reservoir storage at the end of 2011 somewhat mitigated reductions to water users, water deliveries to state and federal water project contractors were restricted again in 2012, as well as in 2013.<sup>66</sup>

California's dry conditions from 2007 through 2009 exacerbated an already tight water supply, where federal and state water deliveries had been reduced in response to a court order to prevent

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<sup>61</sup> California is the country's largest agricultural producer in terms of cash farm receipts—accounting for 14.7% (\$21.2 billion) of the U.S. total agricultural exports in 2013 (the last year for which data are available <http://www.cdfa.ca.gov/statistics/>). California is also the largest producer of many crops.

<sup>62</sup> For more information about the hydrology and policy issues involved in the 2007-2009 California drought, see CRS Report R40979, *California Drought: Hydrological and Regulatory Water Supply Issues*, by (name redacted), (name redacted), and (name redacted).

<sup>63</sup> California Department of Water Resources, *California's Drought of 2007-2009—An Overview*, September 2010, at <http://www.water.ca.gov/waterconditions/drought/docs/DroughtReport2010.pdf>.

<sup>64</sup> Office of Governor Edmund G. Brown, Jr., "A Proclamation by the Governor of the State of California—Drought," at <http://gov.ca.gov/news.php?id=16997>.

<sup>65</sup> See California Data Exchange Center, Department of Water Resources, "Chronological Reconstructed Sacramento and San Joaquin Valley Water Year Hydrologic Classification Indices," at <http://cdec.water.ca.gov/cgi-progs/ioidir/WSIHIST>.

<sup>66</sup> For information on current water supply conditions and historical water allocations to federal water contractors in California, see U.S. Department of the Interior, Bureau of Reclamation, "Central Valley Project Water Supply," at <http://www.usbr.gov/mp/PA/water/>.

extinction of the Delta smelt,<sup>67</sup> as well as to comply with state water-quality standards in the Bay-Delta. These factors are still in play in 2015 and are challenging water managers charged with protecting certain species from harm while also supplying water for farms, cities, and fish and wildlife.

## Drought and Climate Change

The relationship between climate change and future trends in droughts is complex, and the scientific understanding of this relationship appears to be evolving. In 2007, the Intergovernmental Panel on Climate Change (IPCC) released its Fourth Assessment Report, which stated that, globally, very dry areas have more than doubled since the 1970s due to a combination of El Niño-Southern Oscillation (ENSO)<sup>68</sup> events and global surface warming.<sup>69</sup> The 2007 IPCC report added that very wet areas declined by about 5% globally. The report asserted that documented trends in severe droughts and heavy rains showed that hydrological conditions were becoming more intense in some regions.<sup>70</sup>

In 2012, the IPCC issued a new report stating that “there are still large uncertainties regarding observed global-scale trends in droughts.”<sup>71</sup> The new report noted that although its earlier assessment had stated that very dry areas have more than doubled since the 1970s, that observation was based largely on only one study, which relied on a measurement primarily related to temperature, not moisture.<sup>72</sup> A different study, which looked at soil moisture simulations, found that global trends in drought duration, intensity, and severity predominantly were *decreasing*, not increasing, but with strong regional variation.<sup>73</sup>

The 2012 IPCC report assigned medium confidence<sup>74</sup> that there has been an overall slight tendency toward *less* dryness in North America (i.e., a wetting trend with increasing soil moisture and runoff). It noted that the most severe droughts in the 20<sup>th</sup> century occurred in the 1930s and 1950s, where the 1930s drought was the most intense and the 1950s drought was the most persistent. In comparison to the severe megadroughts that occurred in North America hundreds and thousands of years ago, as documented using paleoclimate evidence (discussed earlier in this report), these recent droughts were not unprecedented, according to the 2012 IPCC report.

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<sup>67</sup> The Delta smelt is a species of fish listed as threatened under the federal Endangered Species Act and as endangered under the California Endangered Species Act. *Natural Resources Defense Council v. Kempthorne*, No. 1:05-cv-1207 OWW GSA (E.D. Cal., December 14, 2007).

<sup>68</sup> A discussion of ENSO is provided in the text box entitled “El Niño-Southern Oscillation (ENSO),” above.

<sup>69</sup> S. D. Solomon et al., “Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,” 2007, Cambridge University Press, Cambridge, United Kingdom and New York, NY.

<sup>70</sup> *Ibid.*, Summary for Policy Makers.

<sup>71</sup> C. B. Field et al., IPCC, “Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation,” 2012, Cambridge University Press, Cambridge, United Kingdom and New York, NY, p. 170.

