Drought Update for the South Carolina Hazard Mitigation Plan

May 8, 2017

Information compiled by the Carolinas Integrated Sciences & Assessments (CISA) program

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Drought: Overview

Drought is caused by a lack of precipitation over an extended period of time, often resulting in a water shortage for some activity, sector, or the environment. In contrast to other environmental hazards, droughts develop slowly over a period of weeks, months or years. According to NOAA, drought is the second most costly weather and climate disaster affecting the United States, preceded only by tropical cyclones. From 1980 to 2016, monetary losses caused by droughts equaled $226 billion, or 19% of total losses from natural disasters. Drought, in conjunction with associated heat waves, also contributed to 2,993 deaths during that time period.[1]

Historically, South Carolina has experienced many statewide droughts. They can occur at any time of the year and last for several months to several years. Recent droughts have impacted agriculture, forestry, tourism, power generation, public water supply, fisheries, and ecosystems. Drought conditions can also contribute to diminished water and air quality, increased public health and safety risks, and reduced quality of life and social well-being.

Formation

Drought is a normal part of climate variability that occurs in every type of climate. South Carolina receives adequate precipitation during normal years; the long-term, statewide annual precipitation average is 47.66 inches. However, South Carolina experiences high seasonal and interannual variability. Summer precipitation is normally the greatest, but can also be the most variable since it is connected to localized showers and thunderstorms. Fall is historically the driest season. Winter and spring precipitation occurs mostly through frontal systems.[2] Figure 1 shows interannual variability since 1895; the 10-year moving averages are used to show wet and dry periods. Wetter periods occurred during the 1960s, 1970s, and 1990s, while drier periods occurred from the 1920s to 1950s and since the early 2000s.

South Carolina's precipitation also varies geographically (see Figure 2).

- The Upstate region receives the highest annual averages, ranging from 48 inches to between 70 and 80 inches of rainfall at the highest elevations.
- The central region is, on average, the State's driest. Annual totals are less than 48 inches.
- Areas in the Coastal Plain receive annual precipitation amounts that range from 48 to 56 inches.

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[1] NOAA National Centers for Environmental Information, U.S. Billion-Dollar Weather and Climate Disasters, 2017, https://www.ncdc.noaa.gov/billions/

[2] Mizzell, H. and J. Simmons, 2015, South Carolina's Climate Report Card: The Influence of the El Niño Southern Oscillation Cold and Warm Event Cycles on South Carolina's Seasonal Precipitation. *Journal of South Carolina Water Resources* 2 (1): 3-10.

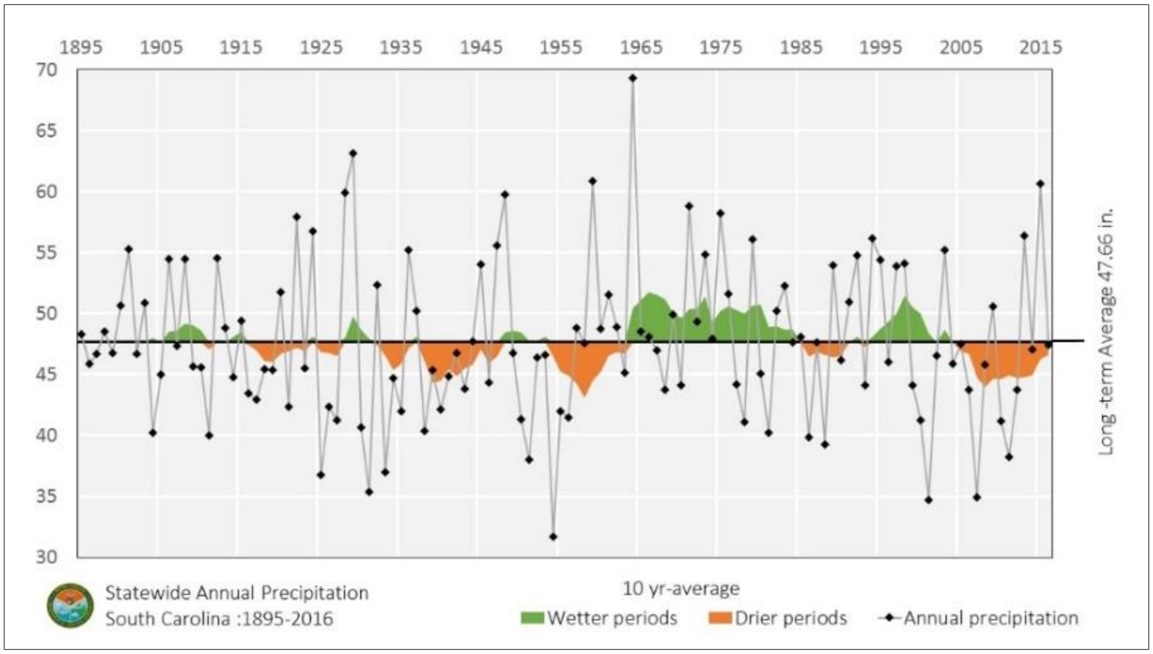


Figure 1. Statewide average annual precipitation for South Carolina with wetter and drier periods (Credit: Louisa Schandera, SCDNR)

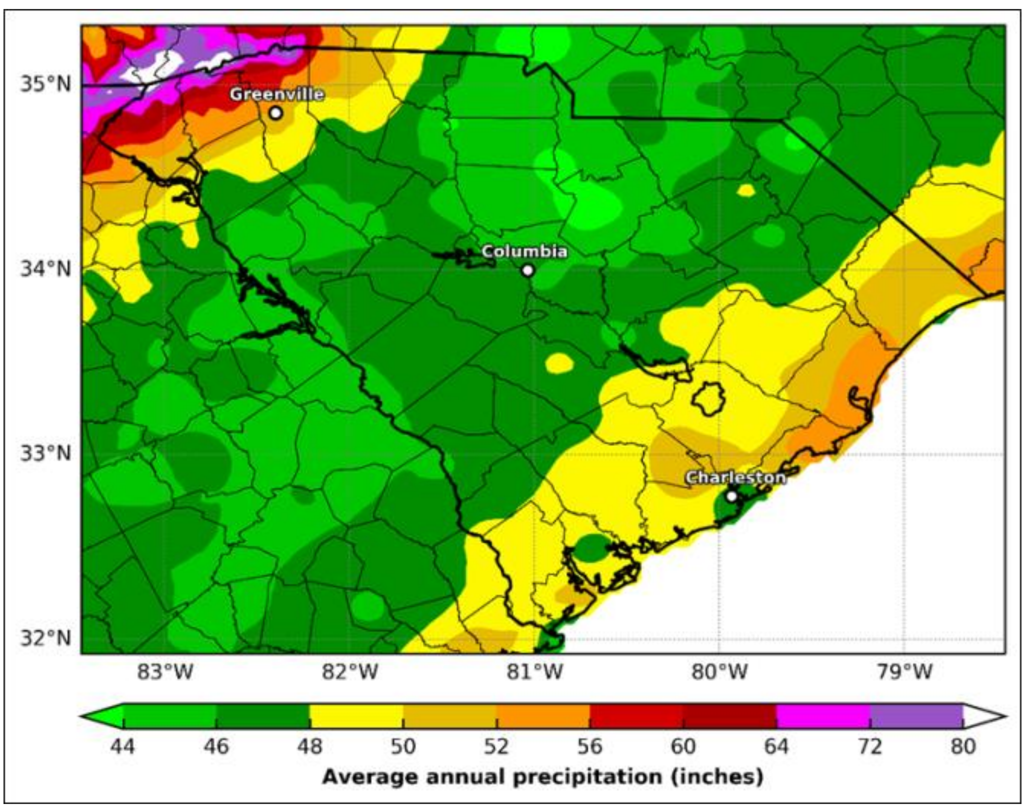


Figure 2. Statewide average annual precipitation for South Carolina (Credit: Jordan McLeod, Southeast Regional Climate Center)