<sup>72</sup> The 2007 IPCC fourth assessment noted that “difficulties in the measurement of precipitation remain an area of concern in quantifying the extent to which global- and regional-scale precipitation has changed.” S. D. Solomon et al., “Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,” 2007, *Changes in Surface Climate: Precipitation, Drought and Surface Hydrology*, chapter 3, section 3.3.1.

<sup>73</sup> C.B. Field et al., IPCC, 2012, p. 170.

<sup>74</sup> According to the report, confidence in the validity of a finding is based on the type, amount, quality, and consistency of evidence and on the degree of agreement. Confidence is expressed qualitatively: low, medium, high.

The 2012 report concluded that despite new studies that have furthered the understanding of mechanisms leading to drought, there is still limited evidence to attribute observed changes. The IPCC assessed that there was medium confidence that anthropogenic influence has contributed to changes in drought patterns in the second half of the 20<sup>th</sup> century, but gave low confidence to the attribution of changes in drought patterns at the regional level.<sup>75</sup> The report noted that some regions of the world have experienced trends towards more intense and longer droughts, such as southern Europe and West Africa. But in other regions, such as central North America and northwestern Australia, droughts have become less frequent, less intense, or shorter.<sup>76</sup>

In 2014, the IPCC released its most recent climate assessment, which stated that for North America decreases in snowpack already are influencing seasonal stream flows. However, the report had medium-to-high confidence that recent droughts (and floods, and changes in mean streamflow conditions) cannot yet be attributed to climate change.<sup>77</sup> Further, the report stated that it is not yet possible to attribute changes in drought frequency in North America to anthropogenic climate change.<sup>78</sup> The report noted that changes in these events, however, may be indicative of future conditions.

### **Did Human-Induced Climate Change Cause the 2012-2015 California Drought?**

Two studies published in late 2014 provide examples of the ongoing scientific discussion about whether emissions of heat-trapping greenhouse gases by human activities have influenced the current California drought. One study claimed that the current drought is the most severe in California's history over the past 1,200 years.<sup>79</sup> The study stated that diminished snowpack, streamflows, and reservoir levels resulted in a convergence of reduced surface water supply with increased demand, a combination that appears unique in California's history. The study stated that 2014 was the worst single drought year in at least the last 1,200 years in California but that it was not the driest year. What made the 2012-2014 drought, and 2014 in particular, stand out was the combination of lack of precipitation and record high temperatures, resulting in extreme dryness according to a soil-moisture metric known as the Palmer Drought Severity Index (PDSI).<sup>80</sup> Attributing a human influence is more tenuous, according to the study, as attribution of a human influence on California rainfall and Pacific storm tracks is equivocal. The study, however, stated that "projections for a continued trend toward higher mean and extreme temperatures are robust." Further, the study linked the future warming to human activities, claiming that "future 'hot' droughts driven by increasing temperatures due to anthropogenic emissions of greenhouse gases ... are assured."

Another study also published in 2014 found that the 2012-2014 dry conditions were not without precedent in California's history. Even with the current drought, the study did not find a clear trend toward wetter or drier conditions over the past 120 years in California.<sup>81</sup> It noted that the impacts of lack of precipitation were exacerbated by warm temperatures and that November 2013 through April 2014 was the warmest winter half-year on record.<sup>82</sup>

<sup>75</sup> C.B. Field et al., IPCC, 2012, p. 172.

<sup>76</sup> The IPCC report was referring primarily to hydrological drought and not to water demand, water infrastructure, and other factors that enhance the effects of hydrological drought.

<sup>77</sup> P. Romero-Lankao et al., *North America*, Intergovernmental Panel on Climate Change, Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel On Climate Change, Cambridge, United Kingdom, and New York, New York, 2014, pp. 1443-1444, at [http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap26\\_FINAL.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap26_FINAL.pdf).

<sup>78</sup> Ibid., p. 1456.

<sup>79</sup> Daniel Griffin and Kevin J. Anchukaitis, "How Unusual is the 2012-2014 California Drought?," *Geophysical Research Letters*, published online December 3, 2014, DOI: 10.1002/2014GL062433.

<sup>80</sup> For a description of the PDSI, see the National Drought Mitigation Center, at <http://drought.unl.edu/Planning/Monitoring/ComparisonofIndicesIntro/PDSI.aspx>.

<sup>81</sup> Richard Seager et al., *Causes and Predictability of the 2011-2014 California Drought*, National Oceanic and Atmospheric Administration, Assessment Report by the NOAA Drought Task Force, December 2014, [http://cpo.noaa.gov/sites/cpo/MAPP/Task%20Forces/DTF/californiadrought/california\\_drought\\_report.pdf](http://cpo.noaa.gov/sites/cpo/MAPP/Task%20Forces/DTF/californiadrought/california_drought_report.pdf).