Drought in South Carolina can begin during any season. Seasonal variability is often associated with variations in weather patterns, such as changes in pressure, storm tracks, and the jet stream. Other factors, such as extreme heat, wind, and evapotranspiration rates, can also influence the development of droughts. For South Carolina, the strength and geographic placement of the Bermuda High, a semi-permanent subtropical area of high pressure in the North Atlantic Ocean, influences precipitation variability in late spring and early fall seasons. This high-pressure system increases solar radiation and increases air subsidence, promoting air stagnation and reducing the probability of substantial precipitation.[3]

The El Niño–Southern Oscillation (ENSO) is another climate phenomenon that influences dry and wet spells in the State. ENSO fluctuates between three phases: Neutral, cooling La Niña, and warming El Niño. Extremes of these oscillations cause extreme weather. Winter precipitation tends to be enhanced during the warm phase (El Niño) and reduced during the cold phase (La Niña). There is a less consistent signal during fall and no evident connection between ENSO and spring and summer precipitation.[4] The La Niña stage of the ENSO is an aid for forecasting seasonal droughts in the region.

Classification

Drought is distinguished into four common types:[5]

- *Meteorological drought* is an extended period of departure from average precipitation for a specific location or region. The amount of deficit is determined using the normal amount of precipitation that would be expected over a given time period for that same location.
- *Agricultural drought* is a lack of adequate moisture to sustain plant growth and development.
- *Hydrological drought* is measured by effects on streamflow, reservoirs, lakes, and groundwater. As these effects may take longer to become noticeable, hydrological drought often lags behind meteorological and agricultural droughts.
- *Socioeconomic drought* occurs when the demand for an economic product exceeds its supply as a result of a weather-related shortfall in water supply.

Location

All South Carolina counties are prone to drought. However, some locations can be more adversely affected by this hazard based on historical occurrences of past droughts, statistical probabilities of future occurrences, changing climate patterns, demand and availability of water supply, and changes in the population. Figure 3 shows the average number of weeks per year that South Carolina experienced drought conditions, for different locations across the State during the 2000-2016 period.

[3] South Carolina State Climatology Office, *South Carolina Climate*, http://www.dnr.sc.gov/climate/sco/ClimateData/cli_sc_climate.php

[4] Mizzell and Simmons, 2015.

[5] National Drought Mitigation Center, *Types of Drought*, http://drought.unl.edu/DroughtBasics/TypesofDrought.aspx

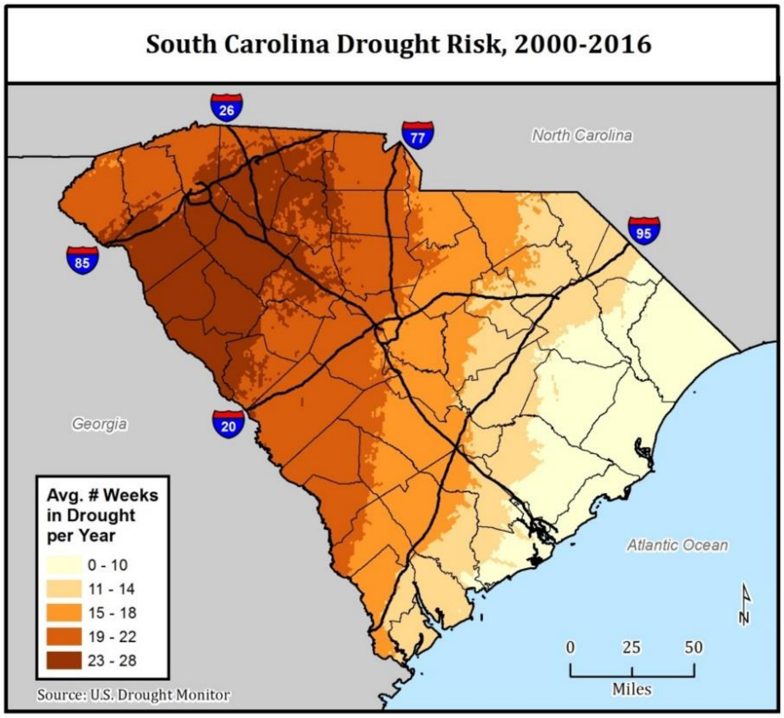


Figure 3. South Carolina's average number of weeks in drought per year

Weekly designations were obtained from the United States Drought Monitor (http://droughtmonitor.unl.edu/) for 2000-2016. Drought occurrence is based on a severity level designation of D1 or greater. (Credit: Hazards and Vulnerability Research Institute, University of South Carolina)

Extent

Droughts are assessed in terms of spatial extent, duration, and severity (or intensity). All South Carolina counties can be affected by drought. Droughts can extend beyond single states into multi-state regions.

Short-term droughts last less than six months and bring agricultural impacts, especially when occurring during growing season. Long-term droughts last more than six months and can last for many years, affecting hydrology, ecology, and societal well-being.

Many different indicators and methods are used to measure and monitor drought severity. The choice of an indicator may depend on the type or classification of drought being considered, the impacts of most interest, and the region or location in which drought is occurring. Different indicators may be calculated using one or more types of information, such as precipitation, temperature, soil moisture, or hydrological data. Due to drought's complexity, multiple indicators are often used to depict severity. Table 1 shows the indicators used by the South Carolina Drought Response Committee to detect drought development, most often referred to as incipient drought, and track drought as it progresses from incipient to moderate, severe, and extreme stages.

Table 1. Drought indicators identified in the South Carolina Drought Regulations

Indicator	Description
Palmer Drought Severity Index	Depicts prolonged (months, years) abnormal dryness or wetness; incorporates temperature, precipitation, and soil moisture data
Crop Moisture Index	Depicts short-term (up to 4 weeks) abnormal dryness or wetness affecting agriculture
Standard Precipitation Index	Compares observed precipitation amount (from (1- to 24-month periods) with long-term averages for the same period
Keetch-Byram Drought Index	Depicts moisture deficiencies in the upper layers of the soil; used to monitor fire danger
U.S. Drought Monitor	A weekly product that uses a variety of drought, climatological, hydrological, soil moisture and other indicators and indices as inputs; designed to provide a national-scale view of drought extent and severity
Average daily streamflow	Considers average streamflow over two consecutive weeks, as compared to historic minimum flows for those same weeks
Ground Water, Static water level in an aquifer	Considers groundwater levels over two consecutive months, as compared to historic levels for those same months

The South Carolina Drought Response Committee and the State Climatology Office (within the Land, Water and Conservation Division of the South Carolina Department of Natural Resources) address drought related issues and responses. The Drought Response Committee is composed of statewide and local members and includes the following South Carolina agencies: Emergency Management Division of the Office of the Adjutant General (SCEMD), Department of Health and Environmental Control (SCDHEC), Department of Agriculture (SCDA), Forestry Commission (SCFC), and Department of Natural Resources (SCDNR).

The State Climatology Office routinely monitors climatic conditions in the State. The Drought Response Committee meets regularly when needed to evaluate conditions and impacts within Drought Management Areas. The committee votes county by county to issue drought status declarations in four drought severity categories: incipient, moderate, severe, and extreme.[6]

Figure 4 represents the percent area in drought based on an analysis of the South Carolina Drought Response Committee's drought status declarations for 1998-2017, when at least one county was in drought. The figure is organized and color-coded according to drought severity designations. The figure shows that during this time period all South Carolina counties have been designated as being in extreme drought (purple), the highest drought severity, at least once. All counties have been designated as being in severe drought (red) multiple times.