<sup>82</sup> California receives most of its precipitation during the winter and early spring months, November through April.

This second study focused on the influence of sea surface temperatures (SSTs) on atmospheric behavior (SST forcing), and examined the role of natural atmospheric variability together with SST forcing as factors influencing the California drought. In its examination of the causes of the current drought, the study observed that generally California dry winters arise from internal atmospheric variability, but that the past three winters also contained a component of SST forcing. The study also noted that many climate model projections show a future *increase* in California precipitation over the midwinter and that “the recent severe all-winter rainfall deficit is thus not a harbinger of future precipitation change.” However, this second study also stated that in the future California may experience a net surface moisture deficit due to the projected increase in evapotranspiration, driven by warmer temperatures, which would exceed the projected increase in precipitation. Both studies appear to support that same prediction.

## Drought Forecasts for the United States

Predicting the intensity and duration of severe drought over a specific region is not yet possible more than a few months in advance because of the many factors that influence drought. Nevertheless, some modeling studies suggest that a transition to a more arid average climate in the American West, perhaps similar to conditions in precolonial North America, may be under way.<sup>83</sup>

Likely consequences of higher temperatures in the West include higher evapotranspiration, reduced precipitation, and decreased spring runoff.<sup>84</sup> These impacts would result from an *acceleration* of the hydrologic cycle, due to increased warming of the atmosphere, which in turn increases the amount of water held in the atmosphere.<sup>85</sup> A possible consequence is more frequent, and perhaps more severe, droughts and floods, although these changes are likely to occur unevenly across the United States. Yet the understanding of hydrologic extremes, such as drought, is confounded by other effects such as land cover changes, the operation of dams, irrigation works, extraction of groundwater, and other engineered changes. Forecasting drought conditions at the regional scale, for example for river basins or smaller, is difficult because current climate models are less robust and have higher uncertainty at smaller scales.<sup>86</sup>

Even though forecasting drought at the regional scale is difficult, understanding potential changes in long-term trends is important for water managers at all levels—federal, state, local, and tribal. Water project operations and state water allocations typically are based on past long-term hydrological trends; significant deviations from such trends may result in difficult challenges for water managers and water users alike.<sup>87</sup>

Conversely, it is also difficult to predict when droughts will end, and in some cases significant regional droughts can end relatively abruptly with the occurrence of major precipitation events.

<sup>83</sup> Richard Seager et al., “Model projections of an imminent transition to a more arid climate in southwestern North America,” *Science*, vol. 316 (May 25, 2007), pp. 1181-1184.

<sup>84</sup> Research results are emerging, however, that suggest that local and regional patterns of precipitation may be variable and that parts of a region or a state could receive higher precipitation than the current average, even if the overall trend over the broader area is towards less precipitation. See K. T. Redmond, “Climate Change in the Western United States: Projections and Observations,” *Eos Trans. AGU*, 90(52), Fall Meet. Suppl., Abstract U11D-02, 2009.

<sup>85</sup> National Research Council, Committee on Hydrologic Science, *Global Change and Extreme Hydrology: Testing Conventional Wisdom*, Washington, D.C., 2011, p. 3.

<sup>86</sup> *Ibid.*, p. 9.

<sup>87</sup> P.C.D. Milly et al., “Stationarity Is Dead: Whither Water Management?,” *Science*, vol. 319 (February 4, 2008), p. 574.



The May 2015 storms that dropped record amounts of precipitation on Texas and Oklahoma essentially ended the Texas drought, for example. In California, high precipitation events known as *atmospheric rivers* (ARs) increasingly are considered critical to ending droughts in the state. These weather features, sometimes referred to as *drought busters*, are extremely important contributors to California precipitation during the winter months. The immediate cause of the current California drought appears to be a region of persistent atmospheric high pressure over the northeast Pacific Ocean offshore Oregon and Washington. The *resilient ridge*, as it is sometimes referred to, has changed the atmospheric circulation patterns so the ARs are blocked from reaching the northern California coastline. How the location, timing, and intensity of major precipitation events, such as ARs, may affect droughts in future climate scenarios is not well understood.

## Conclusion

Drought is a natural hazard with potentially significant economic, social, and ecological consequences. History suggests that severe and extended droughts are inevitable and part of natural climate cycles. Drought has for centuries shaped the societies of North America and will continue to do so into the future. Nonetheless, available technology and scientific understanding remain limited to forecasting any particular drought a few months in advance for a region. The prospect of extended droughts and more arid baseline conditions in parts of the United States and within regions such as the Southwest—possibly exacerbated by human-induced increases in atmospheric temperatures—represents a challenge to existing public policy responses for preparing and responding to drought.

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