[6] More information is available on the Drought Program page, South Carolina State Climatology Office, http://www.dnr.sc.gov/climate/sco/Drought/drought_current_info.php

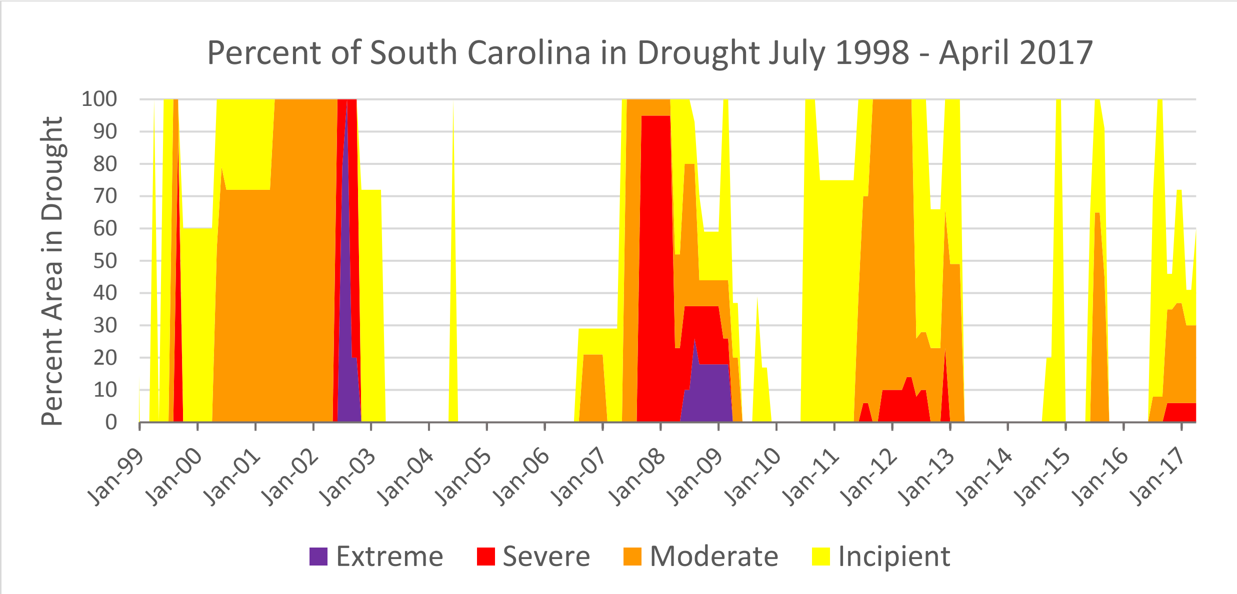


Figure 4. South Carolina Drought Response Committee Drought Status Declarations

Previous Occurrences

Figure 5 identifies unusually wet and dry periods using the Palmer Drought Severity Index, one of the most commonly used drought indices, for the January 1895 – April 2017 time period on a monthly scale. Severe, multiple-year droughts are a common occurrence for South Carolina. Such droughts persisted in the 1920s, 1930s, 1950s, and 1980s. South Carolina is currently experiencing an extended period of dry conditions with severe- to extreme droughts occurring in 1998-2003, 2007-2009, and 2010-2013.

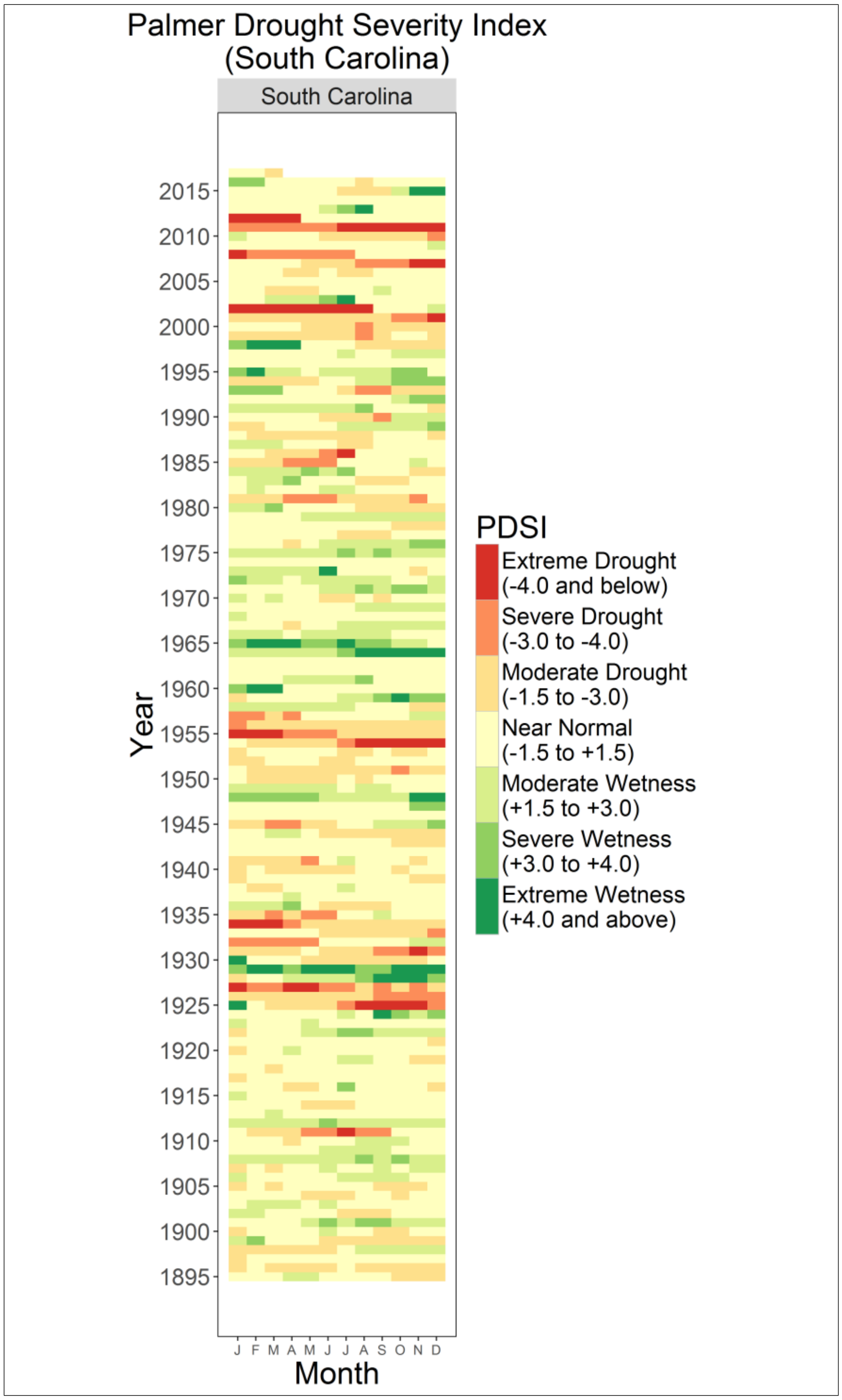


Figure 5. South Carolina drought and wet conditions (1895-April 2017), using the Palmer Drought Severity Index

The rows are years, and the columns are months January through December, reading from left to right. Each square represents a month with a specific measure of dryness (red), wetness (green), or normal (yellow) conditions. (Credit: Carolinas Precipitation Patterns & Probabilities an Atlas of Hydroclimate Extremes, http://www.cisa.sc.edu/atlas/index.html)

Historical and Notable Events

1925: The growing season had a recorded 12.41-inch rain deficit, and the State experienced an overall rainfall deficit of 18.23 inches. Water for livestock was scarce; many streams had record lows, and deep wells went dry affecting water supply and power production.

1954: The year set the current record for the State's driest year with total statewide precipitation of 32.96 inches. An excessively hot summer exacerbated the impacts of limited rainfall. According to National Weather Service reports, crop yield was only 10 percent of its 10-year average production rate. Hurricane Hazel ended extreme drought conditions in eastern South Carolina, although drought continued in western areas of the State.

1985-1986: Due to drought conditions and accompanying reduced stream flows hydroelectric power generation was curtailed by 183,978-megawatt hours at the Lake Murray Saluda Hydropower plant. The U.S. Army Corps of Engineers was forced to purchase $10 million in substitute electricity on the open market to compensate for the reduced hydroelectric power production at the Savannah River Plant.

1993: The Greenville-Spartanburg Airport recorded the hottest and driest month on record up to date in July of 1993. Similar records were set at other locations around the State. The drought, which started at the height of the crop growing season in May and June, devastated South Carolina pastures and hay production. The drought and record heat cost the State a total of $22.5 million in crop losses. The total loss for livestock, hay, and pasture was estimated at $34.7 million.

1998-2002: This drought lasted four years and the precipitation deficits were among the largest in the State history. The two highest levels of drought severity, extreme and severe drought, lasted throughout summer of 2002; in August, State officials declared the entire State to be in the extreme drought. The drought significantly contributed to the southern pine beetle epidemic. The SC Forestry Commission estimated the total impact of the drought at more than $1.3 billion dollars.[7]

2007-2009: Drought affected water levels in many lakes. The Savannah Lakes were more than 19 feet below the target level. Lake Marion dropped 9 feet during 2007 reaching the lowest elevation (66.27 ft-msl) since the 1950s. The hydrological drought impacted water supplies, irrigation capacity, and many lake-related businesses as well as golf courses. Voluntary and mandatory water restrictions were issued across the State due to prolonged drought conditions and associated water supply shortages.

Recent Activity (2010-2016)

2010-2013: Lake Hartwell and Lake Thurmond were 6.5 feet and Lake Jocassee was 21 feet below their target guide curves in March 2012. The inflows into Lake Thurmond for the following three-month were the lowest recorded since 1954. The deteriorating hydrologic conditions reduced the amount of water stored in shallow and deep aquifers.

2015-2016: South Carolina experienced alternating wet and incipient drought conditions. In June 2015, all counties were in incipient or moderate drought. Historic floods in October 2015 alleviated the dry spell for several months. However, in August 2016 drought returned to the State. Hurricane Matthew

[7] SC Department of Natural Resources, 2003, Annual Report: Fiscal Year, July 1, 2002-June 30, 2003, p. 13.

brought excessive rainfall to most counties, but a lack of adequate moisture persisted in the Upstate region.

Drought: Probability

In terms of general descriptors (on a scale unlikely, likely, highly likely), all counties in South Carolina have a likely probability of future drought events. Drought likelihood is based on previous occurrences and severities of drought using indices such as the Palmer Drought Severity Index (Table 2) and statistical probabilities of return periods with below average precipitation (Table 3, Figures 7 and 8).

Drought Severity

South Carolina's modern climatological records of precipitation and temperature are available since the end of the nineteenth century. Palmer Drought Severity Index (PDSI) measurements were constructed from these records to assess drought extent in terms of duration and severity for each climate division in the State (Figure 6). Table 2 shows the level of drought severity (incipient, moderate, severe, extreme) for each climate division, for two time periods (1895-2016, 2000-2016). During the full period of record (1895-2016), the State was in some level of drought for approximately 38% of that time.

In comparison with the full record, South Carolina has experienced droughts of greater severity and has spent more time in drought from 2000-2016. The Northwest and North Central regions experienced drought 63% of the time, and the West Central and Central regions 60% of the time. In addition, the 2000-2016 period shows a larger percentage of time was spent in severe or extreme drought compared to the full record.

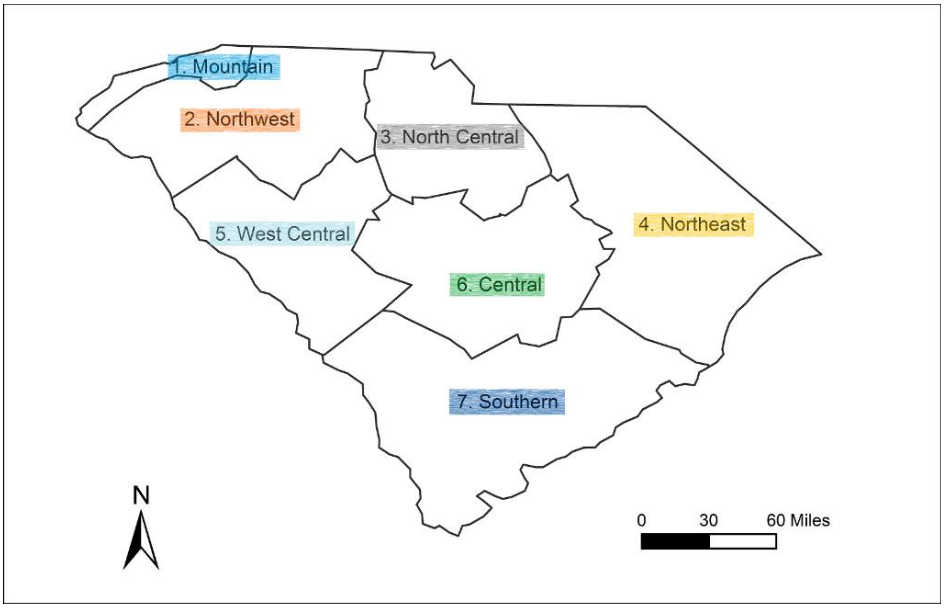
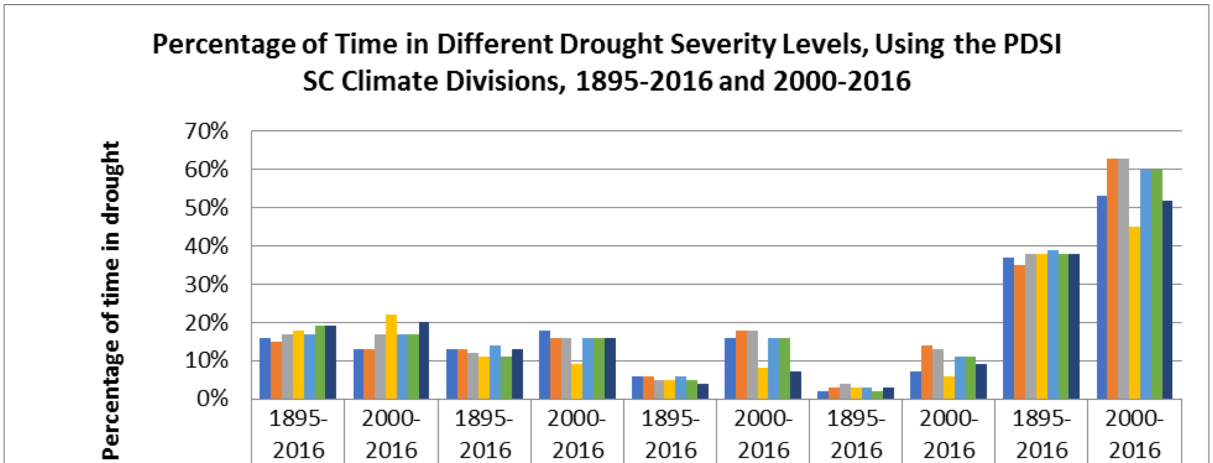


Figure 6. South Carolina Climate Divisions

Table 2. Drought severity in South Carolina as measured by the Palmer Drought Severity Index (PDSI) for each climate division, for the 1895-2016 and 2000-2016 periods



	Incipient Drought		Moderate Drought		Severe Drought		Extreme Drought		All Levels of Drought Severity	
	1895-2016	2000-2016	1895-2016	2000-2016	1895-2016	2000-2016	1895-2016	2000-2016	1895-2016	2000-2016
1. Mountain	16%	13%	13%	18%	6%	16%	2%	7%	37%	53%
2. Northwest	15%	13%	13%	16%	6%	18%	3%	14%	35%	63%
3. North Central	17%	17%	12%	16%	5%	18%	4%	13%	38%	63%
4. Northeast	18%	22%	11%	9%	5%	8%	3%	6%	38%	45%
5. West Central	17%	17%	14%	16%	6%	16%	3%	11%	39%	60%
6. Central	19%	17%	11%	16%	5%	16%	2%	11%	38%	60%
7. Southern	19%	20%	13%	16%	4%	7%	3%	9%	38%	52%

Probabilities of Below-Average Precipitation

Drought is caused by a deficiency of precipitation over an extended period of time. Many of South Carolina's economic sectors are water-dependent but may be affected by precipitation shortfalls at different time scales. For example, droughts of one year or less can affect agriculture while other water uses might be affected by precipitation deficiencies persisting over several years.

Table 3 shows the likelihood of below average precipitation for 1- to 5- year durations.[8] These probabilities are averaged for all climate stations and climate divisions in South Carolina. A probability of "1/5" means that there is a 1 in 5 (20%) chance, and "1/1000" means that there is a 1 in 1000 (0.001%) chance, of receiving the specified percentage of average precipitation. Each value in the table represents the expected percentage of average precipitation associated with the different probabilities and time periods. For example, there is a 1/50 (2%) probability of receiving 67%* of average precipitation in a 12-month period.

Table 3. Mean percentage of average precipitation for different probabilities and different durations in South Carolina (Credit: Carolinas Precipitation Patterns & Probabilities an Atlas of Hydroclimate Extremes, http://www.cisa.sc.edu/atlas/index.html)

	Duration				
Probability	1-year	2-year	3-year	4-year	5-year
1/5	86	90	92	94	94
1/10	79	85	88	90	91
1/25	72	80	83	85	87
1/50	67*	76	80	83	84
1/100	64	73	78	81	82
1/200	60	71	75	78	81
1/500	56	68	73	76	78
1/1000	54	66	71	74	77

The drought return period maps (Figures 7 and 8) also show the percentage of average precipitation that can be expected for droughts of specified durations and specified return intervals. The contours show variations in recurrence intervals of precipitation deficits across the State, with intensifying probability of drought conditions from north to south.

For example, Figure 7 shows the percentage of average precipitation that can be expected during a 12-month (1-year) time period with a 100-year return period. The return period refers to probability of below average precipitation in a single year. A 100-year return means that there is a 1 in 100 (1%) chance of occurrence in a single year. A contour labeled with "64" on the map means that during a 1-year time period, there is a 1% chance of having only 64% of the average one-year precipitation total for that area. Figure 8 shows the percentage of average precipitation that can be expected during longer-term drought (36 months) with a 100-year return period.

[8] Carolinas Precipitation Patterns & Probabilities an Atlas of Hydroclimate Extremes, http://www.cisa.sc.edu/atlas/index.html

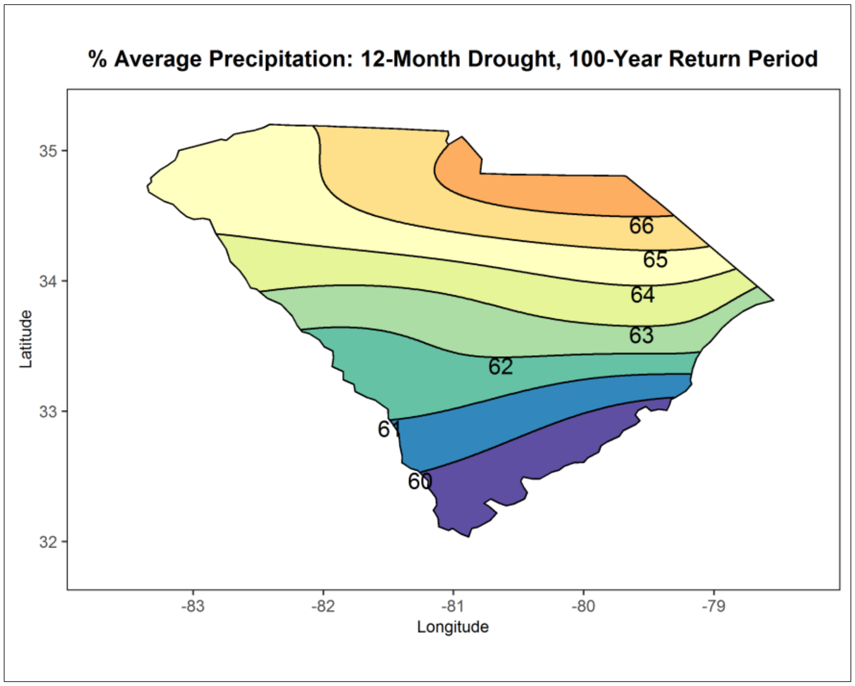


Figure 7. Percent of average precipitation probability for a 12-month drought and 100-year return period over South Carolina (Credit: Carolinas Precipitation Patterns & Probabilities an Atlas of Hydroclimate Extremes, http://www.cisa.sc.edu/atlas/index.html)

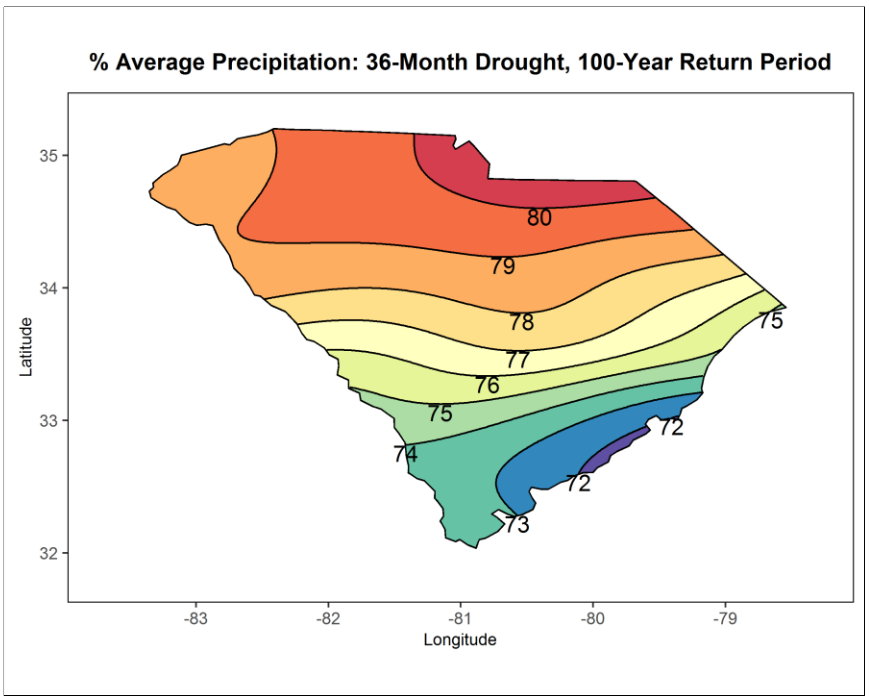


Figure 8. Percent of average precipitation probability for a 36-month drought and 100-year return period over South Carolina (Credit: Carolinas Precipitation Patterns & Probabilities an Atlas of Hydroclimate Extremes, http://www.cisa.sc.edu/atlas/index.html)

Drought: Vulnerability and Impacts

Droughts have far-reaching impacts on multiple sectors, such as agriculture, tourism, energy, and others. Determining the direct and indirect costs associated with drought is difficult due to drought's broad spatial extent and the difficulty in determining specific beginning and end dates.

The impacts associated with these different types of drought can change depending on when and where a drought is happening. State-owned or operated buildings, infrastructure, and critical facilities are exposed to the drought hazard depending on their location. State assets that are more vulnerable to droughts are located in counties that experienced more frequent drought duration and higher drought severity. A drought of a particular severity in the present time could have different impacts compared to past droughts because of changes in water supply and demand, assets, and populations.

Overview of Impacts by Sector

Table 4 provides a historical overview of the wide range of impacts that drought produces, and the many sectors that are vulnerable to and have been affected by drought in South Carolina.

Table 4. Sectors impacted by droughts with South Carolina examples

Affected sectors and resources	South Carolina Examples	
Agriculture: Agriculture, farming, aquaculture, horticulture, forestry, and ranching	Multiple years	**Reduced crop yields**: Figure 9 shows corn crop yield anomalies during past droughts (1954, 1970, 1977, 1986, 1993, 1998, 2002, 2008, and 2011).[9]
	2011-2016	**Loss of pasture land and grazing grasses for livestock**: The USDA Livestock Forage Program provided South Carolina farmers with $17.1 million to compensate for some of these losses during this time period.[10]
Plants and Wildlife: Wildlife, fisheries, forests, and other fauna	2002	**Increased vulnerability to disease**: Four years of drought made pine trees more susceptible to Southern Pine Beetle infestation, leading to estimated timber losses of $220 million.[11] **Habitat degradation**: Blue crab and shrimp fisheries were below normal, due to drought's negative effects on nursery habitat.[12]
Fire: Forest, range, and urban fires that occur during drought events	2016	**Increased risk of fire**: Drought conditions contributed to increased fire occurrence and number of acres burned. The Pinnacle Mountain fire was the largest in Upstate history; over 10,000 acres burned and firefighting costs were more than $5 million.[13]
Water Supply and Quality: Surface or subsurface water supplies (i.e., reservoirs or aquifers)	2002	**Private wells ran dry**, new or deeper wells needed **Saltwater intrusion** in water systems in Pee Dee and Waccamaw River Basin[14]
Energy: Power production and demand	1986, 1999-2002, 2007-2008	**Reduced hydropower generation** in the Santee and Savannah River Basins[15] **Purchase and use of alternate sources of energy** to compensate for loss of hydropower generation
Business and Industry: Non-agriculture businesses	2007-2008	**Lost revenue/increased costs** to landscapers, golf courses, recreation-based businesses due to water shortages
Tourism and Recreation	2002, 2007-2008	**Closed boat ramps** due to low water levels, **cancelled fishing tournaments**
	2016	**Closed trails** at Table Rock State Park due to the Pinnacle Mountain fire
Society and Public Health: Changes in public behavior and human health effects	Multiple years	**Water use restrictions**, **burning bans**
	2016	**Road closures** and **widespread smoke** due to Pinnacle Mountain fire

[9] Data from USDA NASS, analysis and maps developed by Junyu Lu
[10] https://www.fsa.usda.gov/programs-and-services/disaster-assistance-program/index
[11] Bruce Henderson, "Beetle Infestation Causes $220 Million in Damage to North Carolina Pine Trees," The Charlotte Observer, September 29, 2002: http://www.cisa.sc.edu/atlas/events-2002.html
[12] SC Department of Natural Resources, 2003, Annual Report: Fiscal Year, July 1, 2002-June 30, 2003
[13] South Carolina Forestry Commission
[14] South Carolina State Water Assessment, 2nd edition, 2009, South Carolina Department of Natural Resources
[15] South Carolina State Water Assessment, 2nd edition, 2009, South Carolina Department of Natural Resources

Agriculture

Figure 9 is an example of drought impacts on the agricultural sector in South Carolina. It shows corn crop yield anomalies during selected drought years and was calculated based on data from 1944 to 2016. Using statistical and modeling techniques, the effects of weather events and climate variability on corn yields were separated from other factors (such as technological advances) to compare drought's effects on crop yields over time. "Normal yield" refers to the expected yield under the technological conditions of that particular time. Crop yields were considerably lower than expected during drought years, as demonstrated below.

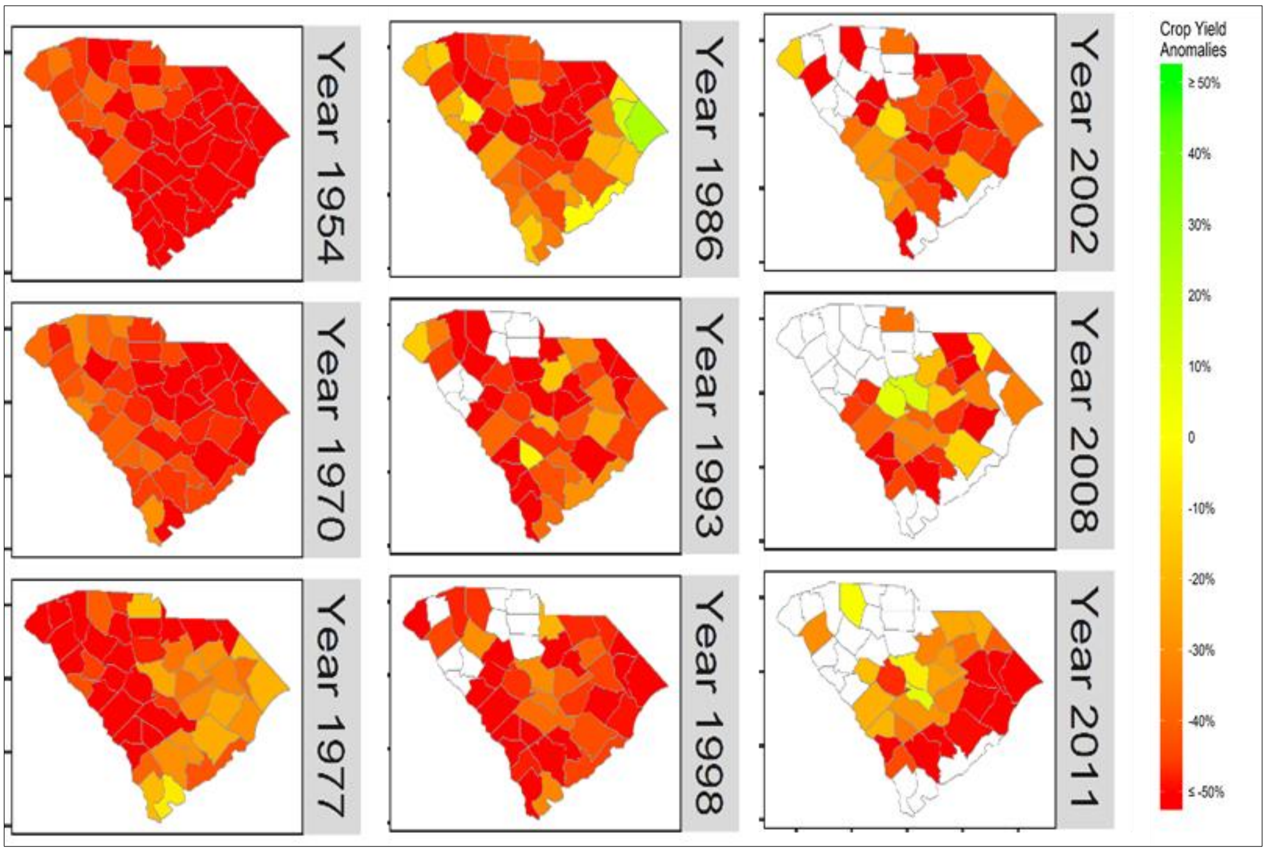


Figure 9. Drought years and corn crop yield anomalies

The maps show the percentage of corn yields that are lower (red) or higher (green) than normal yield conditions (yellow). Counties (in white) did not produce corn, have missing data, or corn yield data was not reported for that year. (Credit: Junyu Lu, CISA/University of South Carolina)

South Carolina has regularly received United States Department of Agriculture Secretarial Disaster Designations due to drought. Figure 10 shows the number of South Carolina counties with disaster designations issued for drought since 2012. USDA Secretarial disaster designations make emergency loans available to producers suffering losses in those counties.

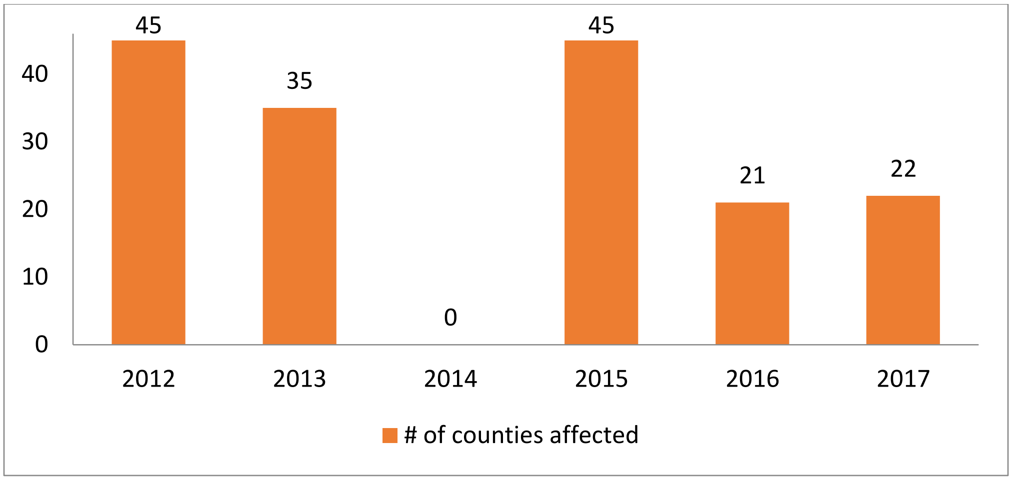


Figure 10. Number of South Carolina counties with USDA Secretarial drought disaster designations[16]

Water Resources

South Carolina's surface water resources depend on precipitation. Short-term droughts, particularly during the growing season, are likely to primarily affect agriculture. Too little rainfall occurring over several seasons can contribute to lower streamflow and reservoir levels, resulting in hydrological drought and impacts to water supplies and water quality.

During winter, South Carolina relies on rainfall to replenish streams, reservoirs, groundwater, and soil moisture. Spring and summer are times of increased demand for water resources for agriculture, drinking water, energy production, recreation, and other uses. Figures 11-14 show seasonal[17] precipitation trends over the 1901-2015 period.[18] They were constructed using NOAA's United States Historical Climatology Network Version 2.5 data (USHCN V2.) from Georgia, North Carolina, and South Carolina.[19] While Figure 14 shows increasing precipitation trend during the fall, typically the driest season of the year, Figures 11 and 13 show a decreasing precipitation trend in the winter and summer seasons. A continuation of this long-term trend could increase vulnerability of South Carolina's water resources to drought. These trends are also found in North Carolina and Georgia, South Carolina's neighbors and with whom the State shares several, major river basins including the Savannah, Catawba-Wateree, and Yadkin-Pee Dee.

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[16] The designations are through March of 2017. United States Department of Agriculture Disaster Designation Information, https://www.fsa.usda.gov/programs-and-services/disaster-assistance-program/disaster-designation-information/index

[17] Climatological seasons are as follows: Winter – December, January, February; Spring – March, April, May; Summer – June, July, August; and Fall – September, October, November.

[18] South Carolina State Climatology Office, "Temperature and Precipitation Trends, 1901-2015," http://www.dnr.sc.gov/climate/sco/Publications/2015TP_Trends/2015TP_main.php

[19] Documentation and references can be found at the USHCN Version 2.5 Serial Monthly Dataset web site (https://www.ncdc.noaa.gov/oa/climate/research/ushcn/).

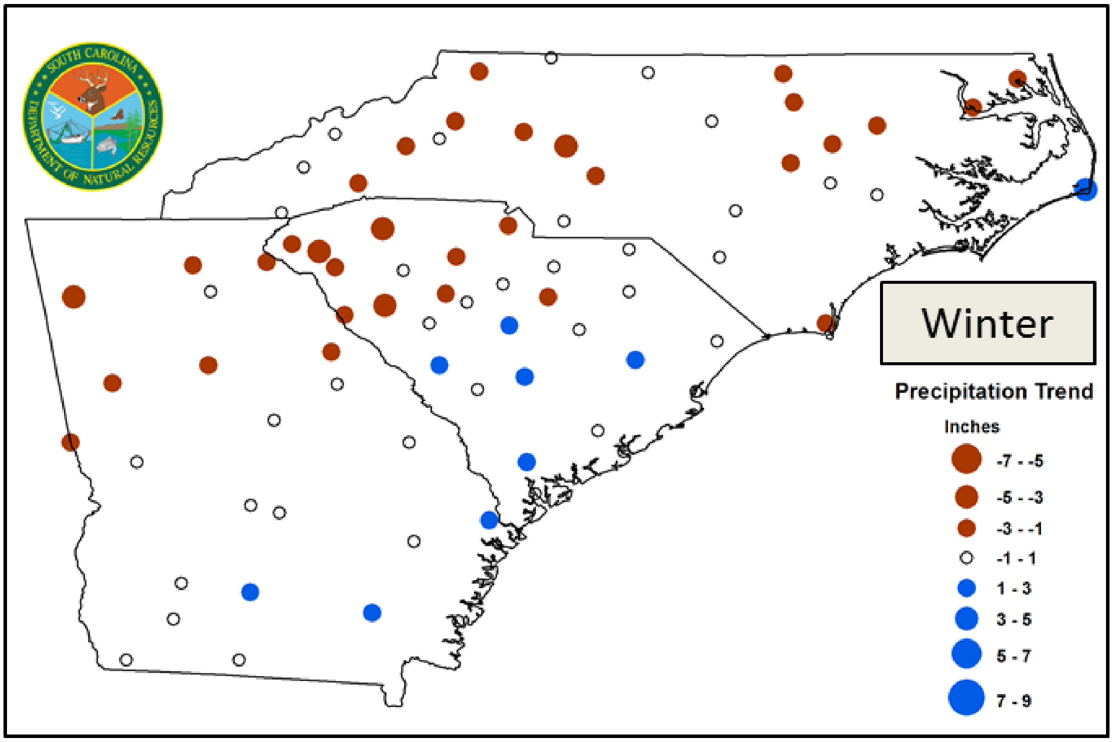

Figure 11. Winter precipitation trends, 1901-2015 (Credit: South Carolina State Climatology Office)

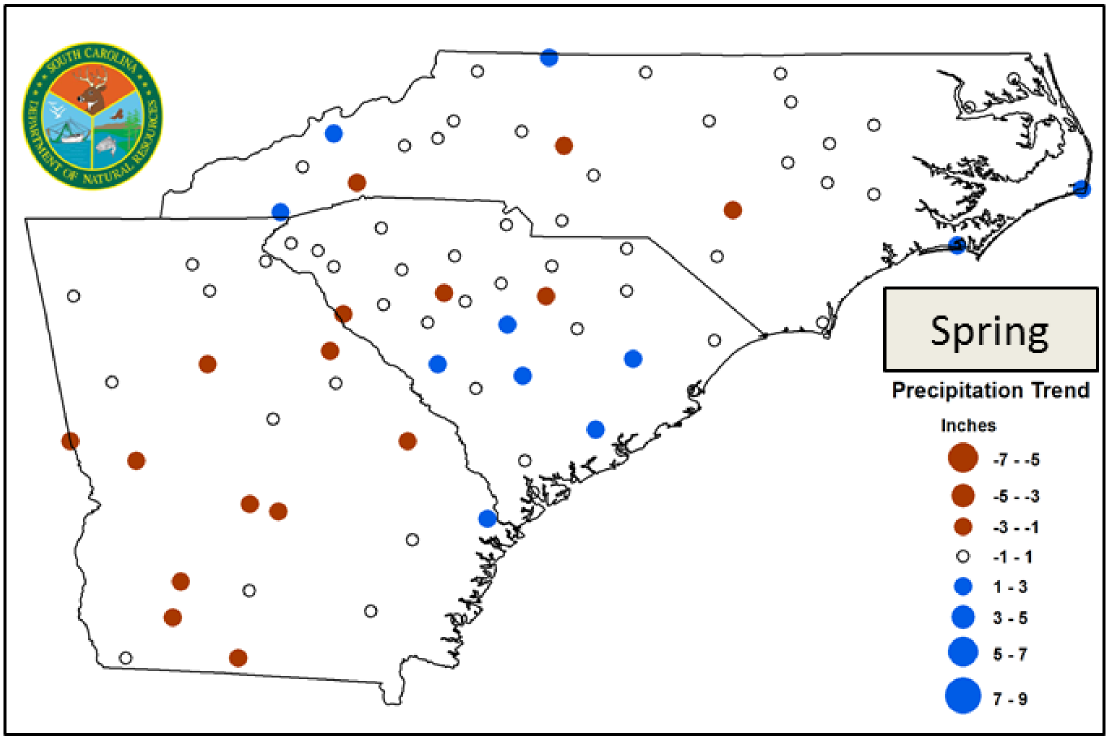

Figure 12. Spring precipitation trends, 1901-2015 (Credit: South Carolina State Climatology Office)

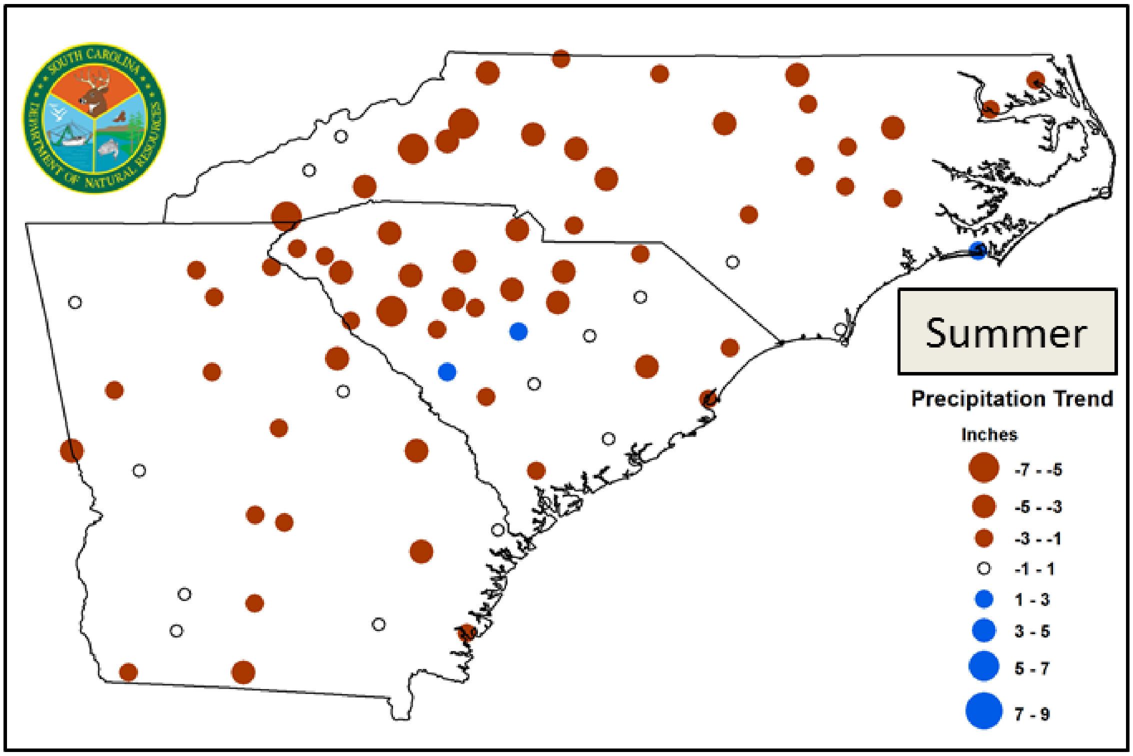

Figure 13. Summer precipitation trends, 1901-2015 (Credit: South Carolina State Climatology Office)

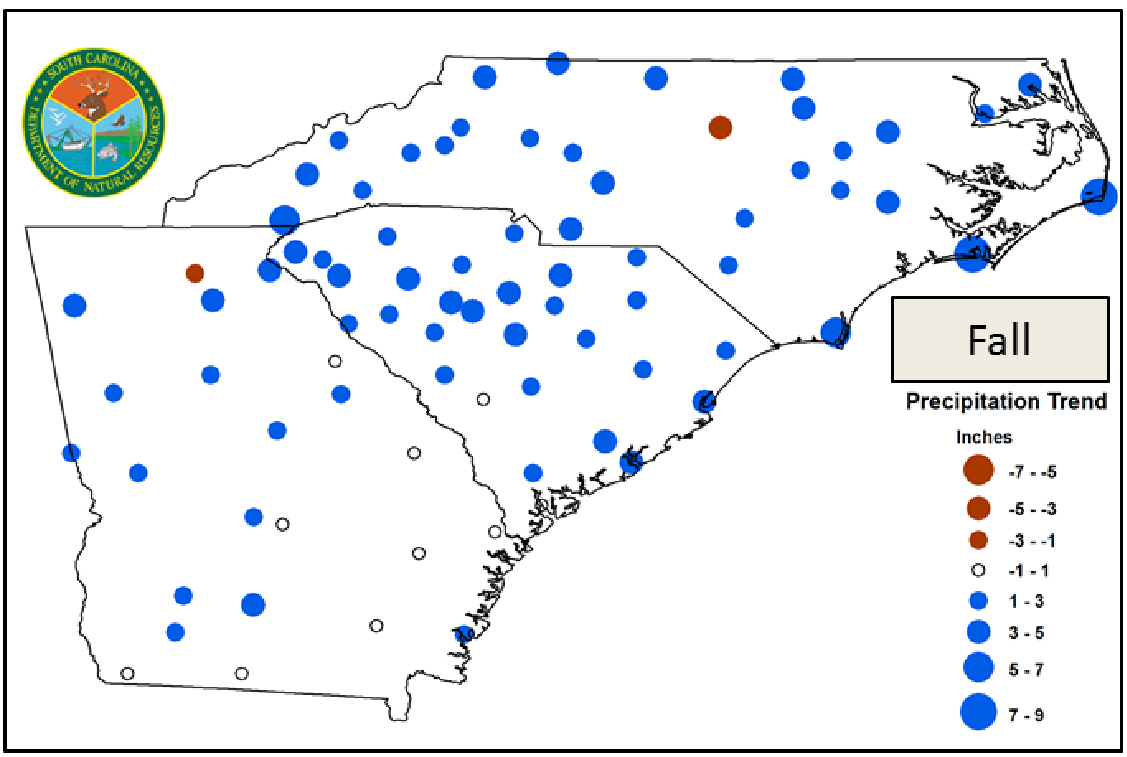

Figure 14. Fall precipitation trends, 1901-2015 (Credit: South Carolina State Climatology Office